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5 Industrial Policy in the Transport Aircraft Industry

Gernot Klepper

5.1 Introduction

Large commercial aircraft production is one of the areas in which the United States accuses European governments of unfair trade practices. Airbus Industrie is undoubtedly heavily supported by subsidies from all participating countries. From 1970 up to today, at least $11–$12 billion (U.S.) has been paid by European governments—some American estimates of that support come to as much as $20 billion (U.S.)—and the development of the A330/340 will require several billion dollars more in the next few years. The cause for these payments was the decision of European governments in the late 1960s to support the entry of a European competitor in the market for large transport aircraft.

Up to now these subsidies have been predominantly paid to finance start-up investments of the now-existing and planned fleet of aircraft—the A300, A310, A320, A330, A340, most likely the A321, and possibly a military freighter. This situation might change in the future, because the German government has agreed to grant production subsidies under specific circumstances. By the end of 1989 Daimler-Benz had merged with MBB, the German partners of Airbus Industrie, and a precondition of Daimler-Benz's acquiring the risky commercial aircraft business was a long-term exchange rate guarantee from the German government. Since aircraft are sold in U.S. dollars worldwide, this could amount to a sizable production subsidy if the DM/dollar exchange rate stays below 1.80 for a considerable time, e.g., in 1990 some 240 million DM will be paid to German Airbus.

This government-supported market entry and the exchange rate guarantees make it an interesting goal to analyze the strategic trade policy issue of European government intervention. One aspect of this competition between Euro-

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pean and American producers was examined by Baldwin and Krugman (1988), who developed a simulation model for the entry of the Airbus A300 in the market for medium- to long-range wide-bodied jet aircraft. The A300 was the first aircraft to be launched by Airbus, and it entered a market segment—a "window," as it is called in the industry—which had appeared in the 1970s due to the strong expansion of air traffic. At that time, Airbus was in an ambiguous situation: it was a new entrant to the overall market for large transport aircraft competing with well-established firms, but it was the first to enter the market segment for which the A300 was designed, whereas deliveries of Boeing's new 767 started six years later.

Baldwin and Krugman explained this situation of being a first-mover and at the same time having little chance to make profits on the A300 by cost differences between Airbus and Boeing—that is, Airbus had an approximately 17 percent higher unit cost at the same scale of production (1988, 25). This apparent cost disadvantage has been attributed by company officials to accumulated learning effects in the production of other aircraft types. They claim that such economies of scope account for Airbus's lack of success, hence the decision to develop the A320/321 and A330/340 in order to supply a complete family of aircraft. One purpose of this paper is to look at the effects of the market entry of Airbus by taking into account the complete family of aircraft.

The simulation model of Baldwin and Krugman uses government support that essentially supports the fixed costs of start-up investments and thus enables the firm to accept a lower than average profitability or even losses. Direct production subsidies, which have been minor in the past, seem to have become more important with the devaluation of the dollar. If the dollar stays at the fall 1990 level there will be substantial subsidies to be paid, at least by the German government. The comparative advantage of the American civil aircraft industry will deteriorate, and political pressures on the U.S. government to retaliate against such policies will increase. The already ongoing dispute about aircraft subsidies will most likely intensify. How such European subsidization of sales and potential American retaliation might affect competition among aircraft producers as well as welfare in the different regions is another topic to be looked at in this paper.

This paper uses the conceptual ideas of Spence (1981) and Baldwin and Krugman (1988) to model the long-term impact of dynamic learning effects on competition. The same approach has also been used by Baldwin and Flam (1989) in a simulation study of the commuter aircraft market. The present effort deviates in its calibration philosophy. Commonly, producer cost differences are calibrated according to market shares: a producer with a large market share is presumed to have lower costs. The source of such cost differences remains unexplained. In this paper, it is assumed that technical know-how is available equally to all producers and that factor prices do not deviate greatly between Europe and North America. The question then is, can the existing market shares and those which are expected for the coming years be reasonably explained without factor price or technological differences?

We show that this is possible by accounting for different times of market entry in the three market segments by two producers: a newcomer and an incumbent. Yet, if the model is calibrated to such a situation, the claim of Airbus officials that Airbus will become profitable as soon as it can supply a complete family of aircraft can not be supported by the simulations.

The paper starts with a short introduction to the specific features of the market for transport aircraft. It is followed by the presentation of the calibration model and a discussion of the calibration procedure. The welfare effects of Airbus market entry are assessed by comparing the existing duopoly to a potential American monopoly and to a potential American duopoly. Then the allocation and welfare effects of an ad valorem subsidy to Airbus are simulated. Finally, the impact of potential retaliation by the American administration on competition among European and American producers is analyzed.

5.2 Industry Characteristics

Today there are three large producers of large transport aircraft: Boeing (over 50 percent market share), Airbus (30–35 percent), and McDonnell Douglas (10–15 percent). Other civil aircraft forms a relatively minor part of the industry in terms of value. In the United States, large transport aircraft covers about 70 percent of all civil aircraft industry shipments. Light transport aircraft, helicopters, business aircraft, and other aircraft account for the rest (U.S. Department of Commerce 1986). The three large producers are embedded in a network of subcontractors that supply aircraft parts. Most important, the engines, amounting to 20–30 percent of the value of an aircraft, are developed by outside companies. Avionics, systems, and components (brakes, tires, etc.) are often subcontracted as well.

The market is small in terms of number of aircraft sold, but each aircraft is an expensive product. Every year, 400 to 500 large transport aircraft are expected to be sold, allowing for some yearly fluctuation. Aircraft prices range from $25 to $30 million for a Boeing 737, to $30 to $32 million for an A320, to around $120 million for a Boeing 747. The relatively small number of aircraft sold goes hand in hand with a long product cycle: it takes five to six years from launch to first delivery. Then an aircraft has a product cycle of at least 20–25 years, during which it may be upgraded to new technological standards.

Large transport aircraft have a complex production technology that results in strong learning effects. An essential part of learning appears in the assembly of an aircraft, which requires craftsmanship and the careful timing of thousands of activities. Such experience is embodied in the work force and accumulates with the number of aircraft that have been produced. There is worldwide consensus that aircraft production exhibits a learning elasticity of 0.2; that is, production costs decrease by 20 percent with a doubling of output (Berg and Tielke-Hosemann 1987; U.S. Department of Commerce 1986; see fig. 5A.1 in the appendix for some empirical examples). Whereas start-up investments and R&D are costly in absolute terms, the economies of scale are dominated by learning effects which amount to 90 percent of the overall economies of scale. Some production stages are not specific to a particular type of aircraft, so that learning effects which are realized in the production of a generic aircraft can influence the marginal cost of producing another generic aircraft. Such cross-effects are strong for updated versions of an aircraft, the so-called derivatives. These effects can be captured by economies of scope. Industry characteristics can then be summarized as (i) static economies of scale (R&D and start-up investment), (ii) dynamic economies of scale (learning in production), and (iii) economies of scope (cross-effects of learning).

5.2.1 Competition

Aircraft producers compete in essentially two ways. There is first the long-run decision about product choice and capacity. The demand in each segment even over a long time horizon is small in terms of the number of aircraft: 3,000 to 4,000 units each in the short- and medium-range markets and around 2,000 units in the long-range market are the expected market sizes over the next 20 years. Since learning effects are embodied in the work force, capacity choice becomes the crucial long-run decision variable.

There is, of course, limited information about future demand. Market forecasts by the large producers over the next 20 years, however, do not differ greatly, suggesting that the game is played under identical expectations. Figure 5.1 illustrates the different types of aircraft that are currently offered by the three producers, according to range and seating capacity. In each of the market segments—short-range narrow-bodied, short- and medium-range wide-bodied, and long-range aircraft—Airbus and Boeing offer competing generic aircraft, with possible derivatives.

