Chapter Title: Industrial Policy and International Competition in Wide-Bodied Jet Aircraft

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3 Industrial Policy and International Competition in Wide-Bodied Jet Aircraft

Richard Baldwin and Paul Krugman

The international market for large commercial jet aircraft is about as far as one can get from the standard trade theory paradigm of static constant returns and price-taking competition. It is an industry in which the survival of firms depends on periodic introduction of new families of aircraft, and the introduction of a new family is marked by massive dynamic scale economies. A huge initial expenditure on development is followed by a steep learning curve at the level of the firm, a curve that industry experts believe lasts throughout the product cycle. The fixed cost and the dynamic increasing returns introduced by learning ensures that this is an industry in which only a few firms can profitably exist. In the world market there are only three significant manufacturers of airframes for jets that seat more than one hundred passengers. It is arguable that in the absence of government support there would be only one.

For those who work on the "new" trade theory that emphasizes increasing returns, dynamics, and imperfect competition, these economic characteristics would in and of themselves make aircraft a natural target for study. An additional reason for interest in the aircraft industry, however, is that the industry is the center of a policy conflict between the United States and Europe. Aircraft production is widely

regarded as a "strategic" industry and has long been a target of industrial policy in Europe. In the late 1970s this policy for the first time achieved some commercial success, when Airbus Industrie, a four-nation European consortium, began to achieve a significant market share with its A300 family of large, medium-range jets. Since then, accusations have flown and tension has risen.

The U.S. dominance of the world aircraft industry is one of the few remnants of the United States' vanishing technological superiority, so a challenge in this area is particularly irksome. Both U.S. manufacturers and U.S. government officials have charged that Airbus has bought market share only with the help of government subsidy. On the other side, the Europeans deny that the government loans supporting Airbus represent a subsidy; they argue that the governments expect to be repaid in full, and they charge in return that U.S. manufacturers receive de facto support from military procurement.

This chapter takes a preliminary look at international competition in the market for large commercial jet aircraft, viewing the competition in terms of the recent style of trade modeling that emphasizes imperfect competition and increasing returns. We develop a simulation model that roughly reproduces the conflict between the United States and Europe in medium-range, wide-bodied transports. The focus is on two questions: How large is the effective European subsidy, and what have been the welfare effects of this subsidy on the United States, Europe, and the rest of the world?

The chapter is in six sections. Section 3.1 presents some background on the industry. Section 3.2 presents a preliminary analytic overview of the welfare issues raised by European targeting. Section 3.3 lays out the analytics of the simulation model; section 3.4 then describes the calibration of the model to data and its solution. Finally, section 3.5 discusses the conclusions and possible future work.

3.1 Technology, Competition, and Cost

The production of aircraft is a technology-intensive industry. That is, relative to other products, a large part of the cost of producing an airplane is the cost of creating the technology embodied in its design and manufacturing. This cost is incurred both directly, in the form of research and development (R&D) expenses, and indirectly, by the acceptance of losses during the initial phase of the learning curve in the expectation that costs will fall with experience.

Like other technology-intensive industries, aircraft is characterized by a distinct product cycle. At intervals, fundamental breakthroughs in design are made, and manufacturers introduce new families of air-

craft to take advantage of these breakthroughs. In between, production costs are reduced through experience, and relatively minor modifications of existing aircraft are undertaken to suit them more precisely to market demand.

Table 3.1 shows the deliveries of large passenger aircraft by manufacturers since the introduction of the first commercially viable jets in the late 1950s. The product cycle is clear-cut. In the late 1950s, turbofan jets, the Boeing 707, and the McDonnell-Douglas DC-8 were introduced and remained strong sellers until the early 1970s. In the mid-1960s, somewhat larger aircraft, the roughly 150-seat 727 and DC-9, were introduced. At the end of the 1960s came the "jumbo jets," wide-bodied aircraft (two aisles)—the Boeing 747 and the McDonnell-Douglas DC-10. Finally, at the end of the 1970s came wide-bodied medium-range jets, the Airbus A300 and the Boeing 767.

The important point is that in contrast to other technology-intensive industries, such as semiconductors, the product cycles in aircraft are quite long. A few 707s are still being produced for military use. While such a long product life is exceptional, the life of a successful airframe is something like twenty years. The counterpart is that each time a new generation is being developed, companies must essentially stake their survival on a successful design.

Once an aircraft has been developed, average cost falls steeply as cumulative production mounts, both because the R&D can be spread over a larger base and because production costs fall with the learning curve. Figure 3.1 presents estimates of costs for the hypothetical new aircraft, as calculated by the U.S. Commerce Department in cooperation with McDonnell-Douglas.

3.1.1 Demand and Competition

Aircraft are capital goods that are one of several inputs into the production of passenger service. The existence of different air routes creates a demand for aircraft with different characteristics and thereby supports a limited Lancasterian differentiation among aircraft. To minimize costs, airlines typically own a mixture of airplanes. Currently there are fourteen types of large turbojets operating in the world air carrier fleet.

The composition of the mix depends primarily on the types of air routes the airline flies. Due to both physical and organizational considerations, a plane will have lower operating costs per passenger the larger it is (because large planes are more fuel-efficient per seat but still need only the same size cockpit crew) and the shorter the planned range (because less space and weight are allocated to fuel storage). Nonetheless, certain routes require long-range planes and some routes

Table 3.1   Deliveries of Large Passenger Aircraft

	1958	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70
707	8	77	91	80	68	34	38	61	83	118	111	59	19
727						6	95	111	135	155	160	115	54
737										4	105	114	37
747												4	92
DC-8		21	91	42	22	19	20	31	32	41	102	85	33
DC-9/MD-80								5	69	152	203	121	54
DC-10													
L-1011													
880/990			14	33	33	16	4	2					
757													
767													
U.S. Manufacturers Subtotal	8	98	196	156	122	75	157	210	319	470	681	498	289
Comet	7	19	20	14	13	2	2	1		1			
Caravelle		18	39	39	35	23	22	18	18	21	14	11	9
Trident							12	18	11	1	11	9	2
VC-10							14	11	7	10	9	2	1
BAC-111								34	46	20	26	40	22
F-28												9	11
Mercure													
A300													
A310													
BAe 146													
VFW-614													
Concorde													
Non-U.S. Manufacturers Subtotal	7	37	59	53	48	25	50	74	82	53	60	71	45
Total	15	135	255	209	170	100	207	284	401	523	741	569	334

are more cheaply serviced by small planes that fly full than by large, half-empty planes. Thus roughly speaking, aircraft are differentiated in a two-dimensional space of range versus number of passengers.

Table 3.2 presents some characteristics of wide-body aircraft now in production. The main point to notice in the table is that not all wide-bodied aircraft are close substitutes. The four-engine Boeing 747 is a monster compared with the other aircraft, both in terms of size and range; essentially there is nothing else like it. The three-engine DC-10 is considerably smaller and shorter-range; it is also at this point almost out of production (see below). Still smaller and shorter-range are the

Table 3.1 (continued)

'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	Total
10	4	11	21	7	9	8	13	6	3	6	8	8	8	969
33	41	92	91	91	61	67	118	136	131	97	26	11	8	1834
29	22	23	55	51	41	25	40	77	92	111	95	82	67	1070
69	30	30	22	21	27	20	32	67	73	58	25	23	16	609
13	4													556
44	32	29	48	42	50	22	22	39	23	73	44	50	44	1166
13	52	57	47	43	19	14	18	36	40	23	11	4	2	379
	17	39	41	25	16	11	8	14	24	29	14	6	4	248
														102
											2	25	18	45
											20	55	29	104
211	202	281	325	280	223	167	251	369	386	397	243	264	196	7082
														112
4	5	3												279
13	11	7	4	6	9	7	4							117
														54
12	7	2	4	2		6	3		3	2	2			231
10	13	19	9	20	17	13	11	13	13	13	11	19	17	218
			6	4										10
			4	9	13	16	15	24	40	45	46	21	19	252
												17	29	46
												7	11	18
				1	4	5								10
				1	6	2			3	2				14
39	36	31	27	43	49	49	33	38	59	62	59	64	76	1361
250	238	312	352	323	272	216	284	412	445	450	302	328	272	8443

A300 and the Boeing 767. It is between these two planes that the effective U.S.-European competition has taken place. Thus we do not look at aircraft as an aggregate and count 747s as part of the U.S. market share. On the demand side, the close substitution is between the 767 and the A300.

