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# 7 Strategic Manpower Policy and International Trade

David Ulph and L. Alan Winters

In many countries growing concern is being expressed about the position of skilled manpower—particularly of scientists and engineers. In some cases the complaint is about skill shortages, and in others about "brain drains"—the flow of highly trained manpower to other countries. While these are sometimes coupled as different facets of the same problem, the first phenomenon arises because of a "failure" of supply, while the second reflects a "failure" of demand.

Many arguments (not all very convincing) have been used to suggest that these phenomena are undesirable and that governments should develop policies to produce more skilled labor or better retain that which they already have. We focus on the argument that this skilled manpower is of strategic importance to an economy because it is essential to the performance of its "high-tech" sector. We will show that the recent work on strategic trade and industrial policy using models of international trade with imperfect competition and economies of scale provides a useful framework in which arguments about the scope and desirability of such manpower policies can be assessed and quantified. When calibrated, our model shows that manpower policies are potentially extremely powerful and important.

However, the focus of the paper is not really manpower policies, for we hope our analysis will demonstrate the crucial importance of understanding these

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manpower issues when formulating trade and industrial policies aimed at supporting a country's high-tech sector.

In section 7.1 we develop a model of an open economy with a high-tech sector in which skilled manpower is used in R&D to produce improved lower-cost techniques of production. There are three further crucial features of the high-tech sector. The market for the output of this sector is the world market, of which the particular economy is only a very small part. Because of the fixed costs of R&D there are only a few major international firms competing in this market, so it is inherently imperfectly competitive. However, because in R&D success breeds success, entry cannot prevent these major firms from enjoying supernormal profits or rents even after deduction of the costs of R&D. The simplest way of capturing this in our model is to operate with a fixed number of firms. Cantwell (1989a) provides the most recent evidence and a good discussion of this persistence phenomenon. Taken together these assumptions mean that the model is essentially one in which countries are in competition with one another through their manpower and industrial policies to get as large a share of these rents from the international market as they can.

This framework is essentially that used by Brander and Spencer (1983) in their argument for support of R&D. As is well known, there are a number of objections to the Brander and Spencer analysis. Dixit and Grossman (1986) show that it depends crucially on the assumption that scientific manpower is essentially in perfectly elastic supply to the high-tech sector. They show that if it is completely inelastic and immobile, then support to the high-tech sector has to be very carefully targeted to have a beneficial effect. While concerns over skill shortages are captured by the inelastic supply assumption, the "brain drain" phenomenon suggests that the immobility assumption is unrealistic. We show that if scientific manpower is mobile then, while support to any arbitrary high-tech industry could be damaging, a policy giving more general support to the high-tech sector as a whole will be beneficial. We extend this to consider the arguments for policy when it is science that is mobile, with companies setting up their R&D labs at centers where scientific manpower is concentrated.

These arguments for support of high-tech industries are tested by allowing for the possibility of international spillovers (in which case it may pay to free-ride on the R&D of other countries), and by having research undertaken by internationally mobile scientists while development is performed by immobile engineers. The final part of section 7.1 considers the nature of R&D policies and shows that if scientists are indeed mobile, then policies should be aimed at encouraging greater demand for them, and a policy of encouraging supply is positively harmful.

The model in section 7.1 is what is known in the R&D literature as a *non-tournament* model, in which each firm can pursue its own independent line of R&D. Even if one firm makes its discovery first and patents it, the lines of research are sufficiently different that this does not prevent other firms from successfully developing, patenting, and using their own discoveries. In section 7.2 we briefly consider what happens when R&D takes the form of a *tournament,* in which firms race to be the first to patent their discovery, because the patent prevents any other firms from exploiting its R&D. We show that many of the arguments of the nontournament model are reversed.