Once capacity is determined, aircraft producers have limited choice over short-run output levels. They essentially produce at full capacity; that is, their time profile of deliveries is determined. A decision to increase capacity is then comparable to a new start on the learning curve.[1] The producers then bargain with airlines in their day-to-day marketing activities over the price of aircraft. Airlines seem to make extensive use of repeated negotiations with the suppliers of an aircraft for a specific market segment. Competition takes the form of a price game at given capacity levels, where the outcome of the long-run quantity game then becomes a restriction in the short-run price game. If demand turns out to be larger than expected, firms will produce at their capacity limit and choose prices which maximize profits. For unexpectedly low demand, the

1. This is supported by the evidence about capacity expansions in Boeing's production plants, which did at first result in very little output effects but in embarrassing quality problems.

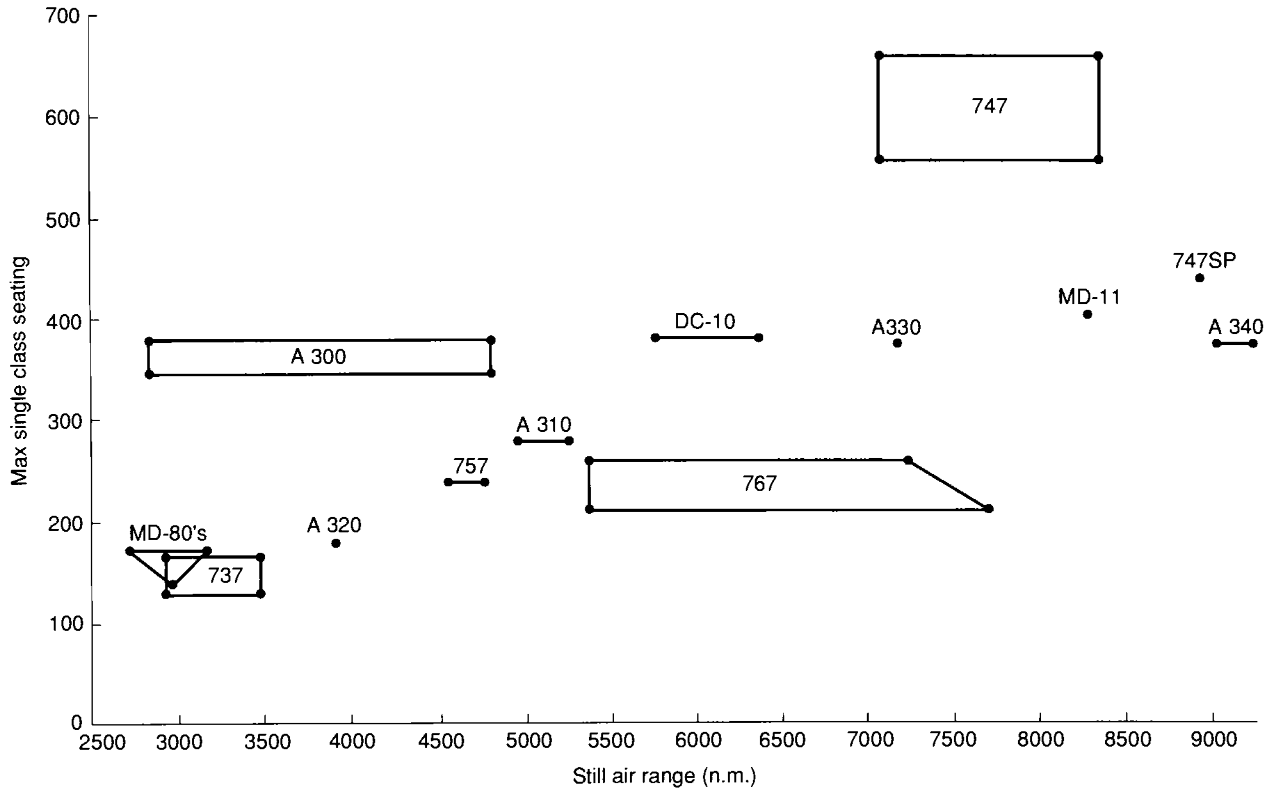

Fig. 5.1 Aircraft characteristics
Source: Hofton (1987)

price game may drive prices down to marginal cost levels. In extreme cases, "white tails" are produced; that is, aircraft are produced without a customer in sight.

5.2.2 Market Entry

Entry in a market such as the one for large transport aircraft is an expensive and time-consuming effort. Dynamic and static economies of scale together with economies of scope give incumbent firms a considerable competitive advantage. It is therefore not surprising that the market entry of Airbus was accompanied by the heavy involvement of European governments. After several commercially unsuccessful projects, European aircraft producers were not willing to take yet another gamble.

When in the 1960s European aerospace firms were considering entering the market for large transport with a new generation of aircraft, this market was almost completely dominated by the three American producers—Boeing, McDonnell Douglas, and Lockheed. Previously produced European aircraft had not been successful commercially, and the belief was that no non-American producer could compete in size with the three firms. In this situation, market entry can be viewed as the first stage of a three-stage decision process. First, commitment by European governments to subsidize the launch of a new aircraft was necessary since, apparently, financing on capital markets without state support was not possible. Second, firms had to decide which market segment to enter, and they had to choose a capacity which would allow them to capture the learning effects of large-scale production and at the same time keep prices at a profitable level. Finally, once the first two decisions were made, firms had to compete with the other producers in the day-to-day business of selling their product.

The first decision must be made under great uncertainty, and not only economic but also political arguments govern this process. Industrial policy aspects such as civil-military interaction in the aerospace industry were important. From the perspective of European firms, government support turned out to be essential. Not only is the financial burden for the launch of a completely new aircraft high, but the commitment by governments to support market entry could also prevent incumbent firms from starting a price war in the hope of stripping the entrant of its financial resources (Brander and Spencer 1983). When the Bonner Protokoll of September 1967 gave British, French, and German governmental support to the launch of the A300 (Berg and Tielke-Hosemann 1987, 1988), the first-stage was considered finished.

Once the A300 came to the market in 1974, airlines were not enthusiastic about buying a new aircraft from a new producer. Parts, maintenance, training, etc., did not fit the products of Boeing, Lockheed, or McDonnell Douglas. Although the A300 was designed to close the window for a high-capacity short- to medium-range transport aircraft and this window surely existed, the market opportunities in this segment were unclear. Lockheed and McDonnell

Douglas were already engaged in head-to-head competition with their L1011 and DC-10. The low prices of these two aircraft could make them competitive even in the shorter-range market segment of the A300. It became clear that Airbus had to supply a complete family of aircraft in order to stay in the market in the long run. This also meant a new commitment by the participating governments to finance new types of aircraft, since the A300 and later the A310 were not even close to their break-even points.

The political decision in the 1960s to support a European civil aircraft industry by subsidizing the development of one new aircraft, the A300, has over time turned into the need to subsidize the market entry of a producer of a complete family of aircraft. Subsidies and guarantees are given today for the development and launch of the A330 and the A340, but this is not necessarily the last step. Airbus has not yet internalized learning and scale effects in the same way as the established producers. The cost disadvantage of later market entry still exists. Airbus competes in market segments in which Boeing has already realized large learning effects and is able to produce at lower marginal cost.

Such a situation invites governments not only to support market entry but to subsidize the domestic firm in order to capture rents from the foreign firm. Brander and Spencer (1985) have shown that in a Cournot-Nash game subsidies paid by one government to its domestic producer who is selling its products in a third country increases profits and welfare. Can Europe gain by not only supporting market entry but also subsidizing the production of its domestic producer? In the past such subsidies have not been paid in significant amounts, but recently, at least by the German government, considerable price support has been given. This development and the impact of potential retaliation by the American government will be included in the simulation exercises.