3.1.2   Government Policy and the State of Competition

At the beginning of the 1970s there were three major U.S. civilian aircraft manufacturers: Boeing, McDonnell-Douglas, and Lockheed. Competitive pressure, however, narrowed the field. McDonnell-Douglas
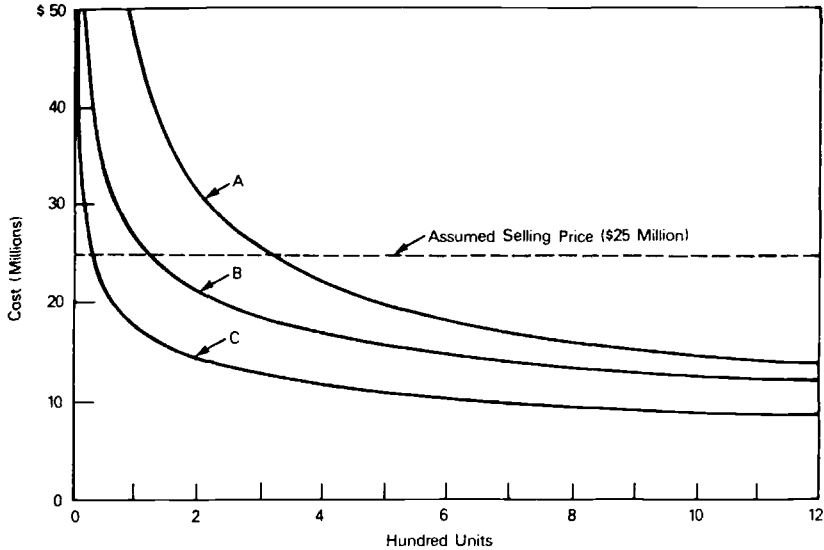
Fig. 3.1   Development and production costs, hypothetical 150-seat
                    transport. *Notes:* A is Total Average Cost = ([Cumulative
                    Production Cost] + [Development Cost])/Number of Units;
                    B is Cumulative Average Production Cost = Cumulative
                    Production Cost/Number of Units; C is Individual Unit Pro-
                    duction Cost, calculated using the following learning curves
                    developed in cooperation with Douglas Aircraft company:
                    units 1–10, 71.4 percent; units 11–20, 76.3 percent; units
                    21–50, 78.2 percent; and units 51 or greater, 81.1 percent.
                    Source: Office of Competitive Assessment.

and Lockheed both introduced three-engine wide-bodied jets (the DC-
10 and the L-1011) that were close substitutes in a market that appar-
ently was not large enough to support two firms. The result was that
both suffered serious losses. Lockheed withdrew from civilian manu-
facturing altogether. McDonnell-Douglas basically exited the market
for wide-bodied aircraft, although it continues to sell substantial num-
bers of narrow-bodied MD-80s. The production of the DC-10 was ac-
tually stopped in 1984; then the company restarted the production line
on a limited basis because it can also sell a military version of the same
aircraft. If it were not for the presence of Airbus, the manufacture of
wide-bodied aircraft would be essentially a Boeing monopoly.

   Airbus was founded in 1970. After some reshuffling, it has ended as
a consortium jointly owned by the governments of France, Germany,
the United Kingdom, and Spain. The mechanics of government support
are complex, but in essence Airbus is able to borrow money that it
will repay only to the extent that the consortium is profitable. In other

Table 3.2   **Characteristics of Wide-Bodied Aircraft**

Maker/Model	No. of Engines	First Delivered	No. of Seats	Range (No. Miles)
Airbus				
A310	2	1985	212	3100
A300 B2	2	1974	251	1550–1910
A300 B4-100	2	1974	251	3050
A300 B4-200	2	1974	251	3300
A300-600	2	1974	267	3550–3750
Boeing				
767-200	2	1982	216	3300–4000
767-200ER	2	1982	216	5300
767-300	2	1986	261	4000
747	4	1969	330–496	5600–6000
McDonnell-Douglas				
DC-10-10	3	1971	250–380	3300
DC-10-15	3	1971	250–380	3780
DC-10-30	3	1971	250–380	5090
DC-10-40	3	1971	250–380	4995

Source: Economist, June 1, 1985.

words, it is able to finance its investment through what is nominally debt, but what closely resembles equity.

The size of the subsidy provided to the A300 is a matter of dispute for the simple reason that it is not a directly measurable quantity. Airbus is currently producing the A300 and the A310. It has also begun to invest in research and development on the A320. It has lost money consistently since its founding. However, all new aircraft lose money at first—that is the nature of a technology-intensive product, in which investment in knowledge is expensed and therefore appears as an accounting loss. The true test is one of future prospects: can Airbus reasonably be expected to yield a competitive market rate of return? Boeing, not surprisingly, claims that it will not, that the development of the A300 would not have been undertaken under normal commercial evaluation of its prospects. European governments deny this and say that they expect to be fully repaid. Most observers agree with Boeing's assessment, but not necessarily with the large estimates of the size of the implicit subsidy that Boeing has circulated.

One important reason Airbus probably would not have succeeded as a private project is that it has taken a long time to achieve significant commercial sales. As table 3.3 shows, the first deliveries of the A300 took place in 1974, but it was not until 1979 that large sales were made. There followed several years of large sales, which then fell off substantially after Boeing introduced the 767.

Table 3.3   Deliveries of Commercial Aircraft

	1969	'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85
A300						4	9	13	16	15	24	40	45	46	21	19	17
767														20	55	29	25
DC10			13	52	57	47	43	19	14	18	36	40	23	11	4	2	n.a.
747	4	92	69	30	30	22	21	27	20	32	67	73	58	25	23	16	24

Source: Economist, June 1, 1985.

3.2   Analytical Welfare Issues

Although competition in the aircraft industry is dynamic in nature, some of the policy aspects can be illustrated with static models. Two models in particular are useful in thinking about the results we derive: a simple model of subsidized entry of a monopolist, and a similarly simple model of subsidized entry of a duopolist.

As a first model for thinking about the effect of the Airbus program, let us disregard the competitive aspect. What would have happened if Airbus's entry had simply been a subsidized entry of a monopolist into a market where no other firms would have produced? This is not entirely irrelevant as a description of the situation. When the A300 was first introduced, it did not face any closely competitive aircraft: it was smaller and shorter-range than the U.S. wide-bodies, larger and cheaper to operate than U.S. narrow-bodies. From 1979 to 1982, in particular, Airbus was clearly filling a market niche that made it in a sense a monopolist.

Figure 3.2 illustrates the position of a monopolist subject to decreasing cost. D is the market demand curve, MR the associated marginal revenue curve, MC the marginal cost curve, and AC the average cost curve. P_m and Q_m are the profit-maximizing price and quantity. As drawn, the monopolist cannot enter profitably. If it were to enter, it would suffer losses equal to the shaded area.

Suppose, now, that a government provides the monopolist with a subsidy sufficiently large to induce entry. Then the shaded area still represents a social loss. Against this, however, must be set the gain in consumer surplus. It is certainly possible that the gain might exceed the loss, so that privately unprofitable entry is socially beneficial.

Where does international trade enter into this story? If there is an integrated world market, all that happens is that the gain in consumer surplus is divided among several countries. Thus if one country subsidizes the entry of a monopolist into an otherwise unprofitable market, the effect will be a gain for all other countries, a possible gain for the world as a whole, and a possible gain for the subsidizing country. It is of course possible that the policy will be beneficial for the world as a whole but not for the subsidizing nation.

Matters become more complex if there is already an incumbent firm. In that case, subsidizing entry will reduce the incumbent firm's profits. If the existing firm is located in a different country from the new firm, the profit shifting can make subsidizing the entry a beggar-thy-neighbor policy.