In section 7.3 we calibrate the model of mobile scientists developed in section 7.1 and show that R&D policy can be powerful. Thus a given amount of resources transferred as a subsidy to R&D can increase GNP by two-and-a-half times the amount transferred—an extremely high rate of return. Finally, in section 7.4 we present the evidence that is available on mobility and on spillovers. Unfortunately, none of this is in a form that would enable us to calculate an elasticity. Nevertheless, it does seem to suggest a fair degree of mobility and so, within our framework, definite scope for beneficial policy support of the high-tech sector.

## 7.1 Nontournament Models

### 7.1.1 The Basic Model

There are two countries, each having two sectors. In the first sector a homogeneous product is produced under constant returns to scale and perfectly competitive conditions using labor alone. Output is measured in such a way that one unit of output requires one unit of labor to produce it. Thus taking the output of this sector as numeraire, the wage rate of labor will be one.

In the second sector there are $n$ imperfectly competitive industries. In each industry production takes place under constant returns to scale using labor alone. For each industry there is a single firm in each of the two countries undertaking production in that industry. For country 1, $a_j$ represents the amount of labor required per unit of output; for country 2 the labor requirement is denoted by $b_j$. Given our previous assumptions, $a_j$ and $b_j$ also represent unit production costs in each of the two firms in industry $j$.

Given these unit production costs, the profits/rents accruing to country 1 in a Cournot equilibrium in industry $j$ are denoted by $r_j(a_j, b_j)$. Introducing the notation

$$r_{ja} \equiv \partial r_j/\partial a_j, \text{ etc.},$$

then standard models of imperfect competition suggest that the functions $r_j(\cdot,\cdot)$ will satisfy the following properties:

$$r_{ja} < 0,\ r_{jaa} > 0,\ r_{jb} > 0,\ r_{jab} < 0. \tag{1}$$

Thus an increase in the unit labor requirements of country 1 reduces its profits, but at a diminishing rate as these requirements get larger: if country 1's labor requirements are already large, then its market share will be small, and so further increases in its labor requirements will be less damaging than if its labor requirements had initially been smaller and market share consequently larger. An increase in country 2's unit production costs increases country 1's profits, while finally, the larger country 2's labor requirements are, the greater country 1's market share is, and so, again, the more it will be damaged by further increases in its own labor requirements.

We now assume that each firm's unit production costs/labor requirements depend on the amount of R&D it undertakes, while this in turn depends on the number of scientists/engineers it employs. Thus if we let $x_j$ be the number of scientists employed by the firm in the $j$th industry in country 1 and $y_j$ the number in country 2, then we assume that

$$a_j = a_j^0 - \phi_j(x_j), \text{ and}$$
$$b_j = b_j^0 - \psi_j(y_j),$$

where

(i) $\phi_j(0) = \psi_j(0) = 0;$

(ii) $\phi_j'(x_j) > 0, \psi_j'(y_j) > 0;$

(iii) $\phi_j''(x_j) < 0, \psi_j''(y_j) < 0;$

(iv) $\phi_j(x_j) < a_j^0$ for all $x_j$, $0_j(y_j) < b_j^0$ for all $y_j$.

If we let $c_j$ be the effective wage rate of a scientist/engineer faced by the firm in industry $j$ in country 1, then, taking the unit production cost in the firm in country 2 as given, $x_j$ is chosen to be

$$\max_{x \geq 0} r_j\left[a_j^0 - \phi_j(x_j), b_j\right] - c_j x_j.$$

Assuming that $\phi_j(\cdot)$ is sufficiently concave that the overall maximand is concave in $x_j$ and that we always have interior solutions then, the unique solution to the above maximization problem is characterized by the first-order condition (f.o.c.)