5.3 The Model

For the purposes of this paper the political decision to support market entry is taken as given. Up to now this support has taken the form of financing the launch investment. Such fixed-cost subsidies do not affect the capacity decisions of the producers. Government support, therefore, only makes credible that the entrant will stay in the market even if entry is not profitable over the planning horizon. Entry-deterring pricing strategies by the incumbent producer are therefore not rational. With entry "exogenously" given, the game amounts to a Cournot-Nash game in capacity over the planning horizon. The possibility that European governments will pay and may already have paid production subsidies is taken up later. Past production subsidies and marketing aid are small compared to the subsidization of the launch investment (Coopers & Lybrand 1988). The amount of production subsidies to be paid in the future is unknown, since these subsides are made dependent on exchange rate developments.

The short-run price game naturally can not be empirically investigated, since it depends on the actual development of demand in the future. Historical examples show that aircraft prices fluctuate with demand; in 1979–83 rebates of up to 20 percent were not uncommon, according to airline officials. Apart from such demand fluctuations, real aircraft prices tend to remain constant over a product cycle. Our focus will be exclusively on the capacity game played between two producers, which one could imagine as being Airbus Industrie and Boeing. McDonnell Douglas is left out of the model, since it has not developed a really new aircraft and seems to function more as a competitive fringe. Until the Pentagon issued a large order for military tanker aircraft recently, there had been doubts whether McDonnell Douglas would stay in the civil market at all.

The model represents a stylized picture of the industry. In particular the production network of a large number of subcontractors is ignored. The producers are modeled as decision units and production units. This approach implicitly assumes that subcontractors have production technologies similar to those of the main firm, i.e., that they experience similar learning effects. An alternative model would only investigate the value added inside the two main producers and assume that intermediate products are bought from a competitive market, a less realistic assumption.

5.3.1 Supply Decision

Since an important part of the economies of scale of aircraft production are incorporated in the learning of the work force over time, a producer must essentially decide what the production capacity for a particular aircraft will be. In this model, entry times are treated as exogenous and correspond to the history of launches and the announced launch dates for the A330 and A340. At the beginning of the model's planning period each producer has to determine the capacity for every type of aircraft, whereby the cost function at that time is determined by the learning effect which has been accumulated in the past. This is done by choosing the rate of production for each aircraft. Profit maximization then requires balancing between large production rates with lower costs and sufficiently high prices which require low production rates.

In reality this will be a sequential decision with updates as time goes on and external parameters such as demand change. Nevertheless, capacity decisions do have a long-run character even if they are not made once and for all. A producer i therefore faces for a given capacity a flow of production y_{it}. The cumulative production x_{iT} at time T is then

$$x_{iT} = \int_0^T y_{it}\, dt. \tag{1}$$

Capacity choice is then equivalent to the choice of x_{iT}.

Each producer has a cost function in terms of cumulated output which incorporates learning effects, fixed cost, and economies of scope. For the purpose of this model, the CES cost function proposed by Baumol, Panzar, and Willig (1982) is chosen. It can incorporate all the desired features. Dropping the time subscripts, the cost of producing $k = 1, \ldots, m$ products for producer i is

(2) $$C_i(x_i) = F_{ik} + \left(\sum_{k=1}^{m} a_{ik}\, x_{ik}^{\beta_{ik}}\right)^{\theta_i},$$

where F_{ik} is the fixed cost for product k; a_{ik}, β_{ik}, $\theta_i > 0$, for all i, k; $x_i = (x_{i1}, \ldots, x_{ik}, \ldots, x_{im})$.

It is assumed that both producers have the same cost function, i.e., that they are equally efficient. Since the incumbent has already realized learning effects he may be on a lower part of his learning curve thus having lower marginal cost. The multiproduct cost function $C_i(x_i)$ has the parameter restriction $0 < \theta_i < 1$, for all i, if there are economies of scope in the production of x. In the one-product case, the cost function reduces to the classic learning curve

(3) $$\frac{\partial C(x)}{\partial x} = \theta\beta a^{\theta}\, x^{\beta\theta - 1},$$

with learning elasticity

(4) $$\mu = \beta\theta - 1.$$

5.3.2 Aircraft Demand

All producers face the same expected inverse demand function for aircraft over the time horizon T,

(5) $$p_k = p_k(x_k, x_{-k}),$$

where

$$x_k = \sum_{i=1}^{n} x_{ik} \text{ and } -k = (1, \ldots, k-1, k+1, \ldots, m).$$

Each firm produces in each market segment an identical product which is subject to cross-price effects from other market segments. For the model simulation, a linear demand representation was chosen:

(6) $$\sum_{i=1}^{n} x_k = b_k + \sum_{k=1}^{m} d_k p_k,$$

where b_k and d_k are the demand parameters.

5.3.3 Equilibrium

The optimal capacity choice of the two producers, $i = A, B$, is found as the solution of a Cournot-Nash game with cumulated output x_{ik} as the strategic variables. The reaction functions have the familiar form. The optimal strategy of producer i, $(\hat{x}_{i1}, \ldots, \hat{x}_{im})$, is given by the m first-order conditions:

$$(7)\quad p_k\left(\sum_{j\neq i}^{n} x_k + \hat{x}_{ik}, x_{-k}\right)\left(1 + \frac{\hat{x}_{ik}}{\varepsilon_k \sum_{k=1}^{m} \hat{x}_{ik}}\right) = \frac{\partial C_i(\hat{x}_i)}{\partial x_{ik}}, \text{ for all } k = 1, \ldots, m$$

where ε_k is price elasticity of demand for product k. The pair $(\hat{x}_A, \hat{x}_B)$ with $\hat{x}_i = (\hat{x}_{i1}, \ldots, \hat{x}_{im})$, $i = A,B$, is a Nash equilibrium if it satisfies equation (7) for all $i = A,B$, and $k = (1, \ldots, m)$.

5.4 Calibration

The effects of market entry cannot be empirically investigated with historical data since Airbus is only now in the process of becoming a producer of a complete family of aircraft and none of its products have reached the end of a product cycle. The approach taken here relies on the history of Airbus and Boeing production up to 1986 and then uses demand forecasts by the large producers up to the year 2006 as an empirical basis for the calibration of the model. This time period covers a complete product cycle for practically all aircraft types modeled here. The Airbus A330 and A340 are the exceptions, because they will not enter the market before 1992. Therefore demand forecasts for the long-range market will not be an entirely adequate description of the demand over the product cycle for these two aircraft types.

Demand forecasts by Boeing were available for the period 1987–2000 (Boeing Company 1987), by McDonnell Douglas for 1987–2001 (McDonnell Douglas 1987), and by Airbus for 1987–2006 (Airbus Industrie 1987). McDonnell Douglas and Boeing forecast an overall demand for about 5,700 large transport aircraft, which if projected to 2006 would predict demand to be about 8,100 aircraft. The Airbus forecast is more optimistic in predicting a total market for 9,797 airplanes. Although all three producers operate with differently defined market segments, thus making comparisons difficult, the main difference can be attributed to a much larger Airbus prediction for the market for short- to medium-range wide-body aircraft. In light of recent experience with airport congestion, this trend toward larger aircraft seems realistic.