Much of the strategic trade policy literature has focused on the possibility that a credible commitment by a government to subsidize entry will deter entry by foreign rivals. In this case entry may turn out to be
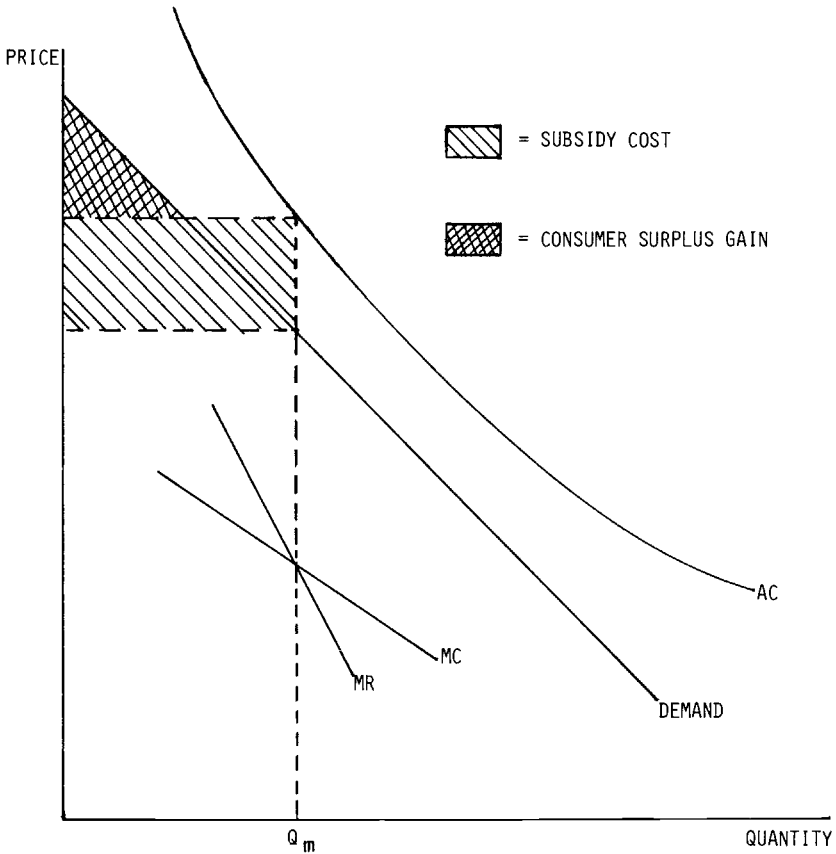
Fig. 3.2   Impact of the subsidized entry of a monopolist

profitable ex post, even though a firm operating without subsidy would not have found it profitable. In the case of the A300, however, it is clear that the Airbus subsidy did not succeed in keeping Boeing out of the market. (The Airbus entry into the 150-seat narrow-bodied market, the A320, may be a different story.) Thus the right model must be one in which entry leads to the formation of a duopoly, in which the subsidized firm has negative profits.

In assessing the effects of this entry, we need to consider first the effect on output and prices. Suppose that after entry, competition takes the form of Cournot quantity-setting. Then we can represent the competition by two firms' reaction functions, as in figure 3.3. In the absence of a government subsidy, output will lie at point A. With a government subsidy, the equilibrium will shift to B, with Airbus's entry causing both a fall in the price and a fall in Boeing's output.
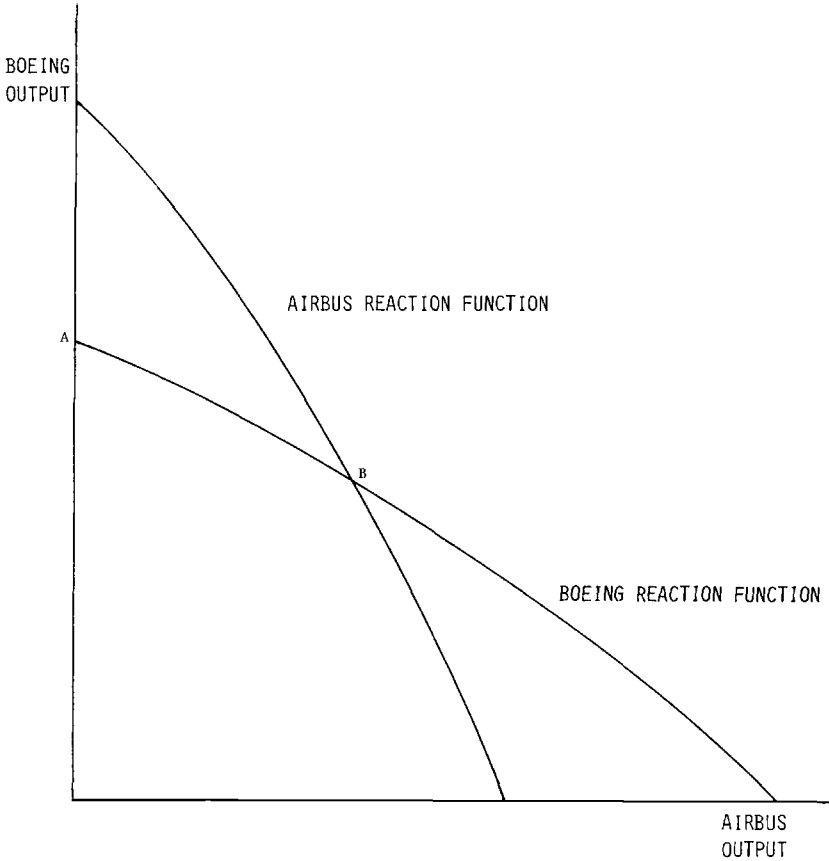
Fig. 3.3 Two possible equilibriums in a Cournot game

To assess the welfare effects in this case, we need to consider three regions: Europe, the United States, and the rest of the world. The effects of the subsidized entry on Europe and the United States are illustrated in figures 3.4 and 3.5.

In figure 3.4 we see the effect of subsidized entry in Europe. The world price is driven down from P_1, the monopoly price, to P_2, the duopoly price. This produces a gain in consumer surplus, illustrated by the shaded area. On the other hand, by assumption, European production, at Q_2, takes place at an average cost that exceeds P_2. This leads to a loss that offsets the consumer gain. As in the case of monopolistic entry, Europe may either gain or lose.

In figure 3.5 we see the effect of Europe's subsidy on the United States. The fall in the price from P_1 to P_2 produces a consumer gain.
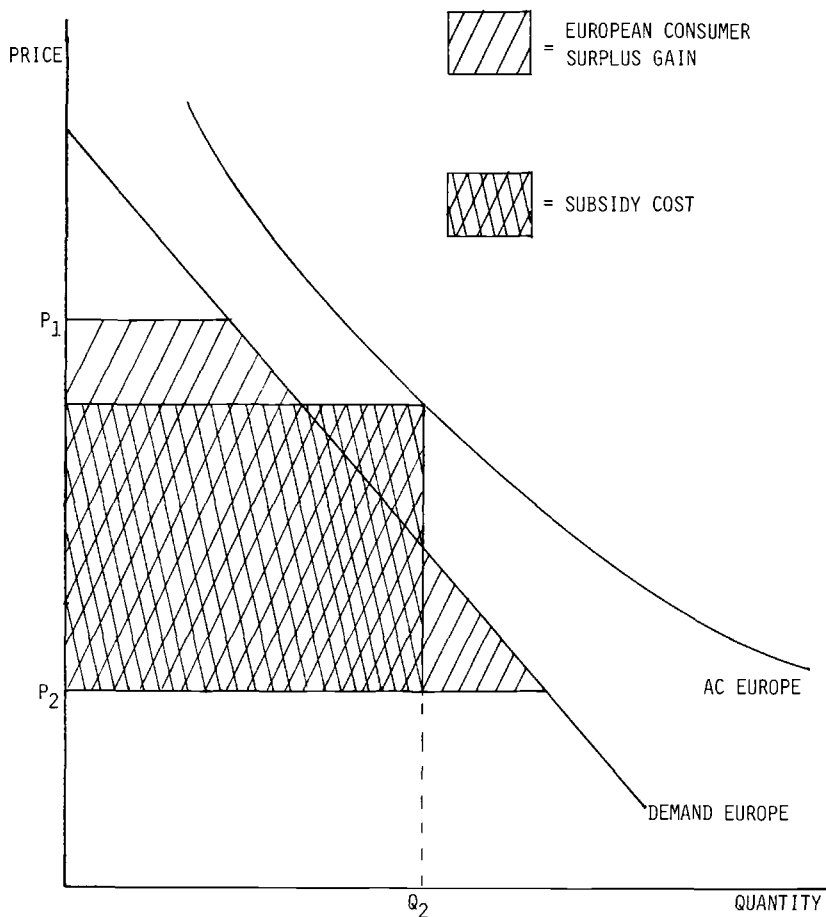
Fig. 3.4   Effect of Airbus entry on European welfare

But there is also a producer loss. This loss consists of two parts. First, at the initial output Q_1, the fall in the price produces a loss. Second, the domestic firm is induced to reduce its output from Q_1 to Q_2. Since even in the duopoly situation marginal cost is less than the price, this output reduction leads to a further loss in profits, also shown in the figure.

