SIX

The Age of the World Wars, 1914–1945

The Case of Diminishing Marginal Returns to the Strategic Bombing of Germany in World War II

By remarking on "the morons volunteering to get hung up in the wire and shot in the stomach in the mud of Flanders," Air Chief Marshal Sir Arthur ("Bomber") Harris aptly captured the incomprehensible gore of trench warfare in World War I—the war to end all wars—and thereby commented on his infinite preference, in World War II, for aerial over ground combat.[1] War from the air, it seemed, had so much more to offer. Harris, upon assuming command of the Royal Air Force's (RAF) Bomber Command in February 1942, toed an unflinching line. Of the 755,531 tons of bombs the RAF was to drop on ten target categories in Germany in the sixty-six months from December 1939 to May 1945, fully 69 percent—some 523,615 tons—fell on cities, a target group euphemistically referred to as industrial areas. The first industrial-area ton, and the only one that month, fell in February 1940. In March and April there was a pause. In May, 154 tons fell, and 298 tons in June. The "phony war" had ended. The monthly bombing gradually increased to 2,384 tons by July 1941, then dropped to 486 in February 1942.[2]

In March 1942, within a month of Harris's assuming command, bombing levels on industrial areas ballooned to 3,241 tons. By May, Harris had organized the first-ever thousand-bomber fleet, to fly to Cologne on the night of 30–31 May. The 1,455 tons of bombs dropped that night[3] were more than half of the entire month's volume of 2,655 tons of bombs directed toward industrial areas. The city's loss was measured in acres, some 600 of them. Industrial area bombing peaked with 8,622 tons the next month, then dropped as German searchlight batteries, flak, and air defense fighters increasingly engaged in the fight and shot down unacceptable numbers of Harris's unescorted bombers.

Harris persisted. On the night of 24–25 July 1943, some 1,200 tons of incendiary bombs ignited a firestorm in Hamburg, and up to 40,000 civilians perished.[4] But Harris did not measure success in lives lost; he totted it up in square miles burned. The Hamburg raid amounted to only less than 10

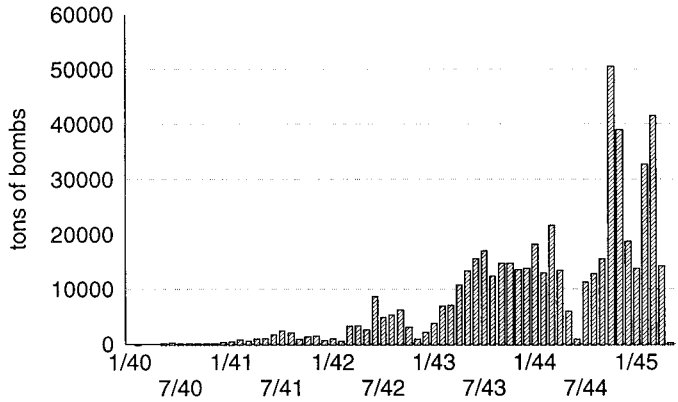

Figure 6.1. RAF bombing tonnage dropped on German industrial areas
Source: *Computed from USSBS, February 1947, Chart 6, pp. 49–91.*

percent of the month's total of 13,291 tons of industrial area bombing. From November 1943 through March 1944, while the Allies, including the bomber units, were to prepare for D-Day, Harris attacked Berlin several times, with little success. He blamed the Americans: "We can wreck Berlin from end to end if the [United States Army Air Force] will come into it . . . It will cost us 400–500 aircraft. It will cost Germany the war." In fact, from October 1943 to March 1944, Harris lost 1,128 bombers, and he nearly wrecked his command. He was rescued between April and September 1944, when Eisenhower, the Allies' supreme commander, took direct control of all Allied air forces to prepare for the Normandy landing and push to the Rhine. Harris's industrial area bombings fell from 21,656 tons in March to 13,395 tons in April, 5,971 tons in May, and a mere 855 tons in June. Following the successful Normandy landing on 6 June, Harris reverted to form, dropping 11,207 tons on industrial areas in July, 12,777 tons in August, and 15,518 tons in September. And when Eisenhower returned direct command, Harris dropped an astonishing 50,465 tons on industrial areas in October 1944 alone (fig. 6.1) and incinerated Berlin and Dresden, by then with American support, in February 1945 when the war had long since been won—on the ground.[5]

What held Harris to his unrelenting stance was his belief—not entirely incorrect until September 1944—that what is nowadays called the surgical mode of strategic bombing was militarily ineffective. Given the British experience in 1940 and 1941, prior to his assuming the leadership of RAF Bomber Command, he derided as "panacea-mongering" the Americans' insistence on

picking out strategic targets and eliminating them with precision bombing. He had a point. When the United States joined the bombing fray in early 1943, the Americans frequently missed their assigned targets so outlandishly that the "bomber crews began making jokes about 'killing sheep' or conducting 'a major assault on German agriculture.'" Harris consequently preferred the sledgehammer to the scalpel.[6]

The theory of strategic bombing—in either mode, precision or area—had been straightforward and attractive. In the memorable, quaint language of the United States Strategic Bombing Survey (USSBS), "strategic bombing bears the same relationship to tactical bombing as does the cow to the pail of milk. To deny immediate aid and comfort to the enemy, tactical considerations dictate upsetting the bucket. To ensure eventual starvation, the strategic move is to kill the cow."[7] Consider the following two less original definitions:

> Strategic bombing . . . is aimed at the systematic destruction of those resources which will most weaken the enemy by denying him the materials or weapons he needs to prosecute the war.[8]

> Strategic bombing is best defined as the use of air power to strike at the very foundation of an enemy's war effort—the production of war material, the economy as a whole, or the morale of the civilian population—rather than as a direct attack on the enemy's army or navy. A strategic air campaign almost always requires the defeat of the enemy's air force, but not as an end in itself. While tactical air power uses aircraft to aid the advance of forces on the ground or on the surface of the ocean, usually in cooperation with those forces, strategic air power usually works in relative independence of armies and navies.[9]

In the hope that military efforts will be starved, strategic bombing, the first definition suggests, is about the bombing of essentially nonmilitary assets, that is, production sites. One shoots at the economic cow that would (re)fill the military's pail. The focus on the ultimate objective—the opponent's ability to prosecute the war—is operationally vague and is at any rate restricted to the physical inputs to war-making, the perceived potential bottlenecks or choke-points, neglecting human capital and institutional aspects.

The second definition helps to separate out strategic from tactical bombing and identifies three operational targets: (a) the opponent's actual arms production; (b) the enemy's economy as a whole that forms the supply chain to and from arms industry facilities; and (c) the morale of the adversary's civilian population. The reflection following the second definition also suggests, with

the hindsight that the many failures of World War II strategic bombing permit, a certain logical sequence of events. Destroy, first, the opponent's ability to defend against air power; then, second, attack those targets inside the opponent's territory that support its war-making on the front, especially the supply chain; and third, wait until the enemy collapses from within. Interpreted thus, strategic bombing is to achieve certain war outcomes by itself, especially to avert the need for a land-based invasion of the opponent's territory, the capture of its capital, and the deposing of its leaders.[10]

Because "it lacked essentially everything except doctrine and will," the strategic bombing of Germany—or of any other state—was never carried out in any such pure form as extreme advocates of air power had hoped. The subsequent claim of many that strategic bombing was not meant to achieve victory all by itself is not only historically incorrect but suspect on logical grounds alone: in the absence of an integrated military strategy across service branches, if strategic bombing was not meant to achieve victory by itself—by attacking the enemy's war production, its economy, and the morale of its people—then what was it to achieve?[11] Consequently, one finds a good many historical narratives that essentially take the following position: yes, high hopes had been invested in strategic bombing; yes, strategic bombing did run into certain practical difficulties; but if nothing else, strategic bombing forced Nazi Germany into expending vast resources on air defenses that otherwise could have been poured into its front-line efforts; therefore, strategic bombing made a valuable, indeed indispensable contribution to winning the European war.[12]

Nearer to the truth is the exact opposite view: had the advocates of strategic bombing not been fitted with blinders, the Allies could have spent more resources, and could have spent them much earlier than they did, to develop long-range fighter-bombers to accompany their bomber fleet. In December 1943, when Brigadier General Ira C. Eaker was relieved of his command of the U.S. Eighth Air Force—and when "Bomber" Harris was losing aircraft by the hundreds and crews by the thousands—the Eighth's new commander, Jimmy Doolittle, noted a sign in his fighter commander's office. It read, "The first duty of the Eighth Air Force fighters is to bring bombers back alive." Doolittle had the sign replaced. It now read, "The first duty of the Eighth Air Force fighters is to destroy German fighters." And that was the crux of the matter: "bombing raids were less about bombing than about provoking the German fighters into aerial combat." Even more, the first duty was "to kill German fighter pilots." Virtually unanimous opinion, across all writers, now holds that ideal-type strategic bombing did not in fact begin until September 1944, after the power of the German air force, the defensive fighter aircraft of

the Luftwaffe, had been broken, especially once the American P-51 (the "Mustang") aircraft, whose development Eaker had held up since June 1943, entered the scene.[13]

However, even though the topic cannot be skirted entirely, this chapter is not primarily about the opportunity cost of strategic bombing. It is about diminishing marginal returns to strategic bombing, such as it was, and makes a very specific, if technical point: to demonstrate that continuous increases in the tonnage of bombs dropped, when other inputs to the war effort remain unchanged, eventually yield declining increases in the destruction sought. In some cases we can even show that more bombing resulted in reduced destruction; not just increasingly smaller, diminishing returns but negative returns.[14]

First we introduce the notion of a strategic bombing production function that permits us to discuss more clearly the concepts of total and incrementally rising, declining, or negative returns to bombing. Next we discuss each of strategic bombing's three elements in turn: bombing to curtail the production of war matériel, bombing of the economy as a whole to undercut the supply chain, and bombing to sap the morale of the civilian population to induce it to revolt or commit acts of sabotage that would result in lowered industrial productivity. Finally we provide a summary assessment and show how the case of the strategic bombing of Germany in World War II generates numerous other examples and hypotheses regarding the manpower, logistics, technology, planning, and operations aspects of war when viewed in light of our six economic principles.

A STRATEGIC BOMBING PRODUCTION FUNCTION

In principle, bombing is open to economic theoretical and empirical analysis. One need merely relate a set of inputs to an output they are to produce. For example, one may write an equation, called a strategic bombing production function, $y_i = f(x_T; \mathbf{x_A}, \mathbf{x_D}, \mathbf{z})$, where y_i is the desired output and denotes the destruction of the defender's assets, x_T refers to the number of tons of bombs dropped, $\mathbf{x_A}$ is a vector (a set of factors) describing the attacker's input variables other than bomb tonnage, with expected positive coefficients (the higher the attack input, the higher the destruction), $\mathbf{x_D}$ is a vector describing the defender's input variables, with expected negative coefficients (the higher the defense input, the lower the destruction), and $\mathbf{z}$ is a vector that captures imponderables such as prevailing weather conditions.[15]

If one draws a hypothetical scatter plot of output of strategic bombing

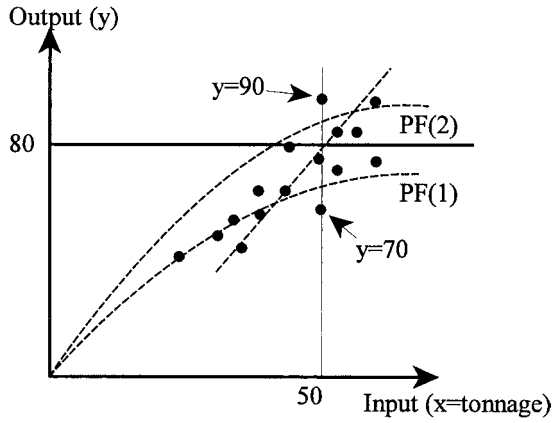

Figure 6.2. Strategic bombing production functions

(some measure of destruction) on a vertical axis against bombing tonnage on a horizontal axis, then it may at first appear that more bombing is associated with increased destruction (fig. 6.2). This is represented by an upward-sloping trend of the data points and a dotted straight line drawn through these points: the more bombing, the more destruction.