For the calibration of the model, three market segments were defined: a market for short- to medium-range narrow-body aircraft (S), one for short to medium-range wide-body aircraft (M), and one for long-range wide-body aircraft (L). For segment S the more conservative estimate of demand was used, mainly since McDonnell Douglas's MD80s compete in this segment but are not explicitly modeled and because of the recent trend toward larger aircraft. The Airbus estimate of about 3,200 aircraft for segment M was adopted. The 1,750 aircraft estimate adopted for segment L is closer to the projected Boeing estimate than to the Airbus and McDonnell Douglas forecasts. Since the A340 as a competitor for the Boeing 747 in market segment L will not enter service before 1993, this is a conservative estimate if the market over the whole product cycle is the basis for capacity decisions. In summary, the three market segments are calibrated to the following benchmarks:

$$x_S = 3{,}500,\ x_M = 3{,}200, \text{ and } x_L = 1{,}750.$$

Listed market prices do not exist for large transport aircraft. Because different customers get different rebates, varied specifications of airplanes, and different arrangements concerning training, spare parts, and maintenance, price documentation is difficult. The prices used here are average prices derived from listed contracts (*Interavia*, current issues) and interviews. They are modeled in constant prices and calibrated to the following approximate benchmarks:

$$P_S = 27,\ P_M = 62, \text{ and } P_L = 100.$$

Technological characteristics are the launch investment which is taken as a fixed cost. For aircraft launched before 1975 an estimate of $3 billion was taken (U.S. Department of Commerce 1986). Any later aircraft was assumed to have a launch cost of $4 billion (*Economist* 1988). Learning effects are generally believed to be strong. A learning elasticity of 0.2 is widely accepted as the correct benchmark for decreases in marginal cost. In the present model with output in the range of 1,000 to 3,000, one can compute directly the contributions of fixed cost and learning to the economies of scale. It turns out that launch investment accounts for only about 10 percent of the overall economies of scale.

Aircraft producers do not reveal marginal costs and synergy effects among the production of different types of aircraft. Airbus officials, however, claim that Airbus Industrie has reached the same level of efficiency as its American competitors. Since no other verifiable information is available, it is assumed that each producer has the same cost of producing the first airplane.

However marginal cost for different producers may differ widely at some point in time, since their aircraft were launched at different times. Suppose two producers have the same constant production rate and the same cost function but started production at different times. The difference in marginal cost at a particular date is then given by the distance between the two marginal cost curves. This difference becomes smaller the larger cumulative production is. Because of the relatively small number of aircraft produced, this difference is of particular importance in the aircraft industry. For the model calibration, accumulated production of Boeing types 737, 757, 767, and 747 and Airbus types A300 and A310 in each market segment up to 1987 entered the cost function as already acquired learning effects.

Since demand for transport aircraft is derived demand, the shape of the demand curve depends on the elasticity of demand for air transport, which is relatively low due to the absence of substitutes, and on the technology of producing air transport services. The price elasticity of demand for air transport seems to lie somewhere between −1.5 (Kravis, Heston, and Summers 1982) and −2.85 (commercial U.S. domestic passenger air service; Baldwin and Krugman 1988). The Baldwin and Krugman estimate is based on a market with larger cross-price elasticities. Therefore the "true" price elasticity for world air transport will most likely be closer to the Kravis et al. estimate. On the other hand, it is a well-known observation that estimated short-run elasticities are considerably smaller than their long-run counterparts. For large airlines the cost share of aircraft amounts to at most 20 percent of total operating cost, and the elasticity of substitution between aircraft and other inputs is low. Therefore the price elasticity of demand for aircraft in general will be rather small, most likely below one.

This finding does not fit the assumed Cournot-Nash framework of a capacity game, since it requires a much larger elasticity in order to attain an equilibrium. An alternative at this point would be to give up the notion of a capacity game and to look for different models that might more adequately describe competition in the aircraft industry without violating estimated parameters. Krugman and Brainard (1988) have tried alternative approaches but have not yet found a satisfying alternative to the capacity game. The other possibility is to assume the capacity game to be the correct model and to determine demand elasticities in the calibration procedure. This, of course, leads to elasticities that are higher than those derived from empirical estimates.

In this paper, the latter choice was taken, i.e., elasticities are treated as endogenous in this model. Assuming demand elasticities to be endogenous requires us to treat profit rates as exogenous, which follows necessarily from the first-order condition (eq. 7), which states that the price-cost markup is a function of market shares and demand elasticities, i.e., that

$$\frac{p_k}{MC} = \left(1 - \frac{MS}{|\varepsilon|}\right)^{-1}. \tag{8}$$

Hence one is left with another unobservable variable. The choice of a rate of profit to calibrate the benchmark must therefore remain arbitrary. Several rates of profit (defined as the ratio of profit to revenue) have been tried in order to assess the robustness of the model with respect to this parameter. The lowest number for which an equilibrium could be established was 5.2 percent. The simulations were then run for different rates of profit between 5.2 and 7 percent. The resulting welfare effects remain stable in relative terms, whereas their absolute size changes slightly.[2] The simulations presented here are based on a rate of return of 5.5 percent, which represents the lowest price elasticity compatible with a robust model. The resulting direct price elasticities are larger than −2 and in the long-range market close to −1. Since the model has

2. For a listing of sensitivity analyses, see Klepper (1990, tables A.4 and A.5).

a linear demand system, the price elasticities vary slightly with the different simulations.

The parameter value for the degree of economies of scope had to be chosen arbitrarily. Its value of $\theta = .97$ can be interpreted as follows: the introduction of a new generic aircraft, when the firm has already experienced the learning effects of about 1,000 older and different aircraft, reduces marginal cost by some 30 percent compared to the situation where it produces its very first airplane as, e.g., in the case of the A300. For this model, in which both producers supply an aircraft in each size category, the impact of different degrees of economies of scope is marginal since the calibration procedure compensates these different degrees by adjusting the constant term of the learning curve. Economies of scope only become important if one firm produces only two types of aircraft. It would then be unable to compete with a full-scale supplier.

On the demand side, poor data availability would have required us to model demand for each type of aircraft independently by setting cross-price elasticities to zero. This was felt to be unrealistic for two reasons: first, there are obvious opportunities for airlines to substitute aircraft, though at considerable costs; second, without positive cross-price elasticities the price-cost markup for long-range aircraft would be much higher than even European supporters of the Airbus project would claim. The range of elasticities yielding reasonable equilibria was very narrow and confined to values below 0.2. Therefore a zero cross-price elasticity between small- to medium-range narrow-bodied (S) and long-range aircraft (L) was chosen. The elasticity between small- to medium-range narrow-bodied (S) and wide-bodied (M) as well as that between wide-bodied (M) and long-range (L) was set to 0.1.

The calibration proceeded then in the following steps. First, the remaining demand parameters and the cost parameters were derived under the assumption of two producers with identical technology and both on the same points of their learning curves; that is, the production prior to 1987 for each producer was taken to be the average of the Airbus and Boeing production in table 5.1. The benchmarks for total number of aircraft sold over the planning period and for aircraft prices are those given above. The resulting equilibrium has the producers equally sharing the total market. In the second step, the learning effects which each producer has already acquired before 1987 in the production of

Table 5.1 **Production up to 1987**

	Market Segment		
	S	M	L
Airbus	0	288	0
Boeing	1,070	149	609

Source: Interavia (current issues).

each aircraft type were used to determine the magnitude of the marginal cost function at the beginning of the planning period. For example, Boeing had already produced 1,070 aircraft in market segment S (see table 5.1); hence the marginal cost of the first aircraft produced in the planning period is derived by computing those costs using the calibrated parameters from the first step and taking the difference between Boeing's actual production and the average of the first step. The allocation derived through this procedure then predicts market shares and cost differences for the two producers; it will be referred to as the base-case calibration.

5.4.1 Base-case Results

The results of the base-case calibration are summarized in table 5.2. Under the assumption of equal technologies for both producers, output in the Nash equilibrium variers due to the cost advantages of previous learning. In market segment S, Boeing's marginal cost advantage is 23 percent, resulting in a market share of 31 percent for Airbus and leaving 69 percent for Boeing. In segment M, where Airbus has a slight advantage through the early launch of the A300, a marginal cost advantage of 6 percent translates into a 53 percent market share. Similarly for segment L, with cost differentials of 15 percent, market shares are 45 percent for Airbus and 55 percent for Boeing.