In general, the welfare effect on the United States is ambiguous. However, if (as is realistic) the United States remains a net exporter even with subsidized European entry, the net effect is unambiguously negative. The reason is that the conventional terms-of-trade effect— the consumer gain, less the profit loss that would be incurred if output
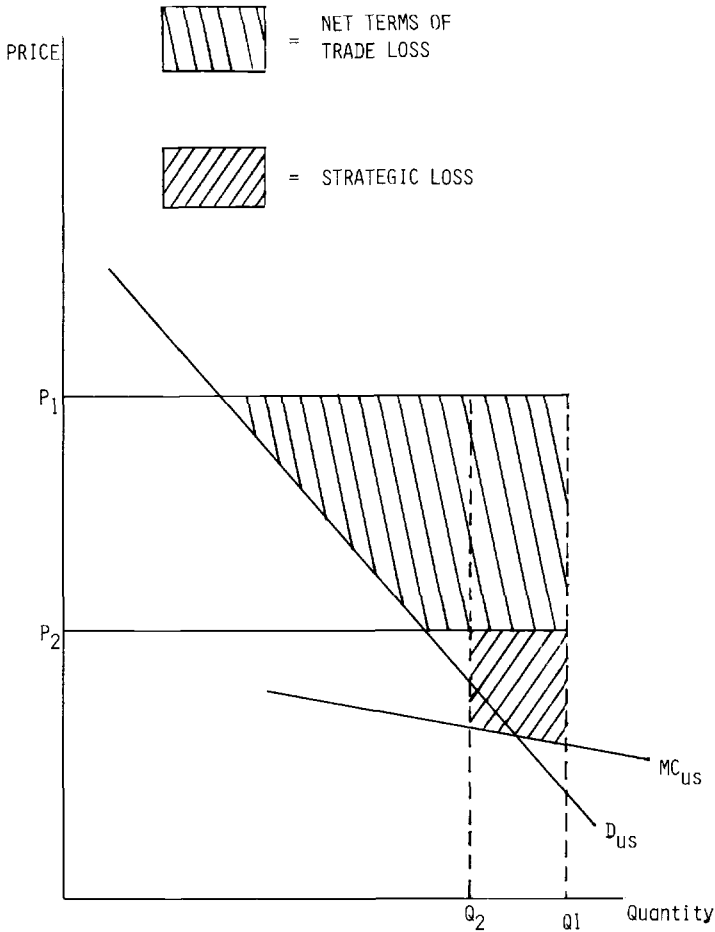
Fig. 3.5   Impact of Airbus entry on U.S. welfare

remained at Q_1—is clearly negative, and to this must be added any negative "strategic" effects, as captured by the decline in Q, even though price remains above marginal cost.

The rest of the world, of course, gains unambiguously from the decline in the price.

To sum up, we see that in a duopoly situation in which the United States remains a net exporter, the effects of subsidized European entry would be unambiguously negative. Europe could gain, but not because the strategic deterrent effect of its subsidy enables it to capture rents; instead, the gains would come on the consumer side.

3.2.1   Putting the Model Together

We have sketched out two models. In the first, Europe is seen as subsidizing the entry of a monopolist into a market where nobody would otherwise produce. This entry benefits everyone except possibly Europe. In the second model, Europe's entry changes a U.S. monopoly into a duopoly. Provided that it is a net exporter even after European entry, the United States must be a net loser. Again Europe can either gain or lose.

Now in actual fact the situation created by Airbus's entry can be viewed as having reproduced each of these situations in turn. When the A300 was first introduced, it did not face close substitutes; thus for several years it might make sense to view Airbus as a new product provided to the world. After 1982 the A300 shared the market with a fairly close substitute, the Boeing 767, of which the United States was a net exporter. Thus the United States was a net gainer during the early years of Airbus's presence, but was a net loser once its own entry into the market had taken place. The overall effect is ambiguous and depends on the relative weight given to the early period versus the later one.

3.3   A Model of Aircraft Competition

To produce a solvable model of competition in aircraft, we abstract from many real-world complications. We focus entirely on the competition between the A300 and the 767, ignoring both the residual presence of McDonnell-Douglas and the linkage between competition in this area and other families of aircraft. Equally important, our treatment of the intertemporal substitutability of aircraft is less than complete. The main focus is on the dynamics of competition that arise from learning by doing and the corresponding strategies of output over time.

3.3.1   Setup of the Model

Aircraft constitute large and lumpy purchases. Since airlines like to have compatible equipment, the usual aircraft sale involves dozens of planes. These planes will usually be built after the order, with the design modified somewhat to the buyer's specifications. Furthermore, aircraft are durable goods. The typical airliner has a service life of twenty years. For these reasons it is typical for each airline to negotiate only once for each model.

Aircraft are not consumed directly but rather constitute one of many inputs into the production of air carrier service. Airlines purchase a variety of planes in order to service their air routes. As discussed above, the composition of a carrier's fleet is chosen to minimize costs. Since

planes are durable goods, buying an additional A300 or 767 will affect an airline's profit via a cost-savings effect for the life of the aircraft. In general, the derived demand for A300s and 767s would depend on the price of all large jets as well as the price of jet fuel, staff wages, and so forth. Appealing to tractability, we shall ignore these cross-price effects.

This cost-saving effect of an additional A300 or 767 clearly depends only on the number of such jets in an air carrier's own fleet. However, in principle the A300s and 767s delivered to other carriers would affect profits by increasing the total supply of available passenger seats and therefore the equilibrium passenger fare. This effect, however, is diluted by several factors. The desired number of passenger seats is determined chiefly by the air routes chosen by airlines. This later choice is in turn determined by a host of demand and cost factors. Aircraft constitute between a third and a tenth of the variable costs (this figure is very sensitive to the price of fuel) of operating an air route. Moreover, the stock of planes chosen is affected by the retirement of old aircraft as well as the purchases of the dozen other types of commercial jets currently in production. To simplify the dynamics we shall ignore this revenue effect. We shall assume that an airline's evaluation of the marginal benefits of an A300 or 767 depends only on the number of them in its own fleet.

Formally, we assume that air carriers choose the number of jets to maximize the discounted sum of profits, taking as given the aircraft's price. If the service life of the aircraft is N years, the first-order condition of a typical airline (in the year it actually purchases planes) is

$$\sum_{i=0}^{N-1} [R^i \Pi'_{t+i}(q)] = p_t ,$$

where q is the number of A300s or 767s it buys, R is the discount factor, p_t is the price of the aircraft, and $\Pi'_{t+i}(q)$ is the derivative of the purchaser's profits in year $t+1$ with respect to q. The standard Kuhn-Tucker conditions hold for all other years (notice we have skirted the consideration that leads airlines to buy all at once rather than year by year). We ignore the integer constraint and assume that the two models are perfect substitutes. Assuming for simplicity's sake that "l" airlines purchase each year, the market demand for the planes is

$$(1) \qquad p_t = \sum_{l=0}^{N-1} R^i b(x_t + x_t^*)^{1/E} ,$$

where we have assumed a functional form for $\Pi'_t = \beta(x_t + x_t^*)^{1/E}$, and b equals $\beta l^{1/E}$. The deliveries of Boeing are denoted by x, the deliveries of Airbus by x^*, and the demand elasticity by E.

It is worthwhile to point out two features of this demand relation. First, it has the form of a standard, atemporal demand function with a constant elasticity equal to E. Second, the quantity sold today depends only on today's price, as long as the airlines find it optimal to buy this year rather than next. This last modification will play an important role below.

Turning now to the producers, we assume there are two firms capable of producing a single good (medium-range wide-bodies). To produce the good, each firm must incur a start-up cost F (paid in the first period). Thereafter, the firms' production costs decline with experience according to the standard learning curve specification. Specifically, the direct marginal production costs of Boeing, c, and Airbus, c^*, in period t are

$$(2) \qquad c_t = h(K_t)^{-g}, \text{ and } c_t^* = h^*(K_t^*)^{-g} ,$$

where K_t and K_t^* are cumulative production to date, and g is the elasticity of cost with respect to cumulative output. K_t and K_t^* are related to x and x^* by

$$(3) \qquad K_t = K_{t-1} + x_t , \text{ and } K_t^* = K_{t-1}^* + x_t^* .$$

To define the objective function of the aircraft manufacturers, we must address the choice of strategic variables. The standard choices are price and quantity. To some extent Boeing and Airbus are selling differentiated products. This would in principle allow them to compete in a Bertrand fashion, by setting a list price and selling to whoever wants to buy at those prices. But the circumstances of the market mitigate against this. Aircraft purchases are negotiated on an individual basis. These deals include financing, options for future orders, spare parts arrangements, and so forth. In the jargon of the industry, these "green stamps" alter the effective price in such a way that price-setting competition is not really feasible. More practically, to model Bertrand competition between two close, but not perfect, substitutes would require an aggregate cross-price elasticity. To our knowledge such a figure does not exist in the industry literature.