In economics, production theory says that an increasing tonnage of bombing is expected to lead to increases in destruction but it also predicts smaller and smaller increments in destruction so long as all the other required inputs, apart from the bombs themselves, are held at constant levels. More bombing is predicted to lead to decreasing gains in additional destruction per additional unit of bombing applied. This is the principle of diminishing marginal returns. Thus, for the data points gathered around the first production function—labeled PF(1)—the increases in destruction are increasing, but at a declining rate. If bombing tonnage were to increase ever further, the level of destruction achieved would peter out somewhere below the horizontal line drawn at y = 80. If this horizontal line is interpreted as the level of destruction needed to obtain victory—call it the victory threshold—then any amount of bomb tonnage alone will not secure victory.

What accounts for greater destruction, and eventual victory, is not more bombing per se but the greater application of other inputs alongside the bombing. Diminishing returns to increased tonnage along PF(1) can be countermanded only by increasing inputs other than bombing tonnage. In terms of the figure, the same tonnage of bombing (e.g., x = 50) can yield greater

destruction only if for instance navigation technology is improved. With "old" technology, few bombers find their target and the destruction that bombing of x = 50 can accomplish is relatively low at y = 70; but with "new" technology, more bombers find their target and the destruction that bombing of x = 50 can accomplish is now relatively high at y = 90. Greater application of or improvements in inputs other than tonnage is depicted as an upward shift in the production function from PF(1) to PF(2). The victory threshold at y = 80 has now been crossed. Whereas tonnage alone would not have achieved victory along PF(1), tonnage combined with other bombing inputs can achieve victory.

With the possible exception of "Bomber" Harris, the Allies were well aware of the operation of this process. Harris essentially believed that PF(1) would at some point cross the victory threshold. Perhaps he believed that the threshold lay not at the equivalent of y = 80 but at some lower level so that it would be crossed by PF(1), or perhaps he believed that PF(1) had a higher trajectory, such as that of PF(2) in the figure. But other than to employ greater proportions of incendiary rather than explosive bombs, Harris was not, at any rate, a believer in technology although he could scarce avoid making use of the improvements the Allies put at his disposal such as radio navigation or four-engine bombers. Instead, he believed that the pure quantity of bombing tonnage would do the trick—hence his well-deserved nickname—and he incessantly complained about bombers being wrestled away from his command to protect ship convoys in the Atlantic or to prepare for D-Day. He was a single-minded believer in the idea that the brute number of tons of bombs dropped would suffice to secure victory, and rarely did he allow himself to express anything less than full confidence in his bombing program.[16]

In contrast to Harris, the British, the Americans, and the Germans fought a tug-of-war over pushing the production function either "up above" or pulling it "down below" the hypothetical victory threshold where each ton of bombs would have more (or less) destructive effect. The Allies worked as assiduously on navigation, targeting, code-breaking, fighter-escorts, pilot training, and myriad other complementary inputs to bombing tonnage as the Germans worked to negate any advantage that might spring from their opponents' efforts.

It is crucial to understand the following point. Virtually all of the strategic bombing debate that ensued during and after World War II is cast in terms of bombing's total destructive effect, of whether or not strategic bombing contributed decisively to Germany's collapse and war loss. In contrast, the aim

here is to think about the incremental destructive effect of additional bombing tonnage applied, the marginal effect as economists refer to it. And there is some tantalizing evidence that we show later, suggesting that the marginal effects of bombing were in fact declining, just as production theory predicts.

Regrettably for economists and other mathematically-minded scholars, it is not possible to establish the coefficients of the strategic bombing production function. The reasons for this are at least fourfold. First, in spite of the availability of a large bombing data set, the number of usable observations is actually fairly small.[17] Take a best-case scenario and suppose output is defined as the destruction achieved as a result of bombing aircraft factories. Of the sixty-six months of strategic bombing (December 1939 to May 1945), there are only twenty-three months during which the United States Army Air Force (USAAF) bombed aircraft factories in Germany and twenty-six months of RAF bombing of such facilities. Allowing for an overlap of six months, the combined data set is of forty-three months of aircraft factory bombing by either force. This yields forty-three data points, barely enough from the point of view of statistical science to arrive at valid conclusions regarding the possible effects of strategic bombing on destruction of aircraft factories.

Second, statistically, these forty-three data points will have to be shared out among the very large number of relevant factors other than bombing tonnage—the factors responsible for the shift in the production function (as in fig. 6.2)—so that not enough data points are left over to identify the destructive returns to varying degrees of bombing tonnage per bombing technique. The list of bombing techniques, or bombing inputs other than tonnage, the $\mathbf{x}_A$ in the equation shown at the beginning of this discussion, is huge. Obvious inputs include the number of sorties flown, the number of bomber aircraft available, the fuel range of the bombers, the bomb load each bomber could carry, the type of bomb carried, and the explosive or incendiary charge of each bomb. Less obvious factors are the accuracy of the navigation system, the accuracy of the bomb-sighting equipment, the availability and range of escort fighters, the percentage of flights turned-around before reaching the designated target, and the flight training and experience of pilots, navigators, bombardiers, and gunners. Improvement in each input would be expected to result in a positive effect—better technique, more destruction—but there are not enough data points per technique to demonstrate this statistically.

Likewise, improvements in German air defenses ($\mathbf{x}_D$), such as searchlights, flak, interceptor aircraft, and air defense strategies, would be expected to yield negative effects: better defenses, less destruction.[18] One may have as many

relevant offensive and defensive inputs in the bombing formula as one has observations of destructive output (namely, forty-three) and therefore cannot statistically ascertain the effect of any one input while also controlling for the influence of the other inputs. Statistically, the results would not be reliable.

Third, the inputs other than tonnage were, of course, never constant. They changed so rapidly during the war that practically every mission flown consisted of a unique set of input values, so that the relevant sample size essentially equals one: each bombing run took place with a unique combination of inputs. On a subsequent bombing run, the number of tons of bombs may have been larger, and the destructive effect may have been correspondingly larger as well, but we could not tell statistically if the improvement in the destructive effect was due to the larger tonnage or to the effect of say better navigation or any other input changes. Statisticians sometimes overcome this sort of problem by aggregating data across fine gradations of inputs to gross gradations. For example, instead of detailing the data set by every type of navigational improvement that was invented, installed, and used, the navigation information can be assembled into two coarse groups: dead reckoning and assisted reckoning. This procedure is statistically acceptable so long as the less-detailed gradations do not gloss over differences that subject matter experts would find of fundamental importance to the issue at hand. Navigation—finding your target—definitely was of fundamental importance as to whether a bomb load dropped would bring about the desired damage. Contra "Bomber" Harris, the history of strategic bombing does not revolve around the tonnage of bombs dropped but around the means of "getting them there," and analysts now seem agreed that the single most important breakthrough in this regard was the destruction of the Luftwaffe's fighter wing and its pilots in the spring and summer of 1944. Thereafter, the strategic bombing fleet could get through. Strategic bombing had its greatest effect when it was unopposed! (And by the time it was unopposed, as from September 1944, the ground war had essentially been won.)

The fourth problem concerns the left-hand side, the y_i, in the formula, the "output" of bombing. The output is not, in fact, clearly defined. While we have plenty of bombing-tonnage and other input data, we are not in possession of unambiguous destruction data. For example, even though plenty of German aircraft factories were bombed (in Germany and in the occupied territories), they also were quickly repaired, rebuilt, or relocated so that the bombing at best delayed rather than destroyed aircraft production. This does

not necessarily mean that the bombing was strategically useless—delays can be crucial—but it does mean that strictly statistical work cannot be carried out in the absence of well-defined output data.

Take another example. "Bomber" Harris succeeded in causing the world's first air-generated firestorm with his attacks on Hamburg. There were four night attacks in all: on 24/25 July 1943, 791 bombers flew on the city, on 27/28 July another 787 bombers came, on 29/30 July yet another 777 bombers appeared on the night sky, and a further wave of 740 bombers arrived on 2/3 August. In all, some 9,000 tons of bombs fell on the city. The Americans contributed over 250 daylight strikes as well. In all, between 35,000 to 50,000 civilians are thought to have died in the ensuing inferno. Murray and Millett write that "more than half of the city's living space, 75 percent of its electric works, 60 percent of its water system, and 90 percent of its gas works were destroyed," and industrial production fell 40 percent for large and 80 percent for small and medium-sized firms. Hewitt adds that "183 large and 4,113 small factories, 580 other industrial plants, 180,000 tons of shipping in the port, and 12 bridges [were destroyed in addition to] 24 hospitals, 58 churches, 277 schools, 76 civic buildings, 83 banks, 2,632 stores, and a zoo with many of its captive animals." It would appear that the "output" of bombing—destruction—has been well measured. And yet, Hewitt continues, "railyards and rail services were operating within hours. Electricity supply exceeded demand within nine days. Industrial production rose swiftly to preraid levels. Dehoused inhabitants were evacuated or relocated in the city within a short time." The German war machinery rolled on. When a boxer is knocked down and he gets up, what exactly is it that one's own energy expenditure of striking the blow has destroyed? Clearly, the opponent's cause is delayed, his energy is sapped, but if he does not stay down, the fight is not won.[19]

In sum, even though the effect of bombing is tractable in economic theory, data problems on the input as well as the output side of the strategic bombing production function prevent statistical analysis, at least of the inferential sort. Decidedly, this does not mean that we are without recourse to data, only that any inferences must be drawn even more cautiously than otherwise would be the case. In the next section, we examine the Allies' bombing of German war production assets; then we look at the bombing of the German supply chain and its civilian economy; and thereafter we take up the topic of area bombing. In each case, we need to distinguish between the total and incremental effects of the bombing. While we tell the story of the former, our particular interest is in the latter.

BOMBING GERMAN WAR PRODUCTION

Strategic bombing theory is quite specific: do not bomb the enemy but bomb his tools. Leave him with nothing but his bare knuckles, and he will see the folly of his ways. Mystique (and myth) of American frontier marksmanship and moral apprehension about indiscriminate terror bombing combined to create a school of thought that elevated precision bombing of an enemy's tools and tool-making capacity to a high form of the ethically fought war.[20] Do not so much fight your enemy as restrain him. Despite the savagery of what was to follow, not only in World War II in Germany but in Japan, Korea, Vietnam, the Persian Gulf War, and the Balkan wars in the 1990s, the uniquely American concern with precision did not come to fruition until, perhaps, and more than sixty years too late, the Iraq War.

Nonetheless, "strategic bombing was not on its face pointless or impossible," Stephen Budiansky reminds us, and he is echoed in this by many authors. Implementation hinged crucially on target identification and bomb delivery. The bomb delivery problem appeared to have been solved with the appearance of the Mark XV bombsight Carl L. Norden developed for the U.S. Navy in the early 1930s. In theory it cut the average bombing error to around 100 feet; it weighed just fifty pounds, and tests from 5,000 feet achieved a 50 percent hit rate on an anchored Navy cruiser, "a stunning improvement over previous accuracy rates." *Collier's* published, on 26 September 1942, an arresting cartoon showing a bombardier asking his navigator, "Was that address 106 Leipzigerstrasse, or 107?" Target identification was supplied by a subsidiary theory: the theory of the industrial web. This would highlight specific choke points, bottlenecks, and sundry critical nodes, war production taps that, once turned off by precision bombing, would paralyze the enemy into submission. It is useful to remember that the Great Depression had barely run its course at this time, and it appeared to confirm this theory of economic dominoes: find and take out the one card that would make the enemy's house of cards collapse upon itself.[21]

The theory would come to naught, not because it was wrong but because it assumed too much and because it was incomplete. It assumed too much, for example, in that even a perfectly functioning bombsight is utterly useless without navigation to get to the target. It is one thing to drop a test bomb on a tethered Navy cruiser when one flies in clear weather to a well-known, predetermined drop-off point; it is quite another thing to find one's way, unescorted and unguided, from an English air base across a cloudy Channel to a rainy

European continent, intercepted by searchlights, flak, and air defense fighters. It was not a matter of finding 106 or 107 Leipzigerstrasse, it was a matter of finding Leipzig—and finding it while one was still alive.