The expected profitability of the activities of the two producers can be computed either over the complete product cycle of their products, by including the sales prior to the start of the time horizon of the calibration, or for the time horizon of the calibration and the period before, separately. Table 5.3 presents all three computations. For simplicity the prices of aircraft prior to the calibration period are set equal to the calibrated prices. This underestimates the profitability of Boeing in a period where it had a monopoly in the long-range market with its 747 and also sold aircraft which are not counted here such as the 727.

The summary in table 5.3 shows how the late entry of Airbus affects profitability and production well into the next century. Airbus will have almost bro-

Table 5.2 **Market for Large Transport Aircraft:[a] 1987–2006 (base-case calibration)**

	Market Segment					
	S		M		L	
	Airbus	Boeing	Airbus	Boeing	Airbus	Boeing
Output	1,103	2,430	1,724	1,528	796	967
Market share (%)	31	69	53	47	45	55
Marginal cost	23.7	18.9	51.0	52.3	63.1	54.9
Price	27.7		62.5		101.0	

[a]For parameters, see Klepper (1990, table A1).

Table 5.3 **Revenues, Costs, and Profits**

	Airbus	Boeing
Revenue (billion $)		
Before 1987	18.0	100.5
1987–2006	218.8	260.6
Overall	236.8	361.1
Profits (billion $)		
Before 1987	−14.7	−7.6
1987–2006	11.9	53.0
Overall	−2.8	45.4
Profits/Revenue (%)		
Before 1987	−82.0	−7.6
1987–2006	5.4	20.3
Overall	−1.2	12.6

ken even by the end of our time horizon, but Boeing will have a rate of return of 12.6 percent. For the period 1987–2006 both Airbus and Boeing are profitable, if the start-up investment had high learning cost of the period to 1987 are not counted. These numbers give a rough indication of the cost disadvantage of Airbus in the 30 years after its market entry. At the end of this period, the comparison is not entirely correct, since by that time in market segments S and L Boeing will supply aircraft types which are at the end of their product cycles, whereas Airbus will have aircraft in the S and L segments which are still relatively new. Therefore Boeing will, during the time under investigation, face development costs for a new generation of aircraft.

5.5 Welfare

5.5.1 Effects of Airbus Market Entry

In order to assess the welfare consequences of government-supported market entry, a fictitious market structure without this entry has to be used as a reference allocation. One can imagine two scenarios which could have become reality after 1970. If, on one hand, concentration in the aircraft industry had continued in the 1970s as it had in the decades before and Airbus had not entered the market, Boeing might have eventually become a monopoly. If, on the other hand, the market were large enough for two or more producers and Lockheed or McDonnell Douglas were efficient producers, a duopoly such as the current situation might have emerged. The difference would be that the market would have two established producers instead of one new entrant and one incumbent. Both alternatives are simulated as benchmarks for the effects of alternative market structures.

Monopoly is simulated by leaving all parameters unchanged, except that there is only one producer, Boeing. Accumulated output in the monopoly situation is slightly smaller but not by a large amount, except in the long-range market segment, where the monopoly supplies almost 20 percent fewer aircraft. Prices rise between 3 percent and 16 percent. Profits to the monopolist almost triple so that the rate of profit over the whole product cycle increases from 12.5 percent in the base case to 27 percent in the monopoly case.

The second alternative is a duopoly with established producers of equal efficiency and thus on the same points of their learning curves. Consequently, they will share the market equally. This situation is simulated by assuming that at the beginning of the calibration period the same number of aircraft in each market segment have already been produced as in the base case. But this time the production has been shared equally by both producers. Only in the short-range narrow-body market does the overall output deviate significantly from the base case. This is induced by the large learning effects incorporated in the 1,070 aircraft produced prior to 1987 in the base case. Otherwise there is little deviation in the allocation from the base case.

Whereas the regional distribution of producer surplus is easy to determine, consumer surplus has to be approximated by the distribution of air traffic. Forecasted regional market shares (Airbus Industrie 1987) were used to distribute consumer welfare among Europe, the United States, and the rest of the world.

Table 5.4 summarizes the welfare effects of Airbus market entry when it is compared to a monopoly and when compared to a duopoly. If a monopoly were the alternative market structure, the market entry of Airbus could be considered successful from a consumer's point of view, but the overall welfare impact is negative. A consumer surplus gain of $36.8 billion is dominated by the producer surplus loss of $110.4 billion, most of which is the monopoly profit of Boeing (table 5.4). The regional distribution reveals welfare gains to Europe and the rest of the world, whereas in North America, i.e., the United States, consumers gain and producers lose.

The European producer surplus figures in table 5.4 do not include govern-

Table 5.4 **Distribution of Welfare Effects of Government-supported Market Entry (million 1986 $ U.S.)**

	Producer Surplus	Consumer Surplus	Total
Relative to monopoly			
Europe	−2,826	10,544	7,718
North America	−107,582	12,631	−94,951
Rest of world	0	13,630	13,620
Total	−110,408	36,795	−73,613
Relative to duopoly			
Europe	−2,826	−905	−3,731
North America	11,974	−1,405	10,569
Rest of world	0	−958	−958
Total	9,148	−3,268	5,880

ment subsidies. If indeed the projected $20 billion subsidies were paid by European governments and financed by European taxpayers, there would be a redistribution of consumer and producer surplus. Market entry would cost European consumers roughly $10 billion, but total welfare to Europe would remain unchanged. Taking these subsidies into account, government-supported market entry by Airbus as an antimonopoly policy—as has been claimed by European governments—did indeed help consumers, but only those outside Europe.

If the market entry of Airbus is compared to the hypothetical situation of a duopoly with equal, mature producers, a surprising welfare effect emerges. Overall welfare in the base case is $5.9 billion higher than in the reference situation. Consumers lose in all regions, but these losses are smaller than the gain in producer rents. Boeing has higher profits in the base case than do the two American producers in the hypothetical duopoly. Two forces, scale and scope effects and the competitive effect, can explain this result. Because of increasing returns to scale, the social optimum is one producer with marginal-cost pricing and large output and, consequently, lower average and marginal cost. The simulated duopoly situation forces both producers up their average cost curves.

In the base case, Boeing of course has lower and Airbus higher marginal cost than in the reference situation. But on average both producers together produce at lower average and marginal cost in the base case. This advantage does not show up in prices, it goes to Boeing in the form of profits. Therefore, the market entry of Airbus has forced Boeing into more competitive behavior than was necessary in a Boeing monopoly, but since Airbus is only a small producer, the scale effects of Boeing with its projected market share of around 60 percent are strong enough to compensate for the high-cost production of Airbus.

The simulations and the two alternative welfare comparisons in table 5.4 show that there is a conflict between competition effects—indirectly consumer-welfare and scale effects, i.e., overall welfare effects. Although the market is simulated to sustain two equal producers, welfare is larger in a monopoly situation, and even an inefficient second producer with small market shares is better than the hypothetical duopoly. This suggests that, in the market for large transport aircraft, scale and scope effects are strong enough to outweigh the output-reducing effects of increasing market power and—in the extreme—of a monopoly. If the model represents the replacement of an established American producer by a European entrant, Airbus, the regional distribution of welfare changes looks ironic. Only North America gains from the Airbus market entry.

5.5.2 Production Subsidies

Up to now simulations of industrial policy have focused only on supporting market entry by subsidizing start-up investments. This policy changes the incumbent's pricing policy. Entry-deterring pricing strategies are not rational, if the commitment of European governments is credible as it was in the case of Airbus. These subsidies do not, however, influence the capacity game between the two producers. This game can be influenced only if output decisions are influenced by production or price subsidies. It has been shown by Brander and Spencer (1985) that the optimal export subsidy rate is that which moves the reaction function of the subsidized firm to the point that would have been chosen by the firm if it were in a Stackelberg-leader position. Since in the case of aircraft, production in general is subsidized and there is domestic consumption, the optimal subsidy is higher than a subsidy on exports alone.