It is a long leap from arguing that price-setting competition is the wrong model to arguing that quantity setting is the right one. In actuality the strategic choice set of Boeing and Airbus probably contains price, quantity, and a wide variety of green stamps. Nonetheless, the Cournot assumption provides a sensible yet simple way to model imperfect competition. Given that we are treating the A300 and the 767 as one homogeneous product, Cournot is a better model than Bertrand.

The objective of firms is to maximize their present value; these are defined as

$$(4) \qquad V = -F + \sum_{t=0}^{T} (P_t - c_t)x_t R^t, \text{ and}$$

$$V^* = -F + \sum_{t=0}^{T} (P_t - c_t^*)x_t^* R^t,$$

where R and R^* are the discount factors of the two firms. We assume that the product cycle has a known length T. After T periods a new technology arrives exogenously and makes this generation of aircraft obsolete.

3.3.2 Profit-Maximizing Behavior

This model is a standard Spence-type (1981) learning curve setup. The major decision that needs to be taken is how sophisticated to make the strategies of the players. In principle, each player should take into account the effect of its current decisions on the future output of the other; that is, current output, because it adds to a firm's stock of experience K, may have a valuable strategic effect in lowering future costs. However, we have chosen (which is perhaps a more realistic option as well) to assume that each firm takes the other's whole output time path as given. This means that the firms do not attempt to act strategically in a dynamic sense, but rather act as monopolists on the residual demand.

In each period the U.S. firm faces a first-order condition of the form

$$(5) \qquad 0 = P_t + x_t(dP_t/dx_t) - c_t - \sum_{i=1}^{T-t} x_{t+i}\,(dc_{t+i}/dK_{t+i})R^i,$$

where the rightmost term represents the shadow value on experience, that is, the reduction in the present value of future costs that an additional unit of current output brings. Let z_t be this shadow value at time t; then it is straightforward to show that z_t obeys the difference equation

$$(6) \qquad z_t = z_{t-1}/R - x_t(dc_t/dK_t).$$

This equation is tied down at one end by the condition that learning has no value in the last period:

$$(7) \qquad z_t = 0.$$

An exactly parallel set of relationships of course applies to the foreign firm.

We turn next to the determination of output at a point in time. Equation (5) may be rewritten as

$$P_t + x_t(dP_t/dx_t) = c_t + z_t \ .$$

In a Cournot duopoly with constant elasticity demand, once we have marginal costs, $c_t + z_t$, we can solve for both market shares and the price. In each period t, it can be shown that the market share of the European firm is

$$(8) \qquad s = \frac{1 - m(1 - 1/E)}{(1/E)\,(1 + m)} \,,$$

where m is the ratio of $(c_t + z_t)$ to $(c_t^* + z_t^*)$. The market price, in turn, can be determined from the relationship

$$(9) \qquad P_t = \frac{c_t + z_t}{1 - ((1 - s)/E)} \,.$$

From the demand curve (1) and the market share, we can then determine x_t and x_t^*.

Up to this point the durability of the good has had no formal role in the model. As noted above, the demand equation (1) is indistinguishable from a static demand function. A problem with the static formulation arises in trying to reproduce the historical situation. Since Boeing did not enter until 1982, Airbus had a monopoly from 1979 through 1981. With a static demand for aircraft, this quantum change in market structure would lead the model to predict a very large drop in the price between 1981 and 1982. However, since planes are capital goods, air carriers have some ability to shift their demand intertemporally. It is therefore unlikely that any airline would purchase at the high, pre-1982 price.

If an airline finds it more profitable to buy today rather than next year, it must be the case that

$$(10) \qquad \sum_{i=0}^{N-1} R^i \, [\,\Pi_{t+i}(q)\,] \, - \, qp_t > \sum_{i=0}^{N-1} R^i[\,\Pi_{t+i+1}(q)\,] \, - \, qp_{t+1} \,.$$

This implies that the price cannot fall too fast. Specifically,

$$(11) \qquad p_t - p_{t+1} \leq (1/q)\Pi_t(q)(1 - R^N).$$

This inequality restricts the rate at which the price falls. As it turns out, this constraint only binds during the Airbus monopoly period.

3.3.3 Solution of the Model

This model can be solved iteratively, using what amounts to the Fair-Taylor method. We used the following procedure.

1. An initial guess is made at the output path. These paths are used to solve for the corresponding sequence of K's and K^*'s.

2. The K's, K^*'s, x_t's, and x_t^*'s are used to construct the sequence of marginal costs for Boeing and Airbus.

3. Given these sequences of marginal costs we can construct the market shares s_t, and $1 - s_t$, the market price series p_t, and therefore the time path of x and x^*.

4. This new series of x_t's and x_t^*'s are fed back into the loop.

The whole process is repeated until it converges. The result is a path of outputs that satisfies the first-order condition for both firms.

3.4 Calibration and Results

We have carried out a simulation of the model described above, with parameters and assumptions designed to resemble the actual competition between Boeing and Airbus in medium-range jet aircraft. We begin by describing the calibration procedure, the base case. Next we examine what our model predicts would have happened if there had been no Airbus program.

3.4.1 Calibration

The first issue that arises in calibrating the model to the aircraft industry is conceptual rather than quantitative: how to represent European industry policy. As we pointed out earlier, the governments backing Airbus have provided loans that could in principle be fully repaid, so they are not a simple subsidy. On the other hand, the loans will be repaid only to the extent of Airbus's profits. Since it seems clear that Airbus is willing to undertake projects that would not appear likely to earn market rates of return, we model the subsidy as equity participation by governments that expect less than the "market" rate of return.

In an industry with a twenty-year product cycle and substantial learning, the discount rate employed by a firm plays a significant role in the choice of its output path. As part of our modeling of the subsidy, we model the Airbus program as one that effectively lowers the discount rate of the European firm to whatever it takes to make entry barely profitable (taking zero as a lower bound). This is conceptually equivalent to calculating the internal rate of return on the A300, and assuming that Airbus chose its output path using this discount rate. We set the Boeing discount rate arbitrarily at 5 percent.

Two parameters of the model are assigned on the basis of industry estimates. Following a survey in the *Economist* (June 1, 1985), we assume the learning curve has an elasticity of .2. That is, a 1 percent increase in cumulative production will decrease direct production costs by .2 percent. From a Commerce Department study (Schlie 1986) we take the initial setup costs as $1.5 billion for both firms.

The price elasticity for wide-bodied medium-range planes poses more problems. We found no direct estimate of this quantity in the existing

literature. Moreover, due to the nature of the market, the exact price of planes is difficult to ascertain and rarely reported. It was therefore impossible to directly estimate the elasticity ourselves. What we have done is to use the fact that the demand for commercial aircraft is a derived demand, together with the predictions of the whole model, to get a rough approximation of the price elasticity.

Using aggregate data on U.S. air carriers we estimated the demand elasticity for commercial domestic passenger air service at 2.85. Assuming that aircraft account for a fifth of the marginal cost of providing air services, we can deduce that the derived demand elasticity for all aircraft is .57. However, medium-range wide-bodied planes are only one of several types of jets. Thus we should expect a cross-price effect in addition to the direct effect. That is, a one percent rise in the price of the A300 results in some substitution toward smaller or larger jets, as well as a rise in the marginal costs of providing air services. We arbitrarily guess at a range for this cross-price elasticity. If we assume it is equal to 1.0, then $E = 1.57$; if it equals 2.0, then $E = 2.57$.

There is an additional source of inferences on E. The total profitability of the two firms depends directly on E (due to the markup equation (9)). In simulations calibrated to an E much greater than 2.5, Boeing makes negative profits. Since by all accounts, the 767 is forecasted to be a profitable project, we focus on E's that are less than 2.57. Similarly, simulations calibrated to much less than 1.57 imply an internal rate of return on the A300 in excess of 3.5 percent—and thus might have been a commercially viable project. Since most studies forecast the A300 to have a low or negative rate of return, we limit ourselves to E's greater than 1.57. We take $E = 2$ as the central case.

It is necessary to recognize somewhere the extra cost incurred by Airbus as a result of its slow development. We approximate the cost by assuming that Airbus incurred its development cost in 1974 but was unable to deliver aircraft until 1979. Boeing, in contrast, is assumed to incur its development cost in the same year that 767 deliveries began, 1982. Both planes are assumed to be sold until 1998.

For allocation of consumer surplus to regions, it is necessary to allocate demand. Based on average numbers for the first half of the 1980s, we allocate 41.5 percent of consumer surplus to the United States, 25.9 percent to Europe, and 32.6 percent to the rest of the world.