(2) $$- r_{ja} \cdot \phi' = c_j.$$

If $d_j$ denotes the effective wage rate of scientists in the $j$th industry in country 2, then the Nash equilibrium inputs of scientists in industry $j$ in the two countries will be functions of the effective wage rates of scientists in these two countries: $c_j$ and $d_j$. Write these as

(3) $$x_j = \xi_j(c_j, d_j), \text{ and}$$

(4) $$y_j = \eta_j(c_j, d_j).$$

Standard conditions suggest that for a wide class of cases

(5) $$\xi_{jc} < 0, \eta_{jd} < 0,$$

so an increase in each firm's costs of hiring scientists lowers its equilibrium input of scientists. In addition, we assume

$$(6) \qquad -\eta_{jd} > \xi_{jd} > 0, \; -\xi_{jc} > \eta_{jc} > 0,$$

so that an increase in a firm's costs of hiring scientists increases the demand for scientists by the other firm but by less in absolute magnitude then it reduces the firm's own demand, thus leading to a net fall in the demand for scientists.

In a similar vein we assume

$$(7) \qquad -\xi_{jc} > \xi_{jd} > 0, \; -\eta_{jd} > \eta_{jc} > 0,$$

so that if the costs of hiring scientists in both countries increase, then the cross-price effect of this is less than the own-price effect, leading to an overall reduction in demand.

Thus the fundamental determinants of the rents/profits earned by each country in any industry are the effective wage rates of scientists faced by that industry in each of the two countries. For through (3) and (4) these determine the number of scientists employed in that industry in each of the two countries: these determine the unit production costs $a_j$ and $b_j$, which in turn determine the rents.

Having set out the basic model we can now turn to a variety of policy issues. Throughout our analysis we will equate welfare with national income. This involves, among other things, following Brander and Spencer in assuming that all high-tech goods are exported. Thus we can ignore consumption distortions and terms of trade effects on consumers. We start with the standard Brander and Spencer result.

### 7.1.2 The Brander and Spencer Result

Suppose country 1 introduces an R&D subsidy in industry $k$, which we take to be a subsidy, $s_k$ to the costs of hiring scientists in industry $k$, $k \in \{1, \ldots, n\}$. What effect does this have on its welfare?

Implicit in the Brander and Spencer analysis is the assumption that the subsidy does not affect the (gross) prices at which industries in the high-tech sector can hire resources from the competitive sector. In our model this is equivalent to the assumption that labor and scientists are perfect substitutes.

Welfare in country 1 is given by income, which is labor income plus profits (rents minus costs of hiring scientists). Given the above assumption this can be written

$$W = L + \sum_j \{r_j[a_j^0 - \phi_j(x_j), b_j^0 - \psi_j(y_j)] - x_j\},$$

where $L$ is the total amount of labor, and we note that the profits of industry $k$ are the social profits—that is scientists are priced at their true cost (unity) since the subsidy is a pure transfer within the economy.

The $x_j$ and $y_j$ terms that appear in $W$ are determined by

(8) $$x_j = \xi_j(1, 1), j \neq k;\ x_k = \xi_k(1 - s_k, 1), \text{ and}$$

(9) $$y_j = \eta_j(1, 1), j \neq k;\ y_k = \eta_k(1 - s_k, 1).$$

So to determine the effect on welfare of an increase in $s_k$ evaluated at the point where $s_k = 0$, we differentiate $W$ totally w.r.t. $s_k$, using (8) and (9) to take account of how $s_k$ affects $x_k$ and $y_k$. Doing this, and recalling the f.o.c. (2), we get

(10) $$dW/ds_k = r_{kb} \cdot \psi_k' \cdot \eta_{kc},$$

which, from (1) and (6), is strictly positive.

The intuition behind the result is straightforward. The subsidy to the industry increases the amount of R&D the firm in industry $k$ in country 1 does and lowers the amount done in country 2. However, with $s_k$ initially zero, the firm in country 1 was doing the socially optimal amount of R&D, so increasing the amount it does has no first-order effect on welfare. But lowering the amount done in country 2 increases its costs, contracts its output, and so raises the price at which country 1 can sell its output, and this brings a first-order increase to the rents earned by country 1. Thus Brander and Spencer conclude that introducing an (R&D) subsidy into any imperfectly competitive high-tech industry is always beneficial.