In order to determine the optimal subsidy for Airbus, alternative subsidy rates have been simulated. It was assumed that only those aircraft types are subsidized in which Boeing has an advantage in terms of learning effects, i.e., short- to medium-range narrow-body and long-range aircraft. The Cournot-Nash game is played in the same fashion and parameter values are unchanged. Figure 5.2 summarizes the output effects of the increasing subsidization of Airbus. Output is measured in total number of aircraft produced. Total output increases by only 6.6 percent if Airbus is subsidized with a 20 percent subsidy on price. Although only aircraft in two market segments are subsidized, Airbus increases its market share in all three segments: from 31 to 60 percent in the short- to medium-range, from 53 to 61 percent in the medium-range wide-

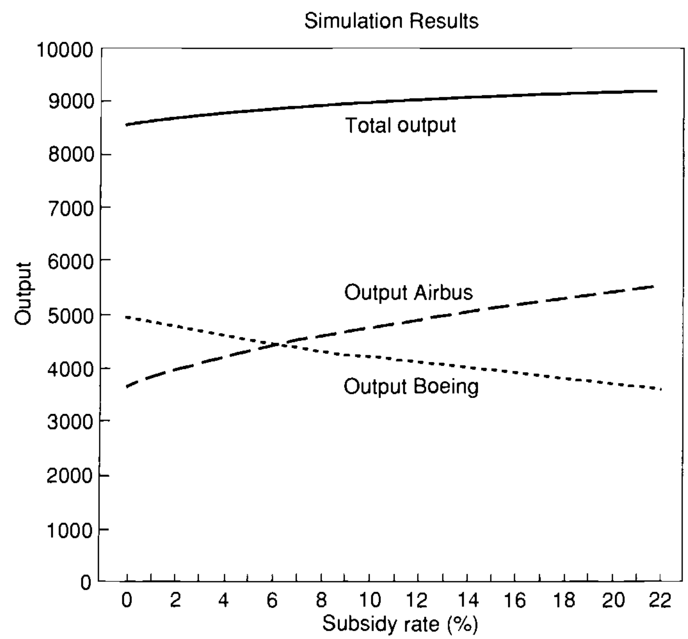

Fig. 5.2 Aircraft production with Airbus subsidies (simulation results)

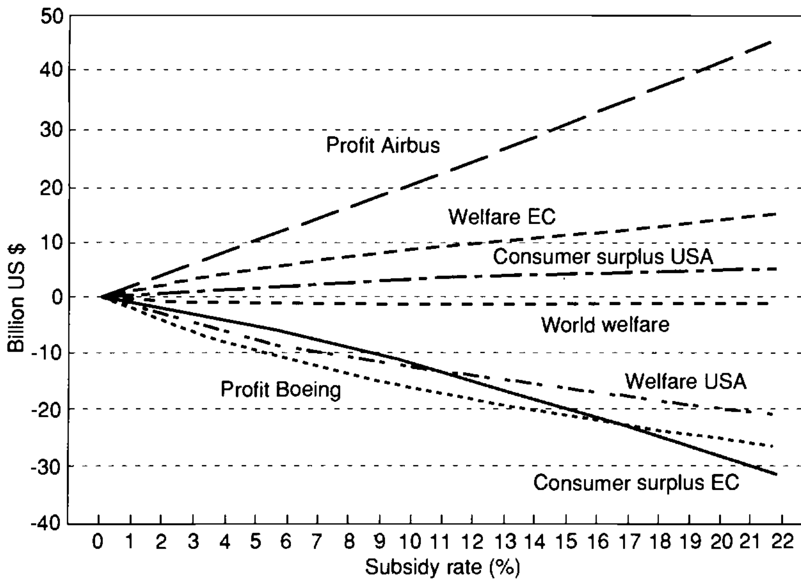

Fig. 5.3 Welfare effects of Airbus subsidies (simulation results)
Note: Consumer surplus EC is net of subsidy payments.

body and from 45 to 53 percent in the long-range market. Figure 5.3 summarizes the welfare effects of increased subsidization. Profits increase faster than subsidies, which does not come as a surprise since Airbus realizes learning effects through larger production, but since Boeing can sell fewer aircraft, prices fall only slightly. Subsidization, in a sense, induces a transfer of learning effects from Boeing to Airbus, leaving consumers relatively unaffected. European consumer surplus net of subsidy payments decreases, e.g., from $33 billion to $5.5 billion in the case of a 20 percent subsidy.

The effect on American and rest-of-the-world consumers and producers is essentially the opposite. There are small gains in consumer surplus due to a slight fall in prices both in the United States and the rest of the world. Boeing's loss in profits is larger than Airbus's profit increases net of subsidy payments. World welfare decreases by less than 1 percent.

Production subsidies have been varied over a large range, but there is no profit- or welfare-maximizing subsidy as in Brander and Spencer (1985). For subsidies higher than 22 percent no equilibrium can be simulated. The reason for this result is essentially the same as for the welfare effects of the market entry of Airbus in the previous section. Airbus profits net of subsidies as a function of subsidy rates are S-shaped, as shown in figure 5.4, with an inflection point around a subsidy rate of 10 percent. This, incidentally, is also the minimum of world welfare (fig. 5.4), and at this subsidy rate Airbus and Boeing have approximately equal market shares. The previous section showed that

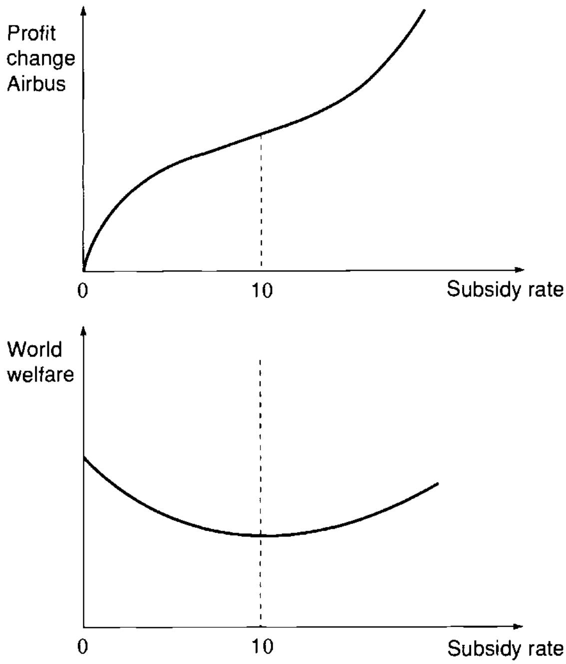

Fig. 5.4 Welfare effects of Airbus subsidies

a monopoly is in overall welfare terms superior to the current situation and even to a duopoly of two identical producers. Welfare effects of production subsidies follow the same logic. Increased subsidization of Airbus first leads to an equalization of market shares and therefore to higher unit cost on average. Hence, world welfare is reduced and the cost advantage of Boeing becomes smaller. Only when subsidization increases beyond 10 percent, does the difference in marginal cost become large enough to ensure that profits increase at a faster rate.

From both a pure profit-transfer perspective and a European welfare perspective, it would be advantageous to subsidize the domestic firm to such a degree that foreign competitors are driven out of the market. This particular simulation result for the aircraft industry depends predominantly on the assumed existence of large economies of scale and barriers to entry. Even though the market is large enough to support two firms—at least in the calibration of this model—a monopoly is superior to a duopoly in terms of world welfare. This result will most likely be true for industries with similar degrees of economies of scale. In that sense, there is a strong incentive to support domestic industry. Although in the present model Airbus is a producer with higher cost, it is advantageous to support the inefficient firm. These arguments, of course,

Table 5.5 **Market Structures with Optimal Production Subsidies**

European Community/ Airbus	United States/Boeing	
	Subsidize	Do not subsidize
Subsidize	?	Boeing monopoly
Do not subsidize	Airbus monopoly	duopoly (status quo)

remain valid only as long as retaliation from foreign governments is not considered.