The theory also proved incomplete. As the Allies were to learn, the Germans proved adept at relocating and redistributing manufacturing sites, at stocking up supplies so that production flows would not be interrupted, at working extra shifts, at corralling slave and foreign workers, and at substituting one raw material for another. Although the Americans rarely wavered in the faith they put in precision bombing, it proved in practice much harder a task than they had made themselves believe.

To the utter amazement of the Allies, despite bombing of German aircraft factories, German aircraft production continuously increased during the war and reached its apex in 1944 with 39,807 aircraft produced. That year, the production high points were July, August, and September when, each month, more than 4,000 new aircraft rolled onto the tarmacs. But by 13 September, the Allies already stood on the Siegfried Line, and the Soviets pushed the Germans back home from the eastern front (to which Germany had committed three-quarters of its troop strength). It was the end game of the war, quite unlike what the champions of strategic bombing had promised.

If not aircraft production itself, perhaps the bombing at least reduced the German potential to produce aircraft. Might Germany have produced even more aircraft without the bombing? To answer that one would need to measure the German potential to produce aircraft (and arms, generally) rather than its actual aircraft (arms) production. The British did just that, only to find that Germany's arms production potential rose right through to the end of the war. An index of actual German armament production (fig. 6.3) set to equal 100 for January and February 1942 rose continuously and tripled to a level of 308 for the third quarter of 1944 (III/44) before falling off to 270 in IV/44, after which it continuously declined to the end of the war.[22] The British write that

> the most careful study has failed to provide any evidence to support the major economic inferences derived during the war from the physical picture of destruction. Paradoxically, . . . war production, far from falling as a result of the levelling of the German cities, continued to mount until the second half of 1944, and its subsequent fall had little to do with the continued bombing of centres of population. It was in the military, not the economic spheres that our attacks had their major strategic effects.[23]

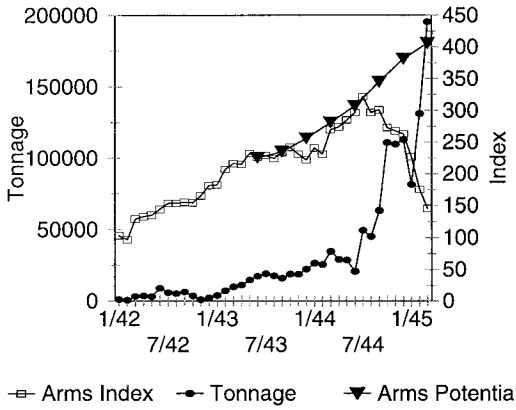

Figure 6.3. Monthly index of actual and potential German arms production, and tonnage of bombs dropped by combined strategic forces, 1942–1945
Sources: *USSBS, February 1947, p. 13 (tonnage), p. 113 (arms index), and BBSU, 1998, p. 91 (arms potential).*

And the Americans write:

> For [the early war] years the conclusion is inescapable that Germany's war production was not limited by its war potential—by the resources at its disposal—but by demand; in other words, by the notions of the German war leaders of what was required to win.[24]

What the bombing may have achieved, in the view of both surveys' authors and later analysts, was to hinder Germany from fulfilling its arms production potential, which reached a high-level mark of 406 in the first quarter of 1945, when the index for actual production had already fallen to 182. According to the numbers, Germany's actual arms production fell only from the third quarter of 1944 (fig. 6.3). What is significant about this is that by that time—after D-Day—the bombing of Germany was not strategic but tactical, to prepare for the advance of Allied troops. It was, as we argue later on, not to coerce Germany to surrender, but to ready it for conquest.[25]

By the time German arms production fell in the third quarter of 1944, only 30 percent of the total tonnage of bombs that the RAF and USAAF would eventually drop on German territory had been expended.[26] That is, *after* D-Day, *after* the invasion of Normandy, *after* the French-German border had been reached, *after* the war on the ground had seen its decisive breakthrough, 70 percent of the bombs had yet to be dropped. The war had already been won

Table 6.1: Tonnage dropped on German aircraft production sites and German aircraft production, January 1941 to December 1944

Month/year	Tons dropped	Aircraft produced	Month/year	Tons dropped	Aircraft produced
1/41	1	633	1/43	0	1,525
2/41	44	871	2/43	4	2,004
3/41	61	1,174	3/43	0	2,166
4/41	35	1,129	4/43	631	2,100
5/41	0	1,037	5/43	211	2,196
6/41	4	1,040	6/43	652	2,316
7/41	22	1,054	7/43	1,301	2,475
8/41	2	1,021	8/43	620	2,337
9/41	17	987	9/43	658	2,214
10/41	0	957	10/43	862	2,349
11/41	0	895	11/43	347	2,111
12/41	0	978	12/43	851	1,734
1/42	40	1,018	1/44	2,356	2,445
2/42	8	906	2/44	4,888	2,015
3/42	0	1,400	3/44	3,954	2,672
4/42	215	1,321	4/44	9,296	3,034
5/42	269	1,315	5/44	5,165	3,248
6/42	316	1,282	6/44	2,477	3,626
7/42	0	1,360	7/44	5,597	4,219
8/42	19	1,345	8/44	7,567	4,007
9/42	173	1,310	9/44	1,444	4,103
10/42	250	1,444	10/44	1,385	3,586
11/42	295	1,307	11/44	547	3,697
12/42	129	1,548	12/44	200	3,155

Source: USSBS, February 1947.

and just needed to be seen through to its conclusion. While there might have been military reason to compress enemy forces into an ever smaller territory where increasing defense density also increases the likelihood of offensive hits, this cannot have been the purpose of strategic bombing if strategic is defined as undermining the enemy from within.

We turn now from the overall arms production picture to the marginal or incremental effects of strategic bombing to examine two specific cases, production in the aircraft industry both inside and outside of Germany (see table 6.1)[27] and production in the chemical industry (used, for example, for explosives production). Evidently, the largest number of aircraft produced occurred during the time period of the most intense bombardment of the industrial sites, in 1944. Without question, German aircraft production rose in spite of increased tonnage of bombing. How then can one assess damage to Germany's aircraft production effort? One approach is to take the highpoint of production, 4,219 aircraft in July 1944, and count, relative to this benchmark, the production shortfall in the other months to learn how this shortfall

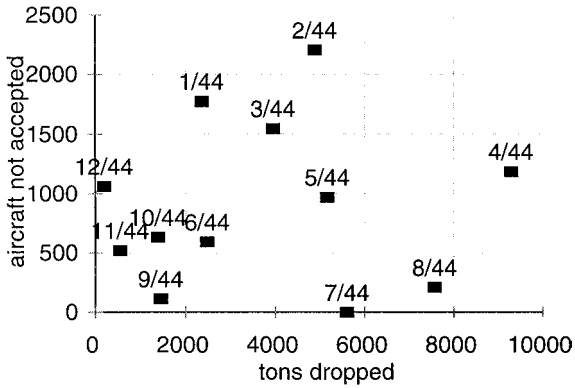

Figure 6.4. German loss of aircraft production
January to December 1944, on account of tons of bombs dropped on aircraft production facilities located in or out of Germany.
Source: *Computed from data in USSBS, February 1947.*

corresponds to bombing tonnage. In July 1944, the shortfall would therefore have been zero; in June 1944, it would be 4,219 minus 3,626 or 593 aircraft short, in May, 4,219 minus 3,248 or 971 aircraft short, and so on.

As neither bombing nor production was seriously ramped up until 1944, we will consider the numbers for that year only. Figure 6.4 presents the numbers visually. The vertical axis measures the hypothetical shortfall, that is, aircraft not accepted into service, relative to the July 1944 benchmark. The horizontal axis measures tons of bombs targeted on aircraft factories. If proponents of the strategic bombing theory were correct, we would expect to see the data trending upward: the more bombing, the greater the shortfall of aircraft not produced. And if the theory of diminishing marginal returns applies, we would expect to see that increasingly higher rates of bombing are associated with declining increases in aircraft not accepted into service. We would expect to see, in other words, something resembling the production function in figure 6.1, which first rises but then tapers off. The picture that we do see is considerably more muddled than theory. But prominently notable is that the four months with the highest bombing levels—April, May, July, and August 1944—are not the months with the highest level of shortfalls, January through March 1944. Moreover, if one were to draw a line through the scatter plot, it evidently would be at first steeply upward-sloping but then bending and flattening out—exactly as the production function in figure 6.1—before

Table 6.2: Tonnage dropped on German chemical industry and industry production index, January 1941 to December 1944

Month/year	Tons dropped	Production index shortfall
2/44	0	12.1
6/44	0	3.2
3/44	3	5.3
4/44	37	0
5/44	160	2.5
8/44	445	20.1
10/44	674	35.7
11/44	758	48.7
1/44	957	4.6
7/44	1,439	5.3
12/44	1,848	58.4
9/44	4,336	34.1

Source: USSBS, February 1947.

bending downward (which would signal negative returns). This evidence would at least not speak against the narrative point to which we alluded earlier, that Nazi Germany's main problem lay not in aircraft production but in pilot production.

A seemingly different, yet much the same, picture emerges with regard to production in the German chemical industry. Production reached a highpoint in April 1944, an index of 101.6, so that the hypothetical shortfall in production that month was zero. We use the April number as the benchmark and subtract from it the index numbers for the other months to calculate month-by-month industry shortfalls and display this against the bombing applied (see table 6.2). At first blush, one might disregard the data point for September 1944 as an outlier and view the number as evidence in favor of successful strategic bombing: more bombing, less production. But statisticians do not simply drop an outlying data point. They ask whether the data point has something important to tell us. And it does. It tells us that even though bombing in September with 4,336 tons was almost six and a half times as intensive as in October (674 tons), the curtailment of chemical industry production was about the same (to an index level of about 35). Moreover, when we examine the raw data in table 6.2, we note that bombing in the 1,000+ ton range reduced the production index to an average of 32.6, whereas production in the 400 to 800 ton range reduced it to 34.8, about the same "bang" for a considerably smaller "buck" of aircraft and crews sacrificed in the attacks.