This still leaves us with three free parameters—the European discount rate and the constant terms in the two learning curves. We carried out a search over parameter values, repeatedly solving the model, so as to choose the values for these parameters that meet the following conditions: nonpositive present value for Airbus; a 1984 price of $50 million corresponding to total sales of forty-eight planes (taken from

Schlie 1986 and the *Economist* survey); and a 1984 Airbus market share of 39.6 percent (also taken from the *Economist*).

To line up the model on these values (for the central case of $E = 2$) required that we set the intercept of the Airbus learning curve 17.2 percent higher that of Boeing. In other words, with equal-length production runs, Airbus's direct production costs would be 17.2 percent higher than Boeing's.

3.4.2   The Base Case

The upper part of table 3.4 shows the results of a solution of the model in the base case where the demand elasticity is taken as 2 and Airbus is given sufficient subsidy to enter the market. Notice that the price falls throughout the product life, but more rapidly before 1982 than after. If it were not for intertemporal substitution on the demand side, the price during the Airbus monopoly phase (1979–82) would be near $100 million, falling to the $50 million range after Boeing's entry. Clearly no airline would purchase a jet in 1981 when it knew that by waiting a year it could save $50 million. This consideration limits the price Airbus can charge in the first three years, as is described by equation (11).

Once both planes are in the market, the price falls very slowly. Despite the presence of substantial discounting by Boeing, the solution is quite close to the constant price path that emerges from learning curve models with no discounting. The slow fall in prices is reassuring since nowhere in the industry literature is there a discussion of a significant price trend. Indeed aircraft industry studies often assume a constant price in evaluating the commercial prospects of a projected aircraft.

The Airbus market share falls through time since it is learning at a lower rate than Boeing. The total deliveries rise slowly as the true marginal cost falls. The simulation predicts total sales of 398 planes for Airbus and 573 planes for Boeing. The figure for Airbus is a bit low compared with other projections, but the Boeing figure is quite near the 600–700 range predicted for the Boeing 767.

Table 3.4 also shows that for $E = 2$, Airbus is simulated to lose money even when it chooses an output path using a zero discount rate. Clearly, Airbus's entry depended on the existence of a subsidy. To calculate the size of the subsidy we need to know the opportunity cost of public funds. Taking this number as 5 percent, the present value of the A300 earnings is a negative 1.471 billion 1974 dollars—a large sum, although not on the scale of the $10–12 billion number sometimes suggested by Boeing.

Boeing's 767, not surprisingly, has a positive present value of $1.02 billion.

Table 3.4 **Simulation Results for the Central Case ($E = 2.0$)**

	1979	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98
BASE CASE																				
Prices ($ million)	61	58	55	52	51	50	49	49	48	48	48	48	48	47	47	47	47	47	47	47
Airbus share (%)	100	100	100	47	43	40	39	37	36	36	35	34	34	34	33	33	33	33	33	33

Consumer surplus (discounted to 1974)

	Europe	U.S.	RoW	Subsidy Cost
Social discount rate = 3%	5843	9363	7355	1294
= 5%	4487	7190	5648	1471
= 10%	2482	3976	3123	1672
Profits	− 836	1020	—	
Discount rate	0%	5%	—	
Cumulative production	398	573	—	

NO AIRBUS CASE (Intertemporal demand substitution)

	1979	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98
Prices ($ million)	—	—	—	70	70	69	68	68	67	67	66	66	66	66	66	65	65	65	64	63
Airbus share (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Consumer surplus (discounted to 1974)

	Europe	U.S.	RoW	Subsidy Cost
Social discount rate = 3%	3962	6348	4987	—
Change from base case	(− 1881)	(− 3015)	(− 2368)	
= 5%	3053	4892	3843	—

Change from base case			(−1434)		(−2298)		(−1805)												
= 10%			1692		2710		2129			—									
Change from base case			(− 790)		(−1266)		(− 944)												
Profits			—		6297		—												
Change from base case					(5277)														
Discount rate			—		5%		—												
Cumulative production			—		542		—												

No Airbus Case (Static demand formulation)

Prices ($ million)	—	—	—	82	78	76	74	73	72	72	71	71	70	70	70	70	70	69	68	67
Airbus share (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Consumer surplus (discounted to 1974)

	Europe	U.S.	RoW	Subsidy Cost
Social discount rate = 3%	2688	4307	3383	—
Change from base case	(−3155)	(−5056)	(−3972)	
= 5%	1996	3198	2513	—
Change from base case	(−2491)	(−3992)	(−3135)	
= 10%	1006	1612	1267	—
Change from base case	(−1476)	(−2364)	(−1856)	
Profits	—	4215	—	
Change from base case		(−3195)		
Discount rate	—	5%	—	
Cumulative production	—	409	—	

Note: RoW = rest of world.

3.4.3   A World without Airbus

The lower part of table 3.4 shows two scenarios for what would have happened, according to our model, if there had been no government support of Airbus. The scenario at the bottom of table 3.4 (static demand formulation) simulates a Boeing monopoly where Boeing enters in 1982 and there is no intertemporal substitution of demand. That is, the demand curve in 1982 is the same as in the base case despite the fact that there were no sales in the 1979–81 period. In addition to delaying the availability of medium-range wide-bodied jets, the absence of Airbus results in a higher market price. In the monopoly case, Boeing consistently sells the 767 for about 40 percent more than it would in the presence of Airbus competition.

A comparison of this scenario with the base case shows that the primary effect of the Airbus subsidy is redistributive. The subsidy benefits all consumers by several billions of 1974 dollars, hurts Boeing's profits by several billion dollars, and costs European taxpayers about a billion and a half dollars. The net welfare effects are much smaller. On net, the subsidy is calculated to improve European welfare by about a billion 1974 dollars (using the 5 percent social discount rate) and harms the United States by about a half billion dollars. The rest of the world, of course, gains due to lower prices.

3.4.4   Allowing for Intertemporal Substitution

The static demand scenario has some problems. Recall that our examination of static models suggested that in the duopoly case the United States could not gain if it remained a net exporter of aircraft. This suggests that the narrowness of the U.S. loss hinges crucially on the consumer gains during the first three years. As we have formulated the model, the availability of aircraft in 1979–81 provides large consumer benefits. This is not a plausible result. Could it really have been so important that wide-bodied jets be available in 1979 rather than 1982?

In the standard learning curve models, demand is taken to be represented by a relation between current price and current sales. Aircraft, however, are capital goods; there is therefore a possibility of intertemporal substitution, with the consumer delaying purchase to wait for a lower price or availability of a better product. To take account of this possibility we run another—more realistic—simulation, assuming that all of the airlines that would have purchased in the 1979–81 period shift their demand to 1982. This simulation in effect increases the constant term in the 1982 demand function by a factor of 3.

The middle part of table 3.4 presents the results of this simulation (intertemporal demand substitution). Note that, as before, the principal impact of the A300 is redistributive. The A300 improves the welfare

of consumers in all regions, reduces the profits of Boeing, and costs European taxpayers approximately $1.5 billion. The difference in consumer surplus with and without Airbus is less drastic although still substantial. On net, Europe loses (except for the low 3 percent discount rate), the United States loses, and the rest of the world gains. Europe is now calculated to have a consumer surplus gain due to Airbus, which is less than the cost of the subsidy by $37 million (for the 5 percent discount rate). For a 3 percent discount rate Europe gains on net from the competitive effect of Airbus by about a half billion dollars. For a 10 percent discount rate, Europe's net loss is almost $.9 billion.

The simulation predicts that Airbus caused a net loss to the United States, but now the net loss is estimated at a much higher $3 billion. The difference lies partly in the fact that U.S. consumers do not gain as much by the existence of Airbus, and partly in the fact that the shifted demand increases the profitability of the Boeing monopoly.

The basic conclusion from table 3.4 is that the subsidized entry of Airbus cost Europe something like $1.5 billion. This expenditure provided large benefits to all consumers, but did substantial harm to Boeing's profits. Overall it seems that the A300 project constituted a beggar-thy-neighbor and beggar-thyself policy for Europe. Allowing for intertemporal substitution of demand, the United States suffered a loss in the sum of producer and consumer surplus for the social discount rates considered. The gain to Europe's consumers outweighs the cost of the subsidy only for a discount rate of 3 percent.

3.4.5   Sensitivity Analysis

So far we have tested the sensitivity of our results only to the social discount rate. We now turn to sensitivity analysis of the demand elasticity. The demand elasticity is crucial since it directly affects all three components of the welfare calculations. Consumer surplus obviously depends on it, as does the profitability of both Airbus and Boeing. This in turn affects our assessment of the size of the subsidy and Boeing's profit loss. Moreover, it is neither estimated independently nor deduced directly from calibration.