### 7.1.3 The Dixit and Grossman Results

Dixit and Grossman argue that what makes these industries high-tech industries are essential inputs of "scientists" or "technologists," which are not used at all in sector 1, but are essential inputs to industries in sector 2. The critical feature which this introduces is that an industry in sector 2 cannot expand just by drawing in additional labor from the non-rent-generating sector 1, but now, assuming a fixed supply of scientists, will have to absorb additional scientists from other high-tech sectors, thus impairing their rent-generating capability.

To capture these ideas, Dixit and Grossman assume that labor and "scientists" are combined in fixed proportions in each high-tech industry. However, we have modeled the role of scientists more explicitly, and in terms of our model the essence of the Dixit-Grossman model is that scientists are no longer perfect substitutes for labor and have a separate endogenously determined gross wage rate. If we let $w$ be the wage of scientists in country 1 and $v$ their wage rate in country 2, then social welfare in country 1 can be written

(11) $$W = L + \sum_j r_j[a_j^0 - \phi_j(x_j), b_j^0 - \psi_j(y_j)],$$

where now, once we add the income of scientists to the profits of the high-tech industries, national income is just labor income plus rents, the question of who gets the rents being a distributional one of no direct relevance to total welfare.

Assuming once again that a subsidy $s_j$ is introduced into industry $j$, the number of scientists in each industry is given by

$$(12) \qquad x_j = \xi_j(w - s_j, v), \text{ and}$$

$$(13) \qquad y_j = \eta_j(w - s_j, v),$$

while the wage of scientists in country 1 is determined by the condition

$$(14) \qquad \sum_j \xi_j(w - s_j, v) = S.$$

Following Dixit and Grossman, we assume the wage of scientists in country 2, $v$, is fixed.

Now when we want to examine the effects of a subsidy on, say, industry $k$ alone we have to differentiate (11) totally w.r.t. $s_k$, taking account of how all the $x_j$, $y_j$, and $w$ vary through (12)–(14). Using the f.o.c. (2) we get

$$(15) \qquad dW/ds_k = (dw/ds_k)\left[\sum_{j=1}^{n} (w \cdot \xi_{jc} - r_{jb} \cdot \psi_j' \cdot \eta_{jc})\right] + \left(-w \cdot \xi_{kc} + r_{kb} \cdot \psi_k' \cdot \eta_{kc}\right),$$

while from (14),

$$(16) \qquad dw/ds_k = \xi_{kc}/\left(\sum_j \xi_{jc}\right) > 0.$$

The intuition behind (15) is as follows. The second term, in parentheses, on the right-hand side tells us that the subsidy has two direct effects. The first, represented by the last term, is just the Brander and Spencer effect already discussed. The second is that it expands the number of scientists in industry $k$ earning the rent $w$. However, because the number of scientists is fixed, the subsidy has the indirect effect of raising the wage rate of scientists, which will act like a tax on every high-tech industry, having precisely the reverse of these two effects on every industry. This is what the first term on the right-hand side of (15) shows.

The most important point to notice here is that, if we sum (16) over all $k$ we get

$$(17) \qquad \sum_{k=1}^{n} (dw/ds_k) = 1,$$

and so, on substituting (16) into (15) and summing over all $k$ we get

$$(18) \qquad \sum_{k=1}^{n} (dW/ds_k) = 0,$$

so that introducing a subsidy into all industries simultaneously just drives up the scientists' wage rate to exactly offset the effect of the subsidy, and so has no effect on any industry, or on welfare. But then, looking at subsidies on individual industries, there must be some industries for which a subsidy has positive welfare effects and others for which it is harmful. Thus while a carefully targeted subsidy can be beneficial, an arbitrarily chosen one may not be—the essential Dixit-Grossman conclusion.

### 7.1.4 Mobile Scientists

A key feature of the Dixit-Grossman model is the fact that scientists are internationally immobile, and so a country's expansion of one industry can only take place at the expense of another in that country. The frequently voiced concerns about "brain drains" suggests that this feature of the model may be crucially unrealistic, so it is interesting to explore the policy implications of allowing scientists to be internationally mobile.