Similar observations can be made for other types of war matériel. "The bottom line is," writes Werrell, "that the Germans had enough equipment:

they lacked fuel and numbers." Thus we turn to the bombing of the supply chain and the civilian economy. But before we do, it is worth reiterating an earlier remark: while we share many authors' skeptical look at the promise of strategic bombing per se, the specific point we make here concerns only the issue of diminishing marginal returns to strategic bombing. Even if the promise of strategic bombing had held true, it would still be the case that an increasing number of bombs dropped yielded, beyond some point, diminishing increases and even outright decreases. In the latter case, resources were squandered. Without any reduction in the specific destruction of aircraft factories, chemicals, and other war matériel the Allies sought, these superfluously applied resources in machines and manpower could have been brought to bear elsewhere in the war effort.[28]

BOMBING THE SUPPLY CHAIN AND THE CIVILIAN ECONOMY

Supply Chain Bombing

The Americans' air war plan, AWPD-1, principally cobbled together by four men in a mere nine days, from 4 to 12 August 1941, contains this famous passage, the mission statement:

> To wage a sustained air offensive against German military power, supplemented by air offensives against other regions under enemy control which contribute toward that power; to support a final offensive, if it becomes necessary to invade the continent; in addition, to conduct effective air operations in connection with Hemisphere Defense and a strategic defensive in the Far East.[29]

Even more bluntly, elsewhere in the document one reads: "If the air offensive is successful, a land offensive may not be necessary." The priority given to Germany and the nod to Hemisphere Defense and the Far East follow the overall pre–Pearl Harbor war plan, Rainbow 5. The air war plan could hardly deviate from this. But the conditional statements—"if it becomes necessary to invade the continent" and "if the air offensive is successful, a land offensive may not be necessary"—reflect both hubris and calculation, resulting from an unwarranted belief in air power based on "the American propensity to see war as an engineering science." The principal architects of America's air war plan calculated that by destroying "50 electric power plants, 15 marshalling yards, 15 bridges, 17 inland waterway facilities, and 27 petroleum and synthetic oil plants," that is, 124 electric, transportation, and oil targets in all, the German economy could be wrecked enough to make the Nazis sue for peace.[30]

To achieve this end, the air war planners realized that German air defenses would need to be overcome. Figuring that an air attrition war might be problematic, they went back to strategic bombing theory: bomb the places that make aircraft. And so they added thirty targets: eighteen aircraft factories, six aluminum plants, and six magnesium plants. George and Kuter had experience with peacetime bombing practice and added an inaccuracy factor to allow for wartime conditions.[31]

All told, AWPD-1 called for 6,860 bombers, in ten groups, for the German war theater alone. Adding in replacements for anticipated losses as well as escort fighters and support aircraft, let alone requirements for the other theaters of war, the sum total came to 63,467 aircraft and nearly 2.2 million men. Given industrial limitations in the Allied countries, it was thought that a suitable aerial armada to undertake an envisioned six-month-long onslaught on the German economy could not be fully assembled before April 1944.[32]

The engineers' formulas hinged on a logical flaw but, because they were ill-informed, also rested on bad assumptions entering the calculations. The logic proceeded like this: first, the objective is to destroy the key nodes of Nazi Germany's industrial web; second, to do that, one needs to get through the air defense system; and third, to do that, one needs to bomb the aircraft manufacturing facilities. This was circular reasoning: to bomb the factories, one needs to get through the air defenses; to get through the air defense, one bombs the factories. The problem was much more of a simultaneous than of a sequential nature. That aside, the planners assumed, as did virtually everyone at the time, that to sustain the war effort the German economy was operating at full capacity. After overrunning Poland, the low countries, France, and a good bit of Scandinavia, the Nazis had now taken on Soviet Russia (22 June 1941). How could the industrial system not be running at full capacity? As Eric Larrabee remarked: "Two myths coincided. Everyone knew that Germans are efficient and everyone knew that dictatorships are efficient: therefore, if Hitler says Germany is totally mobilized for war, Germany must be totally mobilized for war."[33] But unlike what was acknowledged to be required of the Allies to produce their 63,467 aircraft, the Nazis had hardly begun to flex the country's industrial muscle. Likewise, the AWPD-1 planners severely underestimated requirements for escort fighters, misjudged the severity of bad weather over Europe,[34] vastly erred in their estimate of bombing inaccuracy, and—like historians to this day—overlooked Germany's searchlight batteries and flak defenses, a vital, integrated component of the country's air defense system.[35]

Planning for an Allied invasion of the continent, eventually code-named Operation Overlord, had begun in earnest in January 1943 at the Casablanca

conference. Charles Portal was selected to head up all Allied air forces, but for the duration of Overlord they were transferred to the command of Dwight Eisenhower, who, in December 1943, was appointed Supreme Commander, Allied Expeditionary Forces. A series of preparatory air strikes on the French and German railway system during March 1944 was intended to test what would happen to the German supply chain. For the Allies, the results were remarkably positive. As it turned out, Nazi Germany had built its air defenses primarily to protect the Reich, not to defend and hold any occupied territories. For example, Luftflotte Reich was expressly forbidden from pursuing Allied aircraft into France, a rule not revoked until a week after D-Day. French territory was the responsibility of Luftflotte 3, headquartered in Paris, which tended to be staffed by inexperienced controllers and equipped with outdated tools. Consequently, bombing runs on select French rail infrastructure could be flown at relatively low altitude with correspondingly increased bombing accuracy and very low casualty rates (both for Allied crews and civilians on the ground). This was very much in contrast to the results achieved over Germany. Loss rates in March, April, and May ran at 0.6, 0.5, and 2.1 percent, respectively, against non-German targets but at 4.5, 2.9, and 4.15 percent at German targets.[36]

These preparatory excursions were so successful that even "Bomber" Harris could not but admit: "I myself did not anticipate that we should be able to bomb the French railways with anything like the precision that was achieved." He boasted to his crews: "The U.S. air forces, who specialize in precision visual attacks by day, are in particular astonished at the results. You have in fact wiped their eyes for them at their own game."[37] Meanwhile, Harris's American counterpart, General Carl Spaatz, commander of U.S. strategic air forces in Europe, had been "no more eager than Sir Arthur to surrender strategic control of his heavy bombers to the requirements of a ground campaign." Like Harris, he sent bombers on their way to Berlin, for example, on 4 March 1944. A day later, he submitted to Eisenhower a plan to bomb German oil facilities, to stop the Germans not just in Normandy but on all fronts.[38] But Eisenhower stuck to what was called the Transportation Plan—the attack of fuels would come later. The goal was entirely tactical: stop German supplies and reinforcements from reaching Normandy. It was to support an invasion. The air war planners' "if it becomes necessary to invade the continent" had become necessary.

Werrell has argued that "when we discuss the accomplishments of strategic bombing, we are speaking of what occurred during the last months of the war," by which he meant after the summer of 1944.[39] In truth, the exact

Table 6.3: Effects of bomb tonnage dropped on German railroad and fuel industry, January 1944 to April 1945

Month/year	tons dropped	net tons-km not moved	tons dropped	aviation fuel not produced
1/44	367	1,007	0	134
2/44	735	1,774	0	85
3/44	955	0	0	38
4/44	4,003	381	201	9
5/44	7,823	532	2,459	0
6/44	1,955	477	10,877	38
7/44	3,685	709	11,425	164
8/44	2,149	681	12,066	252
9/44	17,615	3,159	8,145	238
10/44	25,221	4,162	12,241	381
11/44	23,554	5,719	32,542	416
12/44	61,392	6,377	11,290	411
1/45	43,644	8,787	8,516	428
2/45	55,391	11,687	18,608	464
3/45	61,007	12,587	24,973	490
4/45	31,253	14,187	7,458	544

Source: USSBS, February 1947.

opposite is the case: Harris and Spaatz had had their chances prior to that time. Eisenhower would not return direct command of strategic air forces to them until early September, and successful precision bombing for strategic purposes would have to wait another half century. Even then, as the events in Kosovo in 1999 and in Iraq since 2003 have made clear, taking out military assets of strategic value does not necessarily curtail an opponent's ability to commit atrocities against civilians. In Kosovo, the civilian slaughter was a major Serbian strategic objective and air power was not able to stop it; in Iraq, air power may have won the war but the fight continues.

The primary effect of the Transportation Plan bombing was that it diminished Germany's military abilities on the front lines. Disrupting land transportation, as we have seen, did not make Germany's arms production potential decline. It did not even affect actual arms production until after September 1944, because the factories had ample stocks of supplies to sustain production. Instead, the crucial point concerned the disruption of translating stocks into flows, the delivery of matériel and troops to the front. Clodfelter calls this effect of the attack on German land transportation "fortuitous rather than intentional." Surprisingly, military historians have paid scant attention to the role of land transportation, especially the German railroad system.[40]

As before, our main concern in this chapter is not with the total effects of bombing but with the marginal or incremental effects. Employing our earlier technique, we use the highpoint of net tons-kilometer moved by the

German railroad system, in March 1944, as our benchmark, calculating net tons-kilometer *not* moved as the destructive objective of the Allied campaign (table 6.3).

Apart from two outliers, one in December 1944, the other in April 1945, it would appear that the more bombing, the larger the desired effect. But with the beginning of 1945, the game was up. We therefore limit our attention only to the year 1944, as in the earlier examples of aircraft and chemicals production. Diminishing marginal returns to increasing loads of bombing of the railroad system are clearly apparent, especially from September to December. By January, February, and March 1945, the production function of bombing the railroads had shifted since the German defenses were by then destroyed, and again a diminishing marginal effect can be observed.

After the success of the Transportation Plan, Eisenhower next turned to Germany's fuel supplies. We have data on stocks of aviation gasoline, motor gasoline, and diesel fuel as well as data on bombing tonnage dropped on fuel plants (although not broken out by fuel type). To stop the Allied aerial onslaught, the crucial category for Nazi Germany was production of aviation fuel. Employing our previous technique one last time, table 6.3 again shows the effects. May 1944 was the highpoint of aviation fuel production (despite nearly 2,500 tons of bombs on fuel plants). Taking this as the benchmark, we measure aviation fuel *not* put into stock (not produced). From June to December 1944, the fuel industry was badly affected by bombing levels of about 8,000–12,000 tons of bombs per month. An extraordinary 32,500 tons of bombs in November did no more damage than either October's or December's bombing. Neither did the large bombings in February and March 1945.

In sum, we have shown two things: strategic bombing as envisioned—a force sufficient to win independent of the military's nonstrategic branches—did not win the European war. It had that chance before Operation Overlord. Thereafter, when Eisenhower used the strategic forces for tactical purposes and ground support operations, bombing became effective but with diminishing marginal returns.

Bombing the Civilian Economy

It appears that the German civilian economy did not suffer greatly from the bombing. To be sure, civilian consumer production and per capita consumption suffered but not because of bombing. Instead, production and consumption suffered because Germany's armed forces requisitioned so many "consumer" goods for their own use. Oxford University historian Richard Overy stresses that most of the reduction occurred from 1939 to 1942, that is, prior

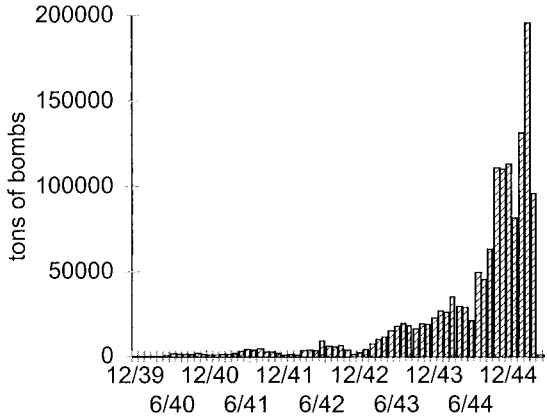

Figure 6.5. RAF/USAAF bombing of Germany, 1939–1945
Source: *USSBS, Statistical Appendix to Over-all Report (European War), February 1947, Chart 6, pp. 49–91.*

to the time when Allied bombers actually got through to German territory (fig. 6.5).[41]

War mobilization in Germany reached 13 million people, but the total German civilian labor force fell by only 3.5 million people, from 39.4 to 35.9 million. Correspondingly, the greatest decline occurred in the male civilian labor force, which fell from 24.5 to 13.5 million. This decline of 9 million men was nearly made up by 7.5 million foreigners and prisoners of war. The average work week changed hardly at all (from 47.8 to 48.3 hours per week between September 1939 and March 1944). Women's labor force participation changed negligibly from 14.6 to 14.9 million and could hardly have been pushed higher. As regards capital, Germany had a comparatively high capital/labor ratio, and the vast majority of industrial work was carried out in single shifts. Even of the crucial arms production facilities, only one-fifth to one-quarter worked a second shift. Strategic bombing damaged or destroyed a mere 6.5 percent of installed German machine tools. This was easily replaced. Raw material stocks were ample, at least for about six months or so after the start of the war. Thereafter, in addition to materials recycling and product redesign, successful campaigns replenished supplies such as "chromium from Bulgaria and Greece, nickel and molybdenum from Finland and Norway, copper from Jugoslavia, Norway and Finland, manganese from Russia, mercury from Italy and Spain, and bauxite from Hungary, France, Yugoslavia

and Italy." It was not until fall 1944 that raw material shortages began to affect civilian and armament production.[42]

In addition, Germany had large inventories of required materials so that temporary setbacks in raw material production did not noticeably affect production of finished civilian and war goods. Moreover, German industry was already geographically widely dispersed; remaining critical industries that were found to be too concentrated in too few locations were dispersed even further. At best, the strategic air war appeared to secure modest delays in further increases in German production, rather than securing decreases. A well-thought-out set of calculations shows that Germany's overall war production potential diminished on account of strategic bombing by a mere 2 percent or so, with the high point of a 3.8 percent reduction occurring in the second half of 1943, well before D-Day.[43]

Bombing the arms supply chain and the civilian economy did not bring about the desired strategic effects — making the enemy collapse from within. The land invasion was necessary.[44]

BOMBING GERMAN MORALE

> It is improbable that any terrorization of the civil population which could be achieved by air attack could compel the Government of a great nation to surrender. . . . In our case we have seen the combative spirit of the people aroused, and not quelled, by the German raids. Nothing we have learned of the capacity of the German population to endure suffering justifies us in assuming that they could be cowed into submission by such methods, or, indeed, that they would not be rendered more desperately resolved by them.