5.5.3 Retaliation

The same logic according to which it is advantageous to subsidize Airbus applies, of course, to subsidizing Boeing, even more so since Boeing has lower unit cost because of learning effects from prior production. Both governments therefore have an incentive to subsidize their respective industries. The interaction of possible outcomes is shown in table 5.5.[3] Whether any government has a dominant strategy depends on the outcome of subsidization with retaliation.

In Brander and Spencer (1985) a Nash equilibrium in export subsidies exists. It is a prisoner's dilemma, since both countries could be better off by jointly reducing subsidy levels but would be worse off by unilaterally reducing subsidies. In the simulation model of this paper, an optimal unilateral subsidy level is not compatible with the existence of two firms. The same is true for retaliation against any subsidy that is low enough to allow both firms to stay in the market. Retaliatory subsidy rates also increase the welfare of the retaliating country up to the point where the foreign firm is driven out of the market. There is no Nash-duopoly equilibrium in government subsidies in this model, so if both governments subsidize, the question is which producer will survive.

Figure 5.5 shows the effects of subsidies on production. The curve labeled "Airbus subsidy effects" shows the different production equilibria traced out for different levels of unilateral production subsidy rates of Airbus by European governments, for a zero production subsidy rate to Boeing. As the European subsidy rate rises from 0 to 20 percent, Boeing output falls from nearly 5,000 to under 4,000, while Airbus output rises from around 3,500 to almost 5,500. The curve labeled "Boeing subsidy effects" shows the effects of varying the Boeing production subsidy rate from 0 to 3 percent, given an Airbus subsidy, which costs $14 billion; a 3 percent subsidy to Boeing, which will cost about $4 billion, will restore Boeing's output to presubsidy levels and therefore restore all of Boeing's learning advantages.

Airbus gains $10 billion of profits in comparison with the no-subsidy equi-

3. It is important to note that this comparison excludes all external economic or political costs of such governmental action.

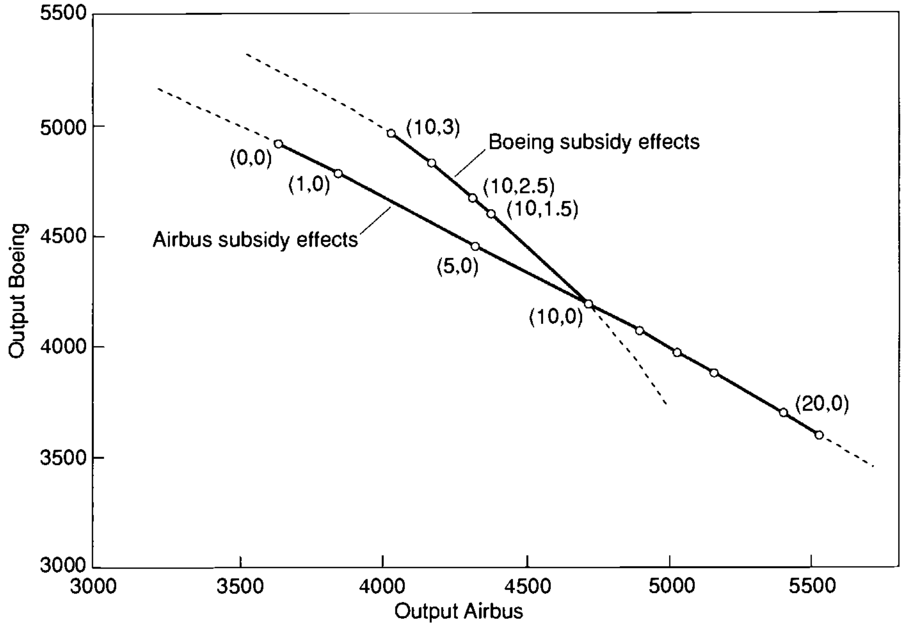

Fig. 5.5 Production effects of subsidies
Note: Numbers in parentheses denote subsidy rates for Airbus and Boeing, respectively.

librium, but the net loss to Europe is $4 billion. Faced with the threat of a Boeing subsidy, Europe does better to close Airbus down. Faced with the possibility of an Airbus production subsidy, the American government can credibly threaten to impose the relatively modest Boeing production subsidy that will make it optimal for Europe not to produce Airbus aircraft.

5.6 Conclusion

In this paper the allocation and welfare effects of industrial policy measures in an industry with strong economies of scale and high entry barriers have been investigated. Production of large transport aircraft has often been considered a prime candidate for the realization, similar to theoretical predictions, of potential welfare gains through industrial and trade policy measures. A stylized simulation model of competition in the aircraft industry is developed, focusing on two distinct industrial policy measures: first, European governmental support of the entry of Airbus Industrie in the market for large transport aircraft and, second, the potential impact of production subsidies, taking into consideration unilateral action as well as possible retaliation.

The welfare effects of government-supported market entry in the aircraft industry are somewhat difficult to interpret, because learning effects and economies of scope are so important that a monopoly would maximize world welfare—not considering distributional aspects. At the same time, the market is large enough to support two producers. It is also ambiguous which hypothetical situation the government-supported market entry of Airbus Industrie should be compared to.

When Airbus's entry is compared to a Boeing monopoly, overall welfare decreases. This is so because monopoly profits disappear, and, while consumers gain in all regions, they do so by less than the profit loss. The reason for this result is that scale and scope effects of producing large transport aircraft are strong enough to outweigh the output-reducing effects of a Boeing monopoly. From the viewpoint of European governments, Airbus's market entry as an "antimonopoly" policy was not successful. Only consumers in the rest of the world will gain. The negative welfare change is due to Airbus's inefficient scale of production relative to Boeing's and due to the high subsidies.

The negative welfare effects of Airbus's entry are even more pronounced when compared to a situation with two established American producers. Airbus's high-cost production yields higher welfare than a duopoly with two identical firms, because the scale effects of the large producer in the unequal situation dominate the competitive effects. Since consumers in all regions lose from Airbus's entry and the American producer, Boeing, gains more than American consumers lose, the market entry of Airbus yields a positive welfare change only in North America.

The basic logic behind these results is not peculiar to the aircraft industry. If economies of scale are large enough, a market structure with a small number of firms can emerge which is, in welfare terms, inferior to a monopoly. Because two or more firms can profitably stay in the market, economies of scale remain unexhausted and—at the same time—are larger than the losses in consumer surplus from monopoly pricing. In asymmetric situations—for example, one large and one small firm—scale effects also come into play. In a symmetric equilibrium, economies of scale are exploited to the least extent. The more asymmetric the equilibrium, the more consumers can gain from the realized economies of scale of the large producers and still have the more competitive output policy. This logic is present in the analysis of production subsidies as well.

Airbus, with a market share of about 30 percent, is the smaller firm. Unilateral subsidization of Airbus will reduce world welfare because of the scale effect just mentioned. The welfare minimum is indeed reached when both producers have approximately equal market shares. Beyond that point, it increases until the other producer leaves the market. Because overall welfare in a monopoly dominates oligopolistic industry structures and because it is usually newcomers and relatively small industries that are supported, the optimal subsidy is one which drives the other firm from the market, i.e., the Stackelberg-leader point is in a region of the other firm's reaction function in which it incurs losses.

With subsidization amounting to a monopolization of the market, retaliation is the natural consequence. The simulations show that the incumbent large firm, through small retaliatory subsidies, can easily be brought into a position where support by the foreign government can be neutralized. The ability and willingness to retaliate should therefore effectively threaten any desire to improve the market position of a small firm by subsidizing it.