We therefore adopt the alternative extreme assumption that scientists are perfectly mobile internationally. This has two immediate effects on our previous model:

1. In (12) and (13) $v = w$, as there is now a single international wage for scientists.

2. The scientists' resource constraint (14) now has to be written

$$(19) \qquad \sum_{j=1}^{n}\Big[\xi_j(w - s_j, w) + \eta_j(w - s_j, w)\Big] = S,$$

where now $S$ is the total supply of scientists in the world.

The formulation of the welfare function now needs some consideration. If we assume that the income of scientists accrues to the country in which they work, then the welfare function is once again given by (11). This assumption clearly reflects deeper underlying assumptions about both the behavior of scientists (not remitting their income home) and of the tax authorities (they cannot or do not tax the income of people working abroad, but can and do tax all the income of people working within their country). This latter statement is made in the context of our earlier assumption, in which we just equated welfare with GNP. When we move beyond that framework, we also have to confront more fundamental issues concerning what set of citizens is to be included in a nationalistic welfare criterion. An alternative assumption about where the income of scientists accrues will be considered in the next section.

Suppose then country 1 imposes a subsidy on industry $k$. What is the effect on welfare? Differentiating (11) totally w.r.t. $s_k$ gives

$$(20) \qquad dW/ds_k = (dw/ds_k)\left\{\sum_{j=1}^{n}\Big[w(\xi_{jc} + \xi_{jd}) - r_{jb}\cdot\psi_j'\cdot(\eta_{jc} + \eta_{jd})\Big]\right\} +$$
$$(-w\cdot\xi_{kc} + r_{kb}\cdot\psi_k'\cdot\eta_{kc}),$$

while, from (19),

$$(21) \qquad (dw/ds_k)\sum_j[\xi_{jc} + \xi_{jd} + \eta_{jc} + \eta_{jd}] = \xi_{kc} + \eta_{kc}.$$

The intuition behind (20) is precisely the same as for (15), the only difference being that the increase in the wage rate affects the equilibrium outputs by raising costs in both country 1 and country 2.

From (5), (6) and (21) it follows that

$$0 < dw/ds_k < 1,$$

and indeed that, if we define

$$\theta = \sum_{k=1}^{n} (dw/ds_k),$$

then $0 < \theta < 1$.

Moreover, summing over (20), we get,

$$\sum_{j=1}^{n}(dW/ds_j) = \theta\sum_{j=1}^{n} (w \cdot \xi_{jd} - r_{jb} \cdot \psi_j' \cdot \eta_{jd}) + (1 - \theta) \sum_{j=1}^{n} (-w \cdot \xi_{jc} + r_{jb} \cdot \psi_j' \cdot \eta_{jc}), \tag{22}$$

which, given our sign conventions in (1), (5) and (6), is strictly positive.

The intuition is that blanket subsidies to all high-tech industries in country 1 cause them to attract scientists from other parts of the world by increasing the wage rate. But, because there are scientists elsewhere, their wage does not have to rise by as much as the subsidy. This means that overall costs in country 1 do fall, which benefits the country. However, there is a second effect, which is that the rise in the international wage of scientists increases costs of production elsewhere, which is again to the benefit of country 1. Now, as in Dixit and Grossman, there is no guarantee that a subsidy to any given industry increases welfare, but, in contrast to their model, a general subsidy to the high-tech sector is warranted.

An important point about the results in this section is that although we have assumed that scientists are perfectly mobile internationally, in fact, any degree of mobility will be sufficient to generate the two effects of a blanket subsidy discussed above: that the wage of domestic scientists does not rise by as much as the subsidy and that there is an increase in the wage of overseas scientists. Hence any degree of mobility will suffice for a policy of blanket support to be beneficial.

Notice also that, as Dixit and Grossman themselves recognize, if there were some degree of internal supply elasticity of scientists, a policy of blanket subsidies could have positive welfare effects. However, the magnitude of the response could be different, because of the different effects of the subsidy on the wages of scientists in the overseas country. Also, as we show in section 7.8, the interpretation of policy can be very different when there is international mobility rather than internal supply elasticity.