So wrote Winston Churchill on 21 October 1917. We do not know why Churchill changed his mind — he may have done so as early as 1918 — but nearly twenty-three years later, on 8 July 1940, he wrote: "We have no Continental army which can defeat the German military power . . . But there is one thing that will bring [Hitler] back and bring him down, and that is an absolutely devastating, exterminating attack by very heavy bombers from this country upon the Nazi homeland."[45] For Britain, the phony war had ended, and in May 1940 it threw its first serious load of bombs on German cities. In July, Bomber Command for the first time employed delayed-action bombs, and on the night of 12 August the first-time use of incendiary bombs followed, dropped on the cities of Bielefeld, Dessau, Frankfurt am Main, Halle, Hamburg, Kassel,

Koblenz, Köln (Cologne), Münster, Neustadt an der Weser, Osnabrück, and Weimar. Up until this time, the Nazis had focused on bombing British shipping. Now, the Luftwaffe responded by attacking the British Isles, indeed British cities. The "Battle of Britain" had begun, and so had "morale" bombing.

For the planners, morale bombing carried moral ambiguity with it. Koch writes "that very few of those responsible for initiating the policy of indiscriminate bombing from the air, or for carrying it out, seem to have felt any moral scruples about it at the time, or indeed to have paused to reflect upon the inevitable results and implications of what they were doing." If not immoral, bombing was certainly amoral: it was what the engineers had to do to win. *Morale bombing* was to become a euphemism, "the cosmetic word for massacre," made most famous by Kurt Vonnegut's *Slaughterhouse Five* (1969). But if the eventual outcome was immoral, that was not what had been planned at the beginning. To the contrary, the record is clear that for the American air war planners morale collapse was to be an incidental consequence of destroying the enemy's industrial web. Like Churchill in 1917, the U.S. air war plan AWPD-1, of August 1941, considered that "area bombing of cities may actually stiffen the resistance of the population, especially if the attacks are weak and sporadic." Moreover, the commander of U.S. strategic forces in Europe, Carl Spaatz, is clearly on the record, as are Ira Eaker, one-time commander of the Eighth Air Force, and other principal players such as Spaatz's bosses, General Arnold and General Eisenhower, that morale bombing, bombing of German cities, bombing of civilians was a no-go proposition.[46]

According to historian Ronald Schaffer the reason for this opposition to morale bombing was not that it was considered immoral but that—in the spirit of war as engineering—it was inefficient. In a detailed account of official histories, records, diaries, autobiographies, letters, and other sources, Schaffer finds that "none of the officers raised anything but pragmatic objections to morale bombing."[47] The pragmatic objections included that such bombing might actually strengthen resistance, that even if bombed, the population might not be able to take on the Nazis, that resources would be diverted from the more important aim of precision bombing of industrial-web targets, and that the Army Air Force's public image might be smeared back home, where there was moral opposition to bombing of civilians, leaving its postwar future in jeopardy.

As for the British, even "Bomber" Harris was not primarily interested in morale bombing. His particular peeve was that precision bombing manifestly did not work so that the only alternative that remained was indiscriminate area

bombing. In this he took solace from the Butt report of August 1941, an account on the inefficacy of British precision bombing. The bombing was found to be pathetically inaccurate. For example, only 22 percent of pilots who even claimed to have hit their target got within five miles of it, let alone hit it. The remainder of the year would be no better. Henry Tizard, a scientific adviser to the British government, remarked in early 1942 that in the previous eight months fewer Germans were killed on the ground than Brits in the air. Thus Harris, in a curious leap of logic, concluded from the Butt report that the targets would not be industries, nor factories, nor morale per se. The targets would be cities. "The only way bombers could destroy *anything,*" writes Stephen Budiansky, "was to destroy *everything.*" Harris was helped, a mere week before his February 1942 appointment to lead Bomber Command, when the War Cabinet changed course and directed that the primary objective of a new air offensive be "focused on the morale of the enemy civil population and, in particular, of the industrial worker." This suited Harris well enough, and city bombing ensued, including the four firestorms in Hamburg, Kassel, Darmstadt, and Dresden that alone caused about half of the estimated 600,000 German aerial bombing civilian war deaths.[48]

When the German defenses had long been breached, in the winter and spring of 1945, "bombers were available in greater numbers than were required to eliminate the remaining important precision targets . . . [thus] they could be used against civilians with no loss of efficiency." Morale bombing slipped, Ronald Schaffer suggests, ever so gradually from pragmatic moralism to immoral practice.[49] But it was not indiscriminate, not uniformly random. To the contrary. It targeted of course cities rather than rural areas; it targeted factories and, with that, working-class neighborhoods rather than the well-off. It thus affected mothers, children, the old, the insane, the invalids, the infirm, and the immobile. The maelstrom of destruction consumed noncombatants and even Reich prisoners without regard to their actual participation in the war or support of the Hitler state. The war engineers' theory of strategic bombing had been put to the test, and the test had gone wrong. The British and, later, the Americans bombed because they could, and the Germans did not because they could not. The Allies had assembled a comprehensive long-range bomber fleet; the Nazis had not.[50]

In the event, neither in Britain nor in Germany did morale bombing have the hypothesized effects. The Germans were the first to learn this, in Guernica, prior to World War II. The Spanish Civil War, which would see Generalissimo Franco rise to a dictatorship that would not end until his death in 1975, became

a welcome proving ground for those who would be titans a few years later. As participants or as observers, all the major players, save Japan, were involved to a greater or lesser degree: the Italians, the Germans, the Russians, the French, the British, and the Americans. The Luftwaffe, in particular, made a sport of putting its tactical and strategic air war doctrines to a real-war test. Despite warnings by the American military attaché that "the Flying Fortress died in Spain," his superiors would not heed the fundamental lessons the Germans learned: an air force must be a whole package of bombers, interceptors, and fighters, and an air force must be integrated into the ground war.[51] When Mussolini—another dictator—ordered his forces to bomb Barcelona, 16–18 March 1938, thousands were killed or wounded, yet Republican resistance to the Fascists rose. So found not only the British but also a Luftwaffe study.

Nearly a year earlier, on 26 April 1937, the German air force, for reasons of diplomatic deniability masked as the Condor Legion, had its own go at terror bombing. Pablo Picasso's *Guernica* became the icon of the massacre (three hundred civilians died in the attack) much as Kurt Vonnegut's *Slaughterhouse Five* years later would become an icon of the Dresden firestorm. There is no indication that Nazi Germany concluded in any way that terror bombing was the best way to conduct war.[52]

The early British bombings of Germany induced, at first, derision. The bombs were widely off the mark, doing little more than rattling the population in the few places where the bombs fell. The security service (the Staatssicherheitsdienst, or SD for short) had set up an ingenious reporting system that would routinely and scientifically sample popular opinion as to the bombings' effects and feed the reports back to the Nazi leadership. A seventeen-volume compilation of these reports was published in 1984. Koch, who examined these records in some detail for the May to September 1940 period, finds little more than reports of sleeplessness, nervousness, "some psychological and physiological wear and tear," but no effect on discipline or productivity. In contrast, the reports that made the round in Britain were gloating with the supposed success of morale bombing. They seemed rather misinformed.[53]

On the British side of the Channel, morale did not seem much dented by the fall 1940 Blitz on London either, nor would it be by later German attacks. For example, Solly Zuckerman, who was to be Britain's Chief Scientist for its postwar British Bombing Survey Unit (BBSU), the U.K.'s equivalent to the USSBS, found that the 1941 German attacks on Hull and Birmingham induced neither panic nor adverse effects on health and productivity, findings the BBSU would later confirm with regard to Germany: "In so far as the offensive against German towns was designed to break the morale of the German

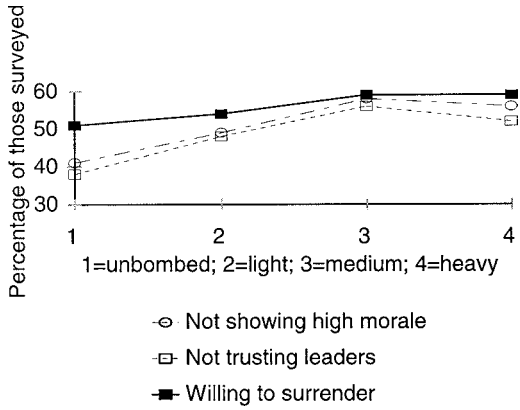

Figure 6.6. Diminishing returns of Allied strategic bombing on German people's morale
Source: *Constructed from USSBS, 30 September 1945, p. 96.*

civilian population, it clearly failed."[54] Moreover, with the power government confers, both sides' officials managed the information to their mutual, if internal, advantage. Morale bombing was to become a "public relations problem [of] managing information for the survivors."[55] The USSBS likewise would later write that although the bombing had measurable, serious effects on civilian morale as it had "appreciably affected the German will to resist," nonetheless, "depressed and discouraged workers were not necessarily unproductive workers."[56]

As before, what is of particular interest to us is not the total effect but the marginal effect: the effect of additional tons of bombs on an already adversely affected morale. It turns out that this is the clearest case for which diminishing returns to bombing (strategic or otherwise) can be shown. One can hardly do better than cite the USSBS conclusion verbatim:

> Continuous heavy bombing of the same communities did not produce decreases in morale *proportional* to the amount of bombing . . . These observations of the diminishing returns from heavy bombing point to the practical conclusion that the maximum *morale* effects of dropping a given tonnage of bombs on Germany would have been attained by lighter raids as widely distributed as possible, rather than by concentrated heavy bombing in limited areas.[57]

For example, the morale of those living in "towns subjected to the heaviest bombing was no worse than in towns of the same size receiving much lighter bomb loads."[58] Figure 6.6, constructed from data in USSBS, shows this diminishing effect.[59] The percentages on the vertical axis are stated in terms of the

Table 6.4: Home destruction and morale

	People showing low morale . . .	
	Cross-section Sample A	Cross-section Sample B
Cities with		
60–80% homes destroyed	55	53
49–59% homes destroyed	58	56
20–39% homes destroyed	59	59
1–19% homes destroyed	43	56
0% homes destroyed	—	41

Source: USSBS, September 1945, p. 96.