The case where $E = 1.57$ seems a reasonable lower bound on the price elasticity. The calculated internal rate of return on the A300 corresponding to this figure is 3.544 percent—a rather high figure. If the demand for wide-bodied medium-range jets were even more inelastic, our simulation would come to the unreasonable result that the A300 would have been undertaken even without government support. Likewise, $E = 2.5$ seems to be a reasonable upper bound, since for this figure the simulation predicts that Boeing barely breaks even on the 767, turning a profit of only $193 million.

Table 3.5   **Sensitivity Analysis for Welfare Results**

Price Elasticity	Demand Formulation	Social Discount Rate (%)	Region		
			Europe	U.S.	RoW
$E = 1.57$	Intertemporal substitution	3	+	−	+
		5	+	−	+
		10	+	−	+
$E = 2.0$	Intertemporal substitution	3	+	−	+
		5	−	−	+
		10	−	−	+
$E = 2.5$	Intertemporal substitution	3	−	−	+
		5	−	−	+
		10	−	−	+

Note: RoW = rest of world.

Table 3.5 presents the sensitivity analysis on E. The table indicates the net welfare effect of the presence of Airbus for each of three elasticities. A positive sign indicates a net gain; a negative sign a net loss. As is evident, the subsidization of the A300 left the United States worse off for all values of E. Specifically, the loss in Boeing's profits due to the A300 always exceeds the gain to U.S. consumers. Similarly, the welfare impact of the A300 on the rest of the world is unambiguous. This is of course expected since the rest of the world neither earns profits nor pays the subsidy, leaving only the consumer surplus gain.

The question of whether the A300 was a good idea for Europe turns out to be rather sensitive to the price elasticity. For relatively inelastic demand the cost of the subsidy is low and the gains to European consumers are high. For the case of $E = 1.57$ we estimate the subsidy cost as a very low $301 million (using a social discount rate of 5 percent), while the European consumer gain is close to $2 billion. By contrast, for $E = 2.5$ the subsidy is in the $2 billion range while Europe's consumer gain is near $1 billion.

3.5 Conclusion

In this chapter we have examined international competition in wide-bodied aircraft. Given the degree of simplification necessary to produce a tractable model, it is difficult to base policy conclusions on our results. What does emerge from the study is the importance of consumers' welfare in determining the desirability of strategic trade policy. This industry is marked by a large fixed-cost cum learning curve, which would appear to be a ready-made setup for strategic trade policy aimed at capturing pure rents. We find, however, that for Europe as a whole

the welfare consequences of Airbus's subsidized entry are dominated not by competition over profits, but by gains in consumer surplus resulting from earlier product introduction and increased competition. While there are many reasons to be skeptical of the precise results, this chapter suggests an important lesson for theoretical I.O. trade models: models that, in the spirit of Brander and Spencer (1981), neglect consumer effects of strategic trade policy, while useful for expositional purposes, are likely to be misleading when applied to real situations in which a sizable fraction of production goes to satisfy domestic demand.

Second, this chapter has brought out just how far from constant returns and perfect competition the industry is. While the aerospace industry appears highly concentrated even in aggregate statistics and is known to be subject to strong increasing returns, it is only when one examines competition at the level of specific products that the decisive role of dynamic economies of scale becomes apparent. The world market in no case supports more than two firms producing aircraft that are close substitutes in demand, and perhaps could only support one without government intervention. Thus Boeing 747s have no close competitors; the A300 coexists with the 767 only because of government support; and when McDonnell-Douglas and Lockheed developed similar craft, the DC-10 and the L-1011, both lost money.

Finally, we should note as a caution that the analysis here focuses on the already existing competition in wide-bodied aircraft. This is not the whole story of the prospective competition. Airbus is about to start delivering the narrow-bodied 150-seat A320. The A320 is intended to meet a new niche (created by the deregulation of the U.S. air carrier industry) for smaller jets to serve as feeders in the hub-and-spoke routing system. Surrounding the A320 is a new set of strategic issues; both Boeing and McDonnell-Douglas have decided not to challenge the A320 directly, but instead to try to leapfrog it by entering a few years later with an improved technology. It is the A320, not the A300, that is the focus of current trade tension.

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Comment   Richard Harris

This chapter is a nice mix of theory and empirical work, and represents the type of analysis we could use a great deal more of in international trade. The chapter draws on some of the authors' earlier work applying the Spence oligopoly learning model to semiconductors. In this instance the application is to commercial wide-bodied aircraft, and in particular to the competition between Boeing and Airbus. It would be difficult to pick an industry for which this model is more appropriate; the industry is close to a pure duopoly, and the overwhelming significance of learning economies that are internal to the firm is well documented.

The first part of the chapter lays out some simple issues of subsidy in static monopoly and oligopoly models. In the duopoly case the authors conclude that there is a welfare loss for the exporting country if entry into a duopoly is subsidized by the importing country. I have no quarrel with this conclusion in the particular model used, but would caution the reader that it is far from general. There are two potential problems, both having to do with the effect of entry deterrence. In the model, the incumbent exporting monopolist has a clear incentive to deter entry. In the commercial aircraft industry the most likely vehicle for deterrence is up-front investment in research and development. R&D costs are a substantial portion of the total costs of any particular aircraft model. It is now well known that the existence of this incentive to invest for deterrence reasons can lead to overinvestment in R&D. In this case the existence of a subsidized potential entrant who can effectively enter with subsidy may reduce this overinvestment, which would be welfare-improving for the country in which the over-investment initially occurred. On the other hand, if the initial situation were one in which entry-deterring investment was not occurring, then the introduction of a subsidized entrant might lead to inefficient R&D races. The net impact in this situation would depend crucially on how consumers gain relative to the inefficiency costs associated with R&D.

On a related topic, the two simple models and the basic dynamic model used later in the core of the chapter all assume that the costs and benefits of R&D are entirely internal to the firm. I believe this is a questionable empirical assumption; the existence of spillovers between firms in the R&D process can reverse many of the conventional conclusions. From the world's point of view, and quite possibly from both countries' point of view, the larger problem could be not enough investment in R&D. It is difficult to balance this traditional concern with issues of entry deterrence, but it is clearly important.

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The main part of the chapter is concerned with a dynamic duopoly model with scale economies derived from a learning curve. It is worth noting two features of this model. First, the solution concept is one of "open loop" equilibrium; each firm takes the other firm's entire future output sequence as given. The importance of this assumption is that it implies that an increase in output today by firm A will *not* increase market share of A in the future, even though learning induces lower marginal costs to A in the future. An alternative would be a "closed loop" equilibrium concept that would focus on cumulative outputs of the two firms as the natural state variables, and in addition would yield a subgame perfect equilibrium. I would guess that the equilibrium in this alternative model would yield lower prices, larger outputs, and greater consumer surplus because of the additional incentives for each firm to preempt *future* market share via current output decisions. The second feature of the model is that the marginal cost, which marginal revenue is anchored to, is a variant of "long-run" marginal cost, that is, marginal cost after learning has ceased. In a model without discounting, this is exactly true, but it is "approximately" true even in this model. Thus because long-run marginal costs remain remarkably constant, so do prices. This is evident in table 3.4, where price sequences are given both before and after entry. Alternative equilibrium concepts might indeed change this result, and the higher the discount rate the more significant the difference might be.

The empirical section of the chapter calibrates the model to a single year's data. The authors choose as a free parameter the discount rate of Airbus. This parameter is chosen so as to equate the present value of the Airbus net revenue stream to zero. They then argue that because this rate is much lower than the discount rate used by Boeing, Airbus is "subsidized." It seems to me this is an inappropriate procedure for two reasons. First, the welfare results of the model are crucially dependent on this calibration procedure. We have no idea what the extent of any actual subsidy is, nor what is the sensitivity of the results to possible errors in estimating the extent of the subsidy. In the computable general equilibrium (CGE) literature a great deal of effort is put into getting estimates of all relevant policy variables. The calibration procedure of the CGE exercises is used only to scale constants and share parameters on utility and production functions. While subject to measurement problems, the CGE procedure does not bury key assumptions regarding policy variables, which are themselves usually the focus of the analysis. In this model I think it is particularly unfortunate that the discount rate for Airbus was used as the free parameter. With learning effects there is at least the potential that the discount rate could be the key structural parameter in determining the characteristics of equilibrium. On theoretical grounds, the existence of capital cost

subsidies does not provide a rationale for discounting cash flows at
something different than the market rate if profit maximization is the
appropriate objective of the firm. In short, I think it would be much
better if the authors used equal discount rates for both firms and in-
troduced the subsidy quite explicitly. Clearly the form of the subsidy
would affect the results.