This simulation study had to be based on extremely few observable parameters so that a number of educated guesses were necessary in order to attain the necessary degrees of freedom for calibration. The most crucial point is the demand elasticity which—compared to empirical predictions—must be higher for securing the existence of a Cournot-Nash equilibrium. If one takes this restriction as given, the sensitivity analysis of alternative values showed that there is only a very narrow range of elasticities for which equilibria exist and for which reasonable results of the calibration come out. Within this range, the welfare results of the simulation study remain robust, if not in their absolute value then in their distributional consequences. Within this Cournot-Nash capacity game framework, one can hardly come up with different welfare results. It remains to be explored, however, whether one can find a theoretical model which represents a reasonable capacity game and at the same time fits beliefs about demand elasticities for large transport aircraft.

Appendix

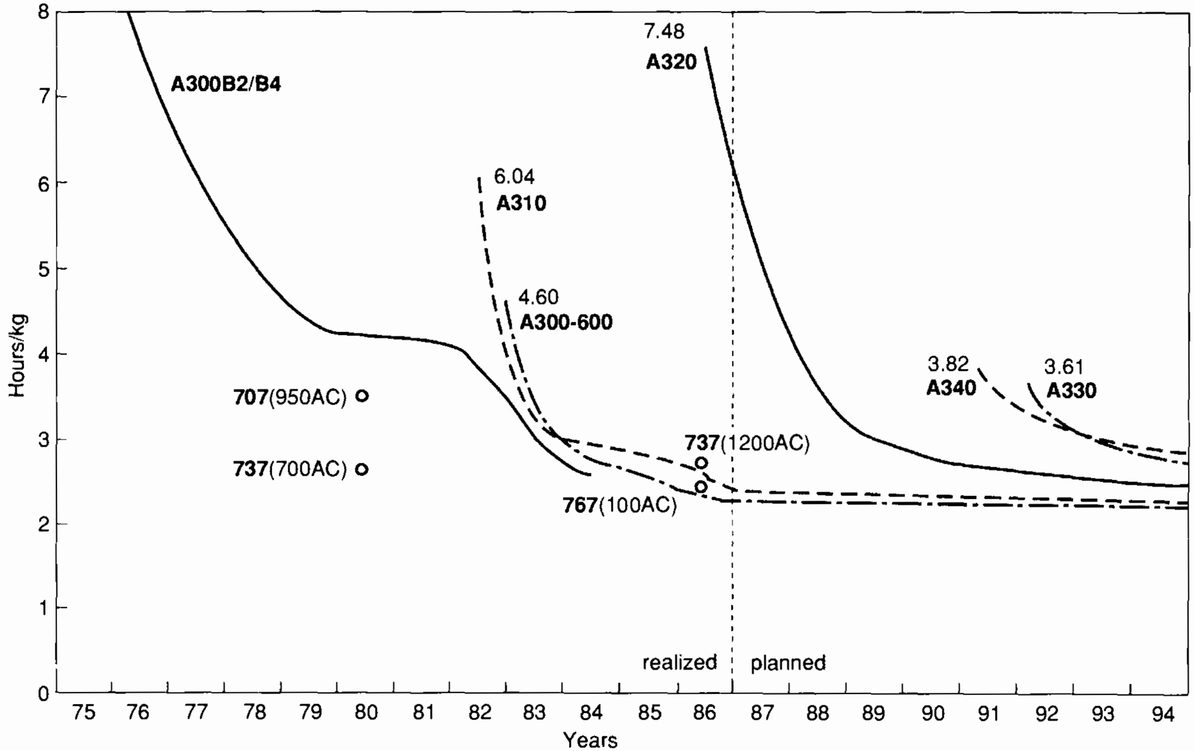

Fig. 5A.1 Learning curves for Airbus (MBB production share)
Source: Supplied by MBB, Germany.

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Comment Heather A. Hazard

The commercial aircraft industry presents a highly seductive case study in strategic trade policy. As one of the most concentrated industries in the world it is

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a clear example of a market shaped by "small numbers of large strategically self-conscious agents (firms and governments), [rather than] by large numbers of small agents competing at arm's length" (Richardson 1989, 1.1). In addition, the cast of characters has been stable (only one firm has exited and one firm has entered in the last 30 years), production is geographically concentrated, and product cycles are long. Despite these characteristics, researcher after researcher has been frustrated in his or her modeling attempts.

Formal modeling efforts have stalled and left us with a paucity of specific advice to offer policymakers. Policymakers, however, must move with the course of events and have had to deal with flare-ups in the GATT over Airbus subsidies, potential joint ventures between U.S. and European firms, and, intriguingly, a new partnership between Boeing and a Japanese consortium of Fuji, Kawasaki, and Mitsubishi. What roadblocks did the researchers run into? What questions might be tackled to assist policymakers?

Dixit and Kyle (1985) began the work on aircraft by setting up a dynamic oligopoly model with both firms and governments as players. They did not attempt to inject any empirical data into their modeling effort, however, and more insight was gained into potential welfare effects than how competition would actually ensue. Baldwin and Krugman (1988) followed with a Spence (1981) type learning curve model (modified to include fixed costs) but deprived the firms of the ability to act strategically (by having them assume the other firm's whole stream of output as given). Through this work they developed insights into the importance of consumer surplus in determining optimal policy and of dynamic economies of scale. They also discovered that they had limited the model unintentionally by neglecting a key aspect of the product: commercial aircraft are extremely durable capital goods. Krugman and Brainard (1988) attempted to overcome this and other problems of modeling demand (such as expectations regarding future products, implicit contracting, and oligopsonistic demand) by turning to a variant of Baumol, Panzar, and Willig's (1982) contestable markets approach. Rejecting the familiar models of competition, they were unable to run the standard simulations. The Krugman and Brainard approach appears to hold further potential to be exploited despite the remaining technical difficulties.

In the paper Klepper has presented here, he turns back to a track of Spence-style modeling he began in 1988. He focuses on economies of scale (both static and dynamic) and economies of scope as the key industry characteristics. Despite his effort to set up a sophisticated framework in which the long-run quantity game serves as a restriction on the short-run price game, his results are unsatisfying. He finds that if demand turns out to be larger than expected, firms will produce at their capacity limit and choose prices which maximize profits. This does not seem to be a good description of the behavior observed in 1989 when the three big producers held orders totaling an estimated $133 billion and yet margins in the industry were still thin.

We clearly need to push our models further, but in what directions? If researchers want to go on and enrich their models in ways that would increase their utility to policymakers, they might want to try and answer a number of questions, including:

1. How should the objective function of government be represented? Should it be restricted to maximizing consumer plus producer surplus and partial equilibrium, or expanded to include (i) technological spillovers from R&D, including learning of engineers about production, (ii) human resource development to encourage workers to invest in learning and to handle upswings in demand, (iii) national prestige (advertisement for technological capability), and (iv) national security?

2. How do we model governments? Should they be modeled as monolithic actors? Or should the United States be modeled as the executive branch and the Congress, for example, and the European Community as member governments and the Commission?

3. What is a subsidy? Is it building military planes first to create economies of scope for commercial aircraft? Building planes without contracts in hand and absorbing inventory costs? Covering exchange rate risk? Cross-subsidization from the military? Accumulated learning from earlier generations?

4. How do we model the buyers, the unions, or the engine suppliers? Do we give them market power or not? (I would argue that we should.)

5. How do we deal with the aging stock problem? We know we see old planes substituting for new planes when (i) fuel prices fall, (ii) capacity constraints combined with strong demand drive prices up, (iii) manufacturers start quoting long delivery lags, or (iv) demand profiles change (for size and length of haul).

6. What are the defects of the GATT Civil Aircraft Agreement? Does it need to be amended? How should it be amended? The heat of this long-standing international trade dispute varies by the state of industry.

7. Can we model the potential of Japanese entry?

This has been a long list of modeling questions but our modeling efforts to date have proved how difficult the competition in even a simple industry can be to penetrate. Fortunately, we have several modeling paths available to us as we continue.

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