Allies' desired outcome: the percentage of people *not* showing high morale, of people *not* trusting leaders, and of people willing to surrender. All three variables show diminishing, indeed *negative,* returns as a function of increasing amounts of bombing. Heavy bombing was less effective in lowering morale than medium bombing. And in contrast to the strong wording of USSBS, even in the absence of any bombing whatsoever, 40–50 percent of the German population was demoralized. Light and medium bombing brought that percentage more surely to the 50 percent mark but not much beyond that,[60] reflective of a ceiling beyond which bombing simply could not reach. The marginal effect was diminishing and even negative, and the total effect was actually small: 59 percent of the unbombed showed "high morale," a percentage brought down by bombing to only 42 percent. Table 6.4 shows a similar diminishing returns effect with regard to home destruction and morale.

ASSESSING THE EFFECT OF STRATEGIC BOMBING

The concept of strategic bombing was first applied on a truly massive scale in World War II, especially in the European theater of operations. Naturally, it would take some time and experimentation to get things "right," to discover what the practical difficulties of such bombing might entail, of whether strategic bombing would be a viable, militarily useful concept or not. A learning curve would be expected. But it was also expected that the learning curve would lead to the expected result: an enemy collapse from within.[61] This was not to happen. The U.S. Air Force's own careful history—although written by independent historians—is quite correct in its assessment that up to late 1943 its forces were "inadequate" to bring about so drastic an outcome. By the end of 1943, "it had become apparent that an all-out attack on Nazi air power would be a necessary preliminary to any successful strategic bombardment campaign"—as Rainbow 5 had foretold. And so the first few months of

1944 were spent taking on the German Air Force. The result was that while "German fighter production was to increase rather than decrease during 1944 . . . production did not keep up with the planned schedule and for that failure the Big Week [in February 1944] and subsequent bomber attacks were largely responsible." In March 1944, however, Eisenhower took direct command of the strategic air forces for the tactical purpose of preparing and succeeding in the Normandy landing. Even as late as January 1945 as many of three-fourths of all United States Strategic Air Force missions were flown in support of the ground troop advance on Berlin. But by this time, the Nazis' game was long over. Ultimately, "victory was possible only through the combined efforts of the several arms of the associated powers and of the civilians behind those arms."[62]

Hewitt writes: "Most of the bombs, heavy bomber sorties, civilian deaths, and urban area destruction in Japan and Germany occurred not when these countries were at the peak of power or merely on the defensive, but after mid-1944 and especially in 1945 when they were on their knees." Of the 1,419,604 tons of bombs to fall on Germany, 1,016,157 fell between July 1944 and May 1945—nearly 72 percent. Of that, much was directed in support of tactical operations on the ground; much of the remainder fell against towns and cities, after the occupied territories had been liberated, after Germany had dispersed its war production into the countryside, and after its supply routes to the front had been cut off. Following D-Day, strategic bombing cleared the brush for conquest. It did not coerce Germany's leaders, nor its civilians, to simply give up the fight.[63]

In Levine's view, this is too harsh a judgment. "The bombers were never expected to win the war alone or avert an invasion, and they received a far lower priority than would have been the case had this been planned." He also believes that the events of 1944 were due "primarily to the belated development of countermeasures to the Germans' radar and homing devices, and not, as is usually said, to the crippling of the German defenses by the loss of territory and gasoline." Indeed, "the efforts of the tactical and strategic air forces cannot be neatly separated. Up to D-Day the tactical forces played an important role in gaining air superiority, and in the final phase of the transportation campaign their efforts fused with those of [the United States Strategic Air Force] and [the Royal Air Force] Bomber Command." The USSBS adds: "During the war it was impossible to assess the real significance of this type of warfare . . . It was impossible . . . to know with certainty whether or not the effects of the air activity against the Reich justified the effort expended."[64] Despite these defenses and considerations, Levine himself concludes:

> During this period [1943 and early 1944] . . . the strategic forces did not accomplish their explicit assigned aims, as set out in the Casablanca and combined bomber offensive directives. They made no important contribution to the winning of the Battle of the Atlantic and did not seriously impair German morale, reduce overall German war production, or stop the manufacture of any critical items.[65]

What, then, did the strategic forces achieve? Levine speaks for many with his view that the marginal effects, such as delaying, but not hindering, German weapons production, "would have justified strategic bombing even if it never accomplished a more positive aim. It is hard to see how any other use of Allied resources could have similarly affected the enemy in the same time period." This echoes USSBS's own account: "If strategic bombing did nothing but force the dispersal of the aircraft industry it would have paid its cost."[66]

This conclusion is illogical. The resources poured into the strategic bombing effort could have been applied elsewhere (e.g., more fighter-bombers for air-to-air combat and in tactical support) where, at worst, they also would have had little incremental effect. But in light of the eventual outcome, one must venture that more tactical air power would have made a declining but positive incremental contribution to breaking through the German defensive lines in France earlier than D-Day on 6 June 1944. An earlier invasion had, in fact, been planned but was not considered possible in light of resource constraints.

Another way to think about strategic forces—a way that perhaps reconciles the contrasting views—is to think of them not in isolation of other inputs but conjointly. Just as targeting technology helped shift the effectiveness of strategic bombing to a higher production function (fig. 6.2), so tactical air power may be seen as just a different technology. Once the "technology" of tactical air power had advanced, it shifted strategic bombing onto a higher production function and above the victory threshold—only that it then became conquest bombing rather than strategic bombing.

Although the data do not permit quantitative analysis in a statistical sense, it is quite clear that as envisioned by the air war planners strategic bombing did not have a significant impact on Germany's war production. Manufacture of weaponry did not fall, but actually rose in the last year of the war. Such effects as strategic bombing did have were due primarily to shift factors (e.g., improvements in the tactical air war) and displacement factors (e.g., German resources poured into air defense) rather than to increased amounts

of bomb tonnage per se. The primary effect that strategic bombing brought was preparation for conquest.

In fairness to the Allied war effort, one must of course acknowledge that they suffered from severe information deficits during the war that made an assessment of the bombing's efficacy difficult. The larger point, though, is that one can well apply a concept in economic theory to the conduct of war. Historian Richard Overy repeatedly points to diminishing returns in the German war economy.[67] For example, in various essays he argues that from 1939 to early 1942, Germany poured increasingly more resources into its arms production machinery, but to declining effect. Only once it was realized that the war would be protracted did the Nazis shift conceptually from more production to more productivity in production, that is, a shift in the production function. This occurred most famously when Albert Speer was appointed armaments minister in February 1942. For example, with little increase in labor — moreover, much of it less productive forced labor — aircraft production nonetheless nearly quadrupled between 1941 and 1944.

STRATEGIC BOMBING AND THE OTHER PRINCIPLES OF ECONOMICS

The preceding sections elaborate how the principle of diminishing marginal returns may be applied to military operations in the case of the strategic bombing of Germany in World War II. This section indicates how the other economics principles used in this book may also be applied to the case.

Manpower and Other Resources

Albert Speer's ascension to direct Germany's arms production effort resulted in a massive streamlining of its efforts and in vastly more efficient outcomes. Arms manufacturing productivity surged as physical, human, and institutional resources were reallocated. The opportunity to forgo production the way Speer would organize it had become too costly. Germany could no longer afford a non-Speer production path, and resources were steered toward higher-valued usage.

An illustration with regard to the expected marginal cost/benefit principle is given by the reallocation of United States strategic air forces in 1942/43 from British bases to the North African theater. The early efforts of the British and American strategic bombing campaign against Germany soon ground to a halt as it was recognized that imprecision in targeting, frequent inclement

weather (cloud cover), limited bomber-range, effective air defenses, and other factors much tempered the high hopes invested in strategic bombing. Shifting air force resources to the African theater would result in a higher differential of benefits and costs. The forces were used to fly missions to Italy (to prepare the invasion there), and beyond Italy to Romania and southeastern Europe, where they were used in an attempt to disrupt raw material supply routes to Germany.

The operation of the principle of substitution is illustrated by Germany's increasing use of foreign and slave labor as it drew its own men to the front lines. To economists, substitution is occasioned by relative price changes. If the use of one resource becomes too costly, people tend to switch to another, relatively cheaper resource provided it fulfills the same overall objective. To use a frivolous example, if the intake of vitamin C is the objective and oranges become more expensive, we would expect people to switch consumption toward grapefruit or blueberries or bell peppers. As the war wore on, the employment of German men in industry became more costly, measured as the forgone opportunity to use them on the front lines where they were more desperately needed. Foreign and slave labor, in spite of the attending addition of supervisory cost, became relatively "cheaper" and an economist could well have foretold this substitution.

Diminishing marginal returns are evident not only in the main theme of this chapter but in many related cases as well. For example, the aforementioned transfer of the USAAF Eighth Division from Britain to North Africa in 1942/43 to fly bombing runs on Italy and southeastern Europe would naturally result in diminishing returns the farther away flights strayed from base. The same anticipated advantage would take more resources to accomplish. But if more resources accomplish the same aim in one case as fewer resources in another, then diminishing returns are at work. This was well recognized by the decision makers who eventually re-relocated the Eighth to higher-valued uses — the western front.

The strategic bombing case also yields plenty of examples on the operation of the principle of (overcoming) asymmetric information before and after an action is taken. On the manpower front, for instance, bombing of Germany from 1940 to 1943 correctly signaled that the Allies did not (yet) have their bombing act together. The Allies revealed a previously hidden aspect of their air force, namely, its relative ineffectiveness. The principle of (overcoming) asymmetric information is also at work in the speed of personnel call-up and mobilization. Successful mobilization relies in part on government's ability to identify and draft men to fight war. It may be presumed that while people

know where they are, government does not. Government is at an informational disadvantage. But part of Nazi Germany's evil genius was its detailed and efficient citizen registration system, a system that allowed massive mobilization in a short amount of time, mitigating the potential obstacle of asymmetric information.

On the flip side, that is, asymmetry after an action is taken, we have the example of successful enemy infiltration by spies. Once a person is a spy (has taken an action), how does one overcome the problem of hidden action (e.g., monitoring that the spy does not become a double-spy)? One must overcome asymmetries in information about intentions. One way to do this is by designing one-way gateways by which information flows only in the desired direction, that is, by placing spies in a position to collect and transmit information from target to home without putting them in a loop that would permit them also to transmit from home to target. A rereading of spy history would probably reveal a number of mechanisms by which the asymmetry problem was addressed, if perhaps not solved. Likewise, we would expect that successful double-agency revolves around the failure of overcoming the asymmetry problem.

A different example of overcoming hidden action asymmetry is given by an insidious form of bonding that leads people to police themselves. The authorities' problem is to avoid defection from the cause. If people disagree with the state, at least some of them will seek to shirk assigned responsibilities. To rein in, the state has to set up a costly monitoring system. Much better (cheaper) to create a "culture" in which people monitor each other and report to the authorities those thought to lack certain vigor and commitment to the state's cause.

Logistics

On the logistics front, the operation of the opportunity cost principle is evident in the switching of strategic air forces for tactical air support missions in preparation for and following D-Day in June 1944. To withhold the use of the strategic air assets would have involved a colossal cost, namely, the forgone opportunity to employ them tactically. The calculation of expected incremental costs and benefits were constantly pondered in bomb-targeting decisions. Examining the month-by-month bombing records, it is empirically evident—and so is the narrative record in the literature—how decision makers oscillated among target preferences as anticipated costs and benefits changed. Where to send the next wave of bombers? Shall we attack German rail stock or canals or bridges or fuel supplies or air fields or arms production sites? Which target

of logistic value to Germany should be attacked next? Much of the decision making involved consideration and reconsideration of anticipated benefits to the Allied war effort and anticipated costs. The costs, crucially, involved not merely the potential loss of airplanes and crew but the opportunity to have used the same aircraft and crew to bomb another target that might have proven of greater value.