My last comment relates to the assumption in the chapter that Boeing
is not subsidized. Non-U.S. observers would think this assumption a
bit peculiar, particularly in the case of commercial aircraft. It is com-
monly argued that the close association of Boeing with the U.S. defense
establishment allows security of market size, together with long-term
cross subsidization of R&D costs; both are obvious effective subsidies
to commercial aircraft development. While no one knows the true
extent of such subsidies, nor how they should be treated in international
trade policy, as economists we should at least acknowledge that these
features of the U.S. market could be a potentially important deter-
minant of international market structure in this and related industries.

Comment   Catherine L. Mann

Richard Baldwin and Paul Krugman's chapter on evaluating the mag-
nitude of the Airbus subsidy arrived on my desk almost concurrently
with a news clipping about the tough stance U.S. trade negotiators
were taking with the Europeans on the Airbus subsidy issue. Coming
on the heels of the "luxury edibles" trade problem, I was certain that
I would have to write a memo on the Airbus topic, detailing this most
recent trade skirmish between the United States and the European
Community (EC). But, as events turned out, with both Boeing and
McDonnell-Douglas backing off from their earlier pressure on the U.S.
trade negotiators, I didn't need to write the memo. Nevertheless, I
found Baldwin and Krugman's essay quite topical and a refreshing
departure from the majority of trade theory papers which only infre-
quently address a real-world issue.

Baldwin and Krugman use Airbus Industrie as an example of a high-
technology industry with dramatic dynamic economies of scale. High
fixed costs of introducing a new generation of aircraft combine with a
significant learning curve in production to lead to steeply downward
sloped average cost curves for each family of aircraft. Such an industry
structure can support only a few firms. Airbus Industrie, founded in

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1970, is a consortium jointly owned by the governments of France, Germany, Spain, and the United Kingdom. It joins Boeing and Mc-Donnell-Douglas as the major participants on the producer's side of the market for civilian aircraft. Lockheed departed the field in the late 1970s.

Baldwin and Krugman consider one mode of competition in demand for civilian aircraft, that between the Airbus A-300 and the Boeing 767. They argue that these models of aircraft are sufficiently different from other aircraft that they can model this competition as Cournot. Before Boeing introduced the 767, the A-300 had a monopoly over this market segment for wide-bodied jets. After introducing the 767, Boeing shared the market with the A-300 in a Cournot duopoly.

Measuring the welfare consequences of the competition between Boeing and the A-300 involves, in part, weighing the gain to consumer surplus of moving from a monopoly to a duopoly against the loss to producer surplus (in this case, Boeing profits) from causing each producer to move back and up the production and learning curve for this generation of aircraft. Baldwin and Krugman estimate that the gain in consumer surplus outweighs the loss in producer surplus, both overall and for all consuming groups (the EC, the United States, and the rest of the world). That Europe gains overall is striking because the gains are spread over all consumers while Europe alone incurs the subsidy necessary for Airbus to enter the airframe industry.

How to measure this implied subsidy? Baldwin and Krugman choose to estimate the internal rate of return on the A-300. The subsidy is the difference between some measure of normal internal rate of return (set at 5 percent for the other participant, Boeing) and the internal rate of return that makes the present discounted value of Airbus's net earnings on the A-300 just equal to zero. They estimate an internal rate of return of 0.75 percent.

As an exercise in analyzing an industry characterized by dynamic scale economies, and one that exhibits imperfect competition and government intervention, the aircraft industry is a terrific one to examine. However, since a main point of the chapter is to estimate the magnitude of a particular subsidy, and the magnitude of the welfare consequences of such a departure from free trade, it is important to characterize the industry with as much specificity as possible, remaining within the bounds of the parsimony required of international quantitative analysis.

While Baldwin and Krugman have done a relatively good job at introducing the important aspects of the production side of the aircraft industry, I think they need to do a better job on the demand side before we can pay too much attention to the estimates of the magnitude and welfare consequences of Airbus's entry into the airframe industry. I have some suggestions for a richer theoretical formulation of the demand side that cast doubt on the monopoly-duopoly structure of the

model. This model suggests that the lifetime of a generation of aircraft may be more related to characteristics of demand than to technological breakthroughs or to the useful life of the aircraft. Moreover, estimating the gains from subsidizing Airbus as the reduction in prices associated with increased competition fails to consider the technological externalities accruing to Europe as farmland gives way to high-technology factories. On the production side, the learning curve occurs not only for a single generation, but for all generations. Finally, from a policy standpoint, it matters whether Airbus will eventually be profitable from this one-time infusion of capital or whether a per unit subsidy will be necessary on all future production.

Operationally, most of my comments can be handled through some sensitivity analysis on the three key parameters. In particular, I suggest that the elasticity of demand for a particular type of airframe is higher, that the Boeing internal rate of return is probably lower, and that the lifetime of a generation may be shorter than the parameter values chosen by Baldwin and Krugman.

Demanders of airframes have a current and projected set of "missions" to which must be applied the existing fleet, new purchases, and purchases from or sales to the secondary market. It would seem that airframes, new and old, contain a vector of attributes designed to match the missions. Age, and the associated trade-off between airframe ownership cost and airframe operating cost, is an obvious attribute. "Brand loyalty" remains an attribute from a maintenance standpoint, although in the new purchases market it apparently has been less important in recent years. Missions can change over the forecast period, either because the specific demander's operational characteristics change (a merger and change of route structure) or because of a more general shift in passenger travel preferences (shuttle flights between cities, or the opening up of certain parts of the country because of economic development there). Because aircraft can be sold to the secondary market (or put back to the manufacturer via "walk-away" leases), the economic life of the airframe to a specific demander may be significantly different from its useful life. Moreover, sufficient change in the industry's route structure (say, because of the move from the direct flight concept to the hub-and-spoke concept) could lead to manufacturers experiencing a significantly different length for the product life-cycle than they had estimated. Finally, developers of airframes and demanders of airframes work together to design new aircraft. Thus, new purchases can be put off until the desired product is ready.

All these factors taken together suggest that it is not appropriate to model the A-300 and 767 as a monopoly-duopoly. First, these wide-bodied aircraft are direct competitors, but indirect competition created by a significant fringe of other aircraft types and by the secondary market restrains prices in the direct competition. Second, in Baldwin

and Krugman's comparison simulation (used to measure the changes in welfare associated with the entry of Airbus), Boeing retains a monopoly because Airbus does not enter. We do not know if perhaps McDonnell-Douglas would have entered the market for wide-bodied airframe if Airbus had not. Therefore, I suggest that the parameter for the elasticity of demand is higher (more elastic) than that suggested in the chapter. At minimum, this parameter should receive a fair amount of sensitivity testing. In fact, Baldwin and Krugman note that aircraft are capital goods and that because this aspect is not included in the model, their simulation results unfortunately show that the price of the A-300 is "too high" in the part of the life cycle where it has the monopoly in the base case simulation.

Baldwin and Krugman estimate the magnitude of the subsidy in part by comparing the internal rate of return for Airbus with that of Boeing. Aircraft are not produced in single generations by a new start-up each time. Airbus Industrie may eventually reach a more reasonable rate of return after it has been in business for the forty-odd years of Boeing. Moreover, while it appears clear that the consortium's governments have subsidized Airbus, the relationship between the defense establishment in the United States and the airframe manufacturers here suggests implied subsidies to their operations as well. Whether those subsidies are contained in Baldwin and Krugman's estimate of a 5 percent internal rate of return for Boeing is unclear. (In fact, Europe's threat to examine just this question might have led to Boeing's quieting its demands for a deeper investigation of the Airbus subsidy.) One could argue that even if the subsidy to Airbus were not outweighed by the consumer gains as measured here, there are clear technological (and defense) externalities gained by the birth of Airbus Industrie.

Policy considerations suggest examining in greater detail the characteristics of the subsidy. A subsidy to entry followed by competitive operations has different policy implications than one where the entrant is never competitive. The Baldwin and Krugman estimate suggests that production costs for the A-300 ran about 20 percent higher than those for the 767. Is this a long-run equilibrium difference in production costs caused by having factories spread all over Europe? Will Airbus have to subsidize each airframe design because Airbus chooses to compete against both Boeing and McDonnell-Douglas at different points in the product spectrum, a competition that we are starting to observe in the next generation airframe in the various families? Or does this subsidy represent the one-time cost of gaining credibility for a new airframe producer? I'm not sure that the model currently formulated can handle a question of this type, but as Baldwin and Krugman note, the action in the political arena is no longer about the A-300 but is about the subsequent models in the family.

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