Not surprisingly, these benefits and costs were often falsely anticipated. The German railroad system proved resilient, for example, because it had so many unexpected (for the Allies) redundancies built in. Not infrequently, attacks on rail yards killed not Germans but foreign and slave workers, causing little substantive damage to Germany's war effort. To keep the trains, trucks, vessels, and aircraft moving—on all sides of the war effort—necessitated an information, communication, and signaling system of extraordinary breadth and depth. The very idea of strategic bombing was predicated on the notion that disrupting Germany's production and logistics would win the war. But once the fight was joined, the information needed to conduct such a war proved insufficient. Had this been more clearly understood from the outset, the strategic bombing effort might never have been made. Instead of acting on reliable information, the Allies frequently had to act on the basis of speculation. Toward the end, however, as Germany's declining capacity to fight the war was rapidly revealed, the situation reversed itself. Not unlike the case of the American Civil War (chap. 5), the Allies could be surer, prior to action, of what to expect. Likewise, German soldiers on the receiving end could be surer of their unhappy fate, and this prompted a serious break in the cultural compact between the Nazi state and its troops. Aerial bombardment and disruption now made it harder for officers to keep track of their underlings, to report them to the higher-ups, to punish the laggard, to pursue the deserter. Hidden action (the pursuit of the troops' real intentions) became more evident but there was not much the Nazis could do anymore. Units and fighting morale disintegrated. In the arena of logistics, things began to break down internally.

The principle of diminishing marginal returns is illustrated more narrowly than in the main sections of this chapter by examining the initial bombing runs into Germany. Only with the catastrophic failure of the bombing run on Schweinfurt in August 1943 did the Allies finally conclude that sending swarms of unescorted bomber planes to Germany territory was folly. German air defenses took down many a plane and crew. Packs of hundreds of bomber aircraft achieved little more than squadrons of smaller size did. This would

not change until the introduction of the American P-47 Thunderbolt and P-51 Mustang aircraft.

Technology

Much has been made of the Allies' befuddlement over Germany's ability to keep producing, even increasing, its armament output. It turned out that Germany was able to disperse its research, development, and production centers widely and effectively. Nonetheless, despite its ability to adjust, dispersal increased communication and transportation costs. The presumption must be that Germany preferred not to disperse and incur the additional cost, subtracting resources it could and would have used to prosecute the war. The Allied effort imposed a however small opportunity cost on the German war effort. But dispersal also forced German managers, scientists, and engineers to be smarter, to make do in new circumstances, to be less visible, less easily tracked, more safely harbored from attack, and yet be equally or more productive than before. At least at first blush, it is not implausible to argue that bombing-induced dispersal assisted the German war effort. Better to know where your enemy is than not to know where he hides. Bombing-induced dispersal deprived the Allies of important information.[68]

The principle of substitution is well illustrated by Germany's technological effort to develop synthetic fuel sources for motor transport as natural oil and gas sources came under attack (cut offs from foreign trade and Allied attacks on German-occupied oil fields in southeast Europe, e.g., Romania). An example of incremental costs and benefits in the technology area is given by the Allies' development of add-on/drop-off fuel tanks to extend the range of their fighter fleet. One of the more fundamental problems the Allies encountered early on in the strategic air campaign was that their bombers could fly farther than their escort fighters. Fitting the fighters with add-on fuel tanks, to be dropped off when empty, allowed them to accompany the bomber fleets farther into German territory. The expected benefits are obvious. But the benefit was bought at a cost: fully loaded, the add-on fuel tanks slowed down Allied fighters, which then proved highly vulnerable to agile German air defense fighters, which merely needed to rise, shoot, and drop down for refueling.

The principle of diminishing marginal returns is illustrated by the curious case of the missing German pilots. As we have seen, it is well documented that almost to the very end of the war, Germany produced astonishingly large numbers of aircraft. What it did not have, or had only in declining numbers, were competent pilots to fly the aircraft. Once the United States did make

the decision to design, build, and introduce the P-47 and P-51, the German Air Force finally encountered a formidable opponent in the air, so formidable that it overwhelmed the Luftwaffe. Survival rates dropped, and German pilots became scarce. Economically, aircraft and pilots are complementary goods. One requires the other. Building aircraft would not solve the problem, neither would fueling them. Without pilots, diminishing returns to more aircraft set in rather more rapidly.

Regarding the overcoming of hidden action problems, the development of the German arms industry serves as an example. Initially, much industry was private and worked on a cost-plus contract basis. The usual arms industry contracting problems that are much discussed today applied back then as well. How does the state know to what degree a privately contracted party honestly and conscientiously fulfills its contractual obligations? There are many ways to address this problem. The German state initially helped finance much of the construction of the industrial assets needed to rebuild its arms industry after World War I. The state engaged in risk-sharing, helped overcome market uncertainty, provided incentives to cooperate as well as incentives to discourage nonperformance (no contract renewal, for example). Eventually, the German state ever more closely tied the arms industry into the state apparatus itself; the industry effectively became nationalized, in deed if not always in name and legal terms.

Planning

Regarding war planning, the P-51 aircraft did not, of course, simply materialize in large numbers over German skies, but neither was the introduction of such a plane utterly unexpected. In anticipation, German officials strenuously argued for spending the necessary resources to further develop its air defense capabilities, but Hitler insisted on expending resources to develop bombers to push the offense. The opportunity cost of devoting resources to the production of bombers is to give up the opportunity to develop and produce fighter aircraft (and pilots) to accompany the bombers or to defend air space from Allied forces. Hitler's proved a fatal strategic mistake, with cascading consequences, and it was, in hindsight, one of the few clearly visible turning points in the war. Just as earlier in the war Allied failure to penetrate Germany's air space revealed information, it was now the other way around. The German Air Force revealed a crucial, if obvious, bit of information: its increasing inability to defend its aerial borders. This induced substitution by the Allies, who started to pour more resources into ever less-costly deeper bombing runs into Germany.

How different things were before the air war was won. The British Bombing Survey Unit illustrates particularly well how war planners labored over picking targets for the strategic air campaign and how various bombing phases developed in light of the available information and the anticipated likelihood of successful runs. Under conditions of uncertainty and setbacks, expected costs and benefits were debated back and forth until this or that commander spoke the final word and set the force on a new course, only to be corrected when the costs proved high and the benefits slim. The returns diminished to such an extent that Arthur Harris abandoned strategic bombing altogether and for the remainder of his career took to obsessively bombing German cities and towns. In return, the Americans gave up on him. There was no way, no tool, no incentive, by which to convince him to change his behavior and stop splitting the limited resources of the air force. The situation would not change until the creation of a combined RAF/USAAF force under American command. This helped to mitigate an incentive alignment problem between British and American forces.

Operations

Finally, we take a look at the operations side of the strategic bombing of Germany. The principle of opportunity cost has already been illustrated with the transfer of command over the Allied air forces to Eisenhower to prepare for the invasion of Normandy.[69] To forgo the use of strategic forces merely because they were so designated would have been an unforgivable misstep. The cost would have been great, quite possibly the failure of the invasion.

The incremental cost/benefit principle has also already been mentioned in regard to the operations phase of the war. The disastrous bombing run on Schweinfurt proved so enormous a miscalculation that it forced the reevaluation of the expected cost of bombing incursions into German territory: for the next several months almost no bombing runs took place at all. Some information can only be obtained in "real time" by the winning and losing of battles. But moral hazard exists in that the men ordering battle are not the men to die. Those who give orders must be subject to a set of incentives (the possibility of being relieved from duty, reassigned, court-martialed, etc.) that induces them to deploy resources under their command to best effect. The fighting men depend on it with their lives. Moral hazard is an aspect of information asymmetry: only the officer knows whether his men really need to be sent into this or that particular battle. As with King David, who covets Bathsheba and sends her husband Uriah, a general, to die in battle, what are a commander's real intentions when he gives orders? What benevolent or malevolent purposes

are hidden beneath the veneer of his uniform, the impressive status his rank conveys to the underlings? To overcome this incentive alignment problem, hierarchies must provide for oversight and recourse. These may include appeal to higher authorities up the rank, but more effective is the simple requirement that commanding officers fight with their men. If the officer is to face death, he will think twice about being heedless; if he is truly mad, a mutiny may well be sanctioned upon inquiry. In World War II, rear-area officers were prone to go along on bombing missions. In addition, ineffective commanders were often fired, showing how the moral hazard problem can and has been addressed.

An example of substitution in the operations phase of strategic bombing was the switch of nighttime for daytime bombing of Germany and of area bombing for precision bombing. An important premise of strategic bombing had been that economic assets of importance to Germany's war effort could be snuffed out by precisely targeting and eliminating them with "surgical" strikes. But in the early 1940s, the scalpel failed for the many reasons previously mentioned: cloudy weather frequently obscured targets resulting in a high percentage of flights returning with bomb-loads intact (as in the Kosovo war of 1999), target acquisition was done by eye until the later development of technically assisted target-sighting, the nimble German Air Force shot down many a slow bomber unescorted by fighter aircraft, and often the bomber crews did not even make it to their assigned targets, losing their way over German territory on account of primitive navigational aids. In frustration, "Bomber" Harris switched from precision bombing to area bombing, from the scalpel to the sledgehammer, which made a bloody mess but without affecting the substance of the war. And for the same set of reasons, that is, the vulnerability of the bomber fleet during daytime runs, Allied commanders switched to nighttime bombing. Of course, this did nothing to facilitate target acquisition, nor the effectiveness of the bombing, and was reflected in the diminishing marginal returns to the morale of the affected bombed population and the relative lack of destruction of industrial assets.

An example of overcoming hidden actions is an early story in the history of electronic warfare. The British, in the spring of 1940, had picked up clues about a system called Knickebein (the Brits called it Headache, not inappropriate in light of the problems Knickebein was to cause). The system actually was used in commercial and military aviation as a blind-landing device. A transmitter would send out parallel "dash" and "dot" pulses. If an airplane was on target, an on-board receiver would merge the two pulses into a steady tone. Deviation to the right or left of target would result in dash-tones or dot-tones predominating and allow the pilot to correct course. A young British physicist

realized that the Germans used the system in reverse—not to guide planes home but to guide them away, to preset targets. Thus, a plane flying into the beam might first fly into a dash-pulse (prepare to drop bombs) and shortly thereafter cross the dot-pulse (drop bombs). Once the Brits discovered how the Germans guided their bombers, the RAF overcame the previously hidden action, Headache, by developing a countermeasure suitably called Aspirins: develop transmitters that fake the Knickebein beam and confuse the German pilots.[70]

As with the other chapters in this book, the main idea in this section is not to fully develop the story of how one can see the operation of economic principles in the strategic air war on Germany in World War II. Rather, it is to provide enough background and flavor to provoke the hypothesis that a fuller account for each one of the items in this section would be worth an article or chapter or book in its own right, that infusing the telling of history with economics may be a productive endeavor.

CONCLUSION

Reconsider an early quote in this chapter: "Strategic bombing bears the same relationship to tactical bombing as does the cow to the pail of milk. To deny immediate aid and comfort to the enemy, tactical considerations dictate upsetting the bucket. To ensure eventual starvation, the strategic move is to kill the cow."[71]

The strategic bombing of Germany in World War II did not "kill the cow." But shooting at the bucket did upset the cow just often enough to stop giving milk or, if it did give milk, to stop it from filling the bucket. The bombing did so, however, with diminishing returns, and the resources expended might well have been used to help prosecute the war in other areas. If the first bullet emptied half the bucket, the second emptied only half of the remaining half, and the third half of the half of the half. While resource application triples from one to three bullets, the amount of additional milk spilled diminishes from one-half to one-quarter to one-eighth. Just how empty does the bucket need to be before the exercise becomes pointless? If the victory threshold lies at reducing the milk in the bucket to one-sixteenth of its full contents, then a fourth bullet becomes necessary despite the diminishing returns. Thus we have not argued that bombing was useless, only that diminishing returns can be seen to have occurred.

If the simile may be taken further, much of the practical difficulty with strategic bombing lies in issues such as figuring where the cow is, if the cow

is a cow or a decoy, or breaking through the barn to get at the cow. Thus we have argued that the Allied effort was not strategic but tactical bombing. It was in fact not to kill the cow, as the strategic bombing theorists imagined, but to make a commotion and to shoot at the bucket, as the field commanders in practice attempted. Of course, even tactical bombing is subject to diminishing returns (shown with examples from German arms, aircraft, fuel, and chemical production, as well as railroad loadings), and the practical difficulties here lie with issues such as finding the right buckets to shoot at, taking square aim, being close enough to take square aim, doing so in daylight or appropriately illuminating the bucket for nighttime, overcoming countermeasures that shield the bucket, and so on. A final point, not much considered in the chapter but very important to the actual conduct of the war, is that Nazi Germany's expansionist drive asked perhaps too much of the cow and its bucket: they could not give and hold all the milk required.

APPENDIX A

A Matrix for the Strategic Bombing Case

Principle	Manpower	Logistics	Technology	Planning	Operations
Opportunity cost	Albert Speer takes over war planning and production	D-Day: use of strategic air force for tactical purposes	dispersion of German production facilities	Hitler's personal insistence on building bombers, not fighters	using strategic forces for tactical purposes (push to Berlin)
Expected marginal costs/benefits	U.S. strategic forces transferred to North Africa in 1942/43	target selection: bomb German rail, water, or fuel supplies?	Use of add-on/drop-off fuel tanks to extend escort fighter range	BBSU: switching phases of the strategic bombing plans	Schweinfurt did not work: marginal benefit overestimated; marginal cost underestimated
Substitution	use of foreign/slave workers to free up Germans for front-line duty	German railroad system had many redundancies	synthetic fuel plants built in Germany	defeat of Luftwaffe finally lowered cost of deep penetration bombing runs	Allies substitute night for day bombing; area for "precision" bombing
Diminishing marginal returns	the 8th running operations in SE Europe while being based in North Africa	Allied bombers had insufficient number of escort bombers	German air plane production: plenty of aircraft but not pilots	"Bomber" Harris gives up on precision bombing, starts area bombing	morale bombing
Asymmetric information (overcoming) hidden characteristics	massive but ineffective bomber fleets correctly signal Allied weakness, 1940–1943	in lieu of reliable info, Allies speculate about German supply chain strength	Hitler fails to perceive signals regarding the P-51 and similar new Allied technologies	failure of Luftwaffe in air war reveals hidden characteristic; changes air war planning	moral hazard for commanding officers to send men to battle
Asymmetric information (overcoming) hidden actions	Nazi "culture" to police manpower mobilization and effort	desertion of transport convoys in final war stage; enforcement of "contracts" impossible	German state engages in risk-sharing by financing the construction of German industrial assets	creation of combined strategic air command mitigates incentive alignment problem	Knickebein, Headache, and Aspirins

APPENDIX B

Percentage of Allied Bombing Tonnage by Target Class by Month

Period	Aircraft factories	Airfields, aerodromes	Oil, rubber, chemicals, explosives	Land transportation	V-weapons launching sites
Dec. 1939	0.00	100.00	0.00	0.00	0.00
Jan.–Dec. 1940	0.00	50.00	50.00	0.00	0.00
	0.00	50.00	0.00	0.00	0.00
	0.00	88.46	0.00	0.00	0.00
	0.00	93.14	0.98	5.88	0.00
	0.00	10.00	19.22	41.25	0.00
	2.67	13.53	23.66	22.89	0.00
	4.95	22.33	17.44	15.03	0.00
	12.45	14.73	22.79	6.67	0.00
	1.30	4.79	4.36	12.63	0.00
	0.92	11.52	15.09	8.87	0.00
	2.82	11.38	13.35	12.23	0.00
	1.25	4.07	5.79	7.72	0.00
Jan.–Dec. 1941	0.06	1.48	7.96	5.05	0.00
	1.91	2.65	6.73	6.78	0.00
	2.56	2.90	7.44	4.16	0.00
	1.14	2.53	3.15	4.58	0.00
	0.00	1.91	6.44	22.32	0.00
	0.07	2.22	0.18	36.99	0.00
	0.41	3.07	1.44	15.82	0.00
	0.03	2.90	0.14	30.88	0.00
	0.38	1.75	2.33	19.40	0.00
	0.00	2.70	0.00	19.10	0.00
	0.00	0.99	0.08	0.74	0.00
	0.00	0.45	2.21	0.00	0.00
Jan.–Dec. 1942	1.30	2.21	0.00	0.00	0.00
	0.53	1.86	0.00	0.20	0.00
	0.00	0.50	0.00	0.27	0.00
	3.73	0.64	0.00	2.08	0.00
	6.14	0.96	0.14	0.14	0.00
	2.67	1.03	0.10	0.09	0.00

Naval and water transportation	Miscellaneous manufacturing	Industrial areas	Military targets	All other targets	RAF not classified
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	50.00	0.00	0.00	0.00
11.54	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	24.53	5.00	0.00	0.00
2.06	6.64	15.33	2.88	1.18	9.16
12.61	7.60	5.49	3.14	0.24	11.16
3.72	8.37	8.89	3.93	6.61	11.83
56.28	2.23	3.66	2.23	3.66	8.88
30.19	5.10	7.83	2.21	5.02	13.25
21.91	6.06	8.19	6.54	4.26	13.24
19.52	3.55	18.74	3.71	1.93	33.72
16.27	0.65	25.18	1.54	0.59	41.21
24.63	0.26	33.45	0.74	1.87	20.98
32.27	4.71	25.84	0.80	0.38	18.95
34.93	6.99	32.23	1.17	0.49	12.80
26.19	1.47	26.39	0.70	1.47	13.12
16.93	1.23	32.05	1.89	0.96	7.46
19.39	3.24	44.50	0.35	2.37	9.40
10.36	5.00	34.86	0.98	1.10	13.75
23.10	8.16	23.21	1.59	0.40	19.67
20.44	0.90	31.41	6.54	0.14	18.78
14.54	0.18	37.37	0.05	0.05	46.02
32.07	0.00	21.07	0.00	0.03	44.17
44.55	0.00	32.84	0.10	0.00	19.01
27.83	0.00	32.21	0.00	0.00	37.38
7.04	12.97	68.00	0.00	0.71	10.50
17.63	7.33	58.45	0.26	0.56	9.31
7.47	4.77	60.68	0.09	0.53	19.09
1.95	0.01	72.97	0.03	0.34	20.81

(*continued*)

APPENDIX B

Continued

Period	Aircraft factories	Airfields, aerodromes	Oil, rubber, chemicals, explosives	Land transportation	V-weapons launching sites
	0.00	1.13	0.00	0.27	0.00
	0.22	1.19	0.01	0.51	0.00
	1.91	0.25	0.04	0.53	0.00
	3.37	1.28	4.18	3.86	0.00
	5.22	0.96	0.00	1.24	0.00
	2.80	1.21	0.00	5.12	0.00
Jan.–Dec. 1943	0.00	3.61	0.25	6.43	0.15
	0.03	0.81	0.19	1.63	0.00
	0.00	1.81	0.22	7.30	0.00
	3.05	5.02	0.00	3.26	0.00
	0.85	6.07	0.29	2.17	0.00
	2.28	5.39	1.60	4.18	0.00
	3.39	13.83	2.20	7.28	0.00
	1.47	8.64	6.13	15.11	0.00
	1.42	13.37	0.05	0.05	0.00
	2.73	7.43	0.94	14.57	0.00
	1.05	5.59	2.23	13.25	0.92
	2.18	7.93	3.31	13.53	3.37
Jan.–Dec. 1944	4.35	8.65	1.89	1.89	6.51
	9.59	9.66	0.25	8.88	2.95
	5.08	9.75	0.13	23.45	2.78
	9.02	10.07	1.44	39.57	4.28
	3.50	11.14	4.03	40.08	2.10
	1.28	10.26	9.52	28.02	7.16
	3.10	4.50	13.38	20.75	3.74
	3.94	11.66	14.86	17.45	1.17
	0.95	5.43	9.56	23.67	0.00
	0.91	2.42	9.89	22.95	0.00
	0.38	1.64	25.83	24.71	0.00
	0.14	3.07	11.04	51.28	0.01

Naval and water transportation	Miscellaneous manufacturing	Industrial areas	Military targets	All other targets	RAF not classified
10.34	0.02	49.79	0.07	0.13	38.25
1.62	0.09	61.78	0.59	0.07	33.91
1.48	0.07	68.42	0.03	0.13	27.14
1.93	0.08	50.47	0.00	0.07	34.76
11.05	0.09	28.74	0.00	0.00	52.71
5.42	2.06	55.73	0.26	1.41	25.99
24.24	1.45	42.40	1.56	3.30	16.61
39.04	0.47	49.65	0.35	1.24	6.60
15.80	15.36	39.92	0.54	2.44	16.62
10.60	3.75	52.73	1.91	2.88	16.81
15.88	2.68	55.14	2.34	6.38	8.21
6.53	0.24	55.35	10.43	4.33	9.67
3.41	1.29	48.18	1.21	6.84	12.38
2.46	6.82	38.62	1.92	5.05	13.76
3.32	3.46	35.83	3.79	5.51	12.93
5.50	1.88	49.73	1.51	5.54	10.17
6.22	2.86	49.76	2.86	4.94	10.33
5.95	3.51	47.10	3.57	4.32	5.23
4.30	1.75	40.71	2.61	6.73	7.11
3.43	2.83	32.18	7.34	11.12	11.77
2.44	2.63	37.50	2.89	6.43	6.93
1.97	2.02	17.98	4.07	3.59	6.00
2.79	1.11	9.69	15.30	3.91	6.35
2.16	0.49	11.26	13.20	10.11	6.53
1.33	2.36	28.68	7.07	7.94	7.15
2.95	1.17	21.51	12.01	5.09	8.20
1.32	4.90	12.22	28.55	3.15	10.25
0.93	7.68	33.93	11.97	2.97	6.35
0.22	0.47	27.89	8.45	4.25	6.16
1.47	2.31	15.44	4.37	5.90	4.96

(*continued*)

APPENDIX B

Continued

Period	Aircraft factories	Airfields, aerodromes	Oil, rubber, chemicals, explosives	Land transportation	V-weapons launching sites
Jan.–May 1945	0.00	3.61	0.25	6.43	0.15
	0.03	0.81	0.19	1.63	0.00
	0.00	1.81	0.22	7.30	0.00
	3.05	5.02	0.00	3.26	0.00
	0.41	6.18	6.14	35.53	0.16
Overall percentage for Jan. 1939 to May 1945	2.06	6.10	9.54	27.20	1.43

Source: Computed from USSBS, February 1947, chart 6.
Note: The last line in the table is the overall percentage per target class. For example, of the 2,770,237 tons of bombs dropped by USAAF and RAF, 2.06 percent were intended for aircraft factories.

Naval and water transportation	Miscellaneous manufacturing	Industrial areas	Military targets	All other targets	RAF not classified
1.61	1.39	16.89	2.82	5.19	5.90
1.56	1.19	21.33	3.59	5.54	7.66
5.10	4.23	19.94	3.89	4.68	7.18
7.63	0.90	11.20	15.43	5.44	10.97
1.31	0.00	18.78	10.05	0.08	43.66
3.90	2.53	24.95	8.36	5.24	8.70