### 7.1.5 Immobile Scientists, Mobile Science

An alternative possibility is that scientists are internationally immobile but that science is not—that is, that firms can buy scientific research from scientists located in other parts of the world. Given problems of confidentiality, this may entail locating an R&D lab in that other country—which appears to be what multinational corporations (MNCs) do (see section 7.4.2, below). Formally this is equivalent to the outcome that arises when scientists are mobile but either they remit their earnings home or else their "home" country can tax away their earnings. What are the policy implications of the possibility of mobile science?

We assume that science is perfectly mobile in the sense that it is perfectly homogeneous so that companies always buy their science at the lowest price, so once again the wage of scientists will be the same in both countries. If $S$ once again stands for the total number of scientists in both countries, while $S^1$ stands for those in country 1, then the overall scientist resource constraint is once again given by (19), while the equilibrium outputs of the various industries are once again given by (12) and (13), with $w = v$.

The main difference is that since country 1 is not confined to buying its science at home and its scientists are not confined to working for home industries, the welfare function becomes

$$W = L + \sum_j \{r_j[a_j^0 - \phi_j(x_j), b_j^0 - \psi_j(y_j)] - w \cdot x_j\} + w \cdot S^1.$$

We then find that

$$(23) \qquad dW/ds_k = (dw/ds_k) \cdot \left\{S^1 - \sum_j x_j - \sum_j [r_{jb} \cdot \psi_j' \cdot (\eta_{jc} + \eta_{jd}]\right\}$$
$$+ r_{kb} \cdot \psi_k' \cdot \eta_{kc},$$

where $dw/ds_k$ is once again given by (21) and so is positive. The last term on the right-hand side of (23) is the Brander and Spencer effect.

From (7) the last term in the braces is positive, reflecting the fact that all industries in country 1 gain because the increase in the wage induced by the subsidy forces all industries in country 2 to contract. Finally if $S^1 \geq \sum_j x_j$, meaning that the country is not a net importer of science, then driving the price of science up is not harmful.

We thus reach the conclusion that if the country is not a net importer of science, then a subsidy to any arbitrary high-tech industry is positively beneficial—which is the Brander and Spencer conclusion. However, if the country is a net importer of science, then even a uniform subsidy may not be desirable. A major determinant of whether or not a country is a net importer or exporter of science will be the number of scientists it has. In this case, to justify what is here a policy of encouraging the demand for scientists may only be appropriate if the supply has also been increased.

### 7.1.6 Distinguishing between Research and Development

In most of the economics literature, research and development are treated as a single process labeled R&D. However, in a number of contexts it is now being recognized that it is important to distinguish carefully between research and development as two distinct though interrelated features of the process of generating new products/technologies. This distinction could be particularly important in the context of the models discussed in the preceding two sections, for it might be that while the "scientists" who work on research are fairly mobile, the "engineers" who work on development are not. Equally, while it may be possible for companies to locate research labs abroad where the scientists are, development work must take place where production is to be carried out.

To explore the implications of this distinction we will now assume that research requires inputs of scientists, while development requires inputs of engineers, and that, in country 1 (resp., country 2), for every scientist employed in industry $j$, $\alpha_j$ (resp., $\beta_j$) engineers have to be employed. Thus there are fixed proportions in research and development, capturing the idea that the two are distinct and necessary phases of investment, and one cannot be substituted for the other.

Even though on the demand side, scientists and engineers may not be substitutable, it is always possible that they are perfect substitutes on the supply side—that essentially there is a pool of people who become either scientists or engineers, depending on which pays most. In this case nothing in our model would be affected. The more interesting case, then, is where scientists and engineers are imperfect substitutes on the supply side as well. We will assume that there is a fixed supply of scientists and a fixed supply of engineers.

Without working through the analysis formally, it is fairly clear from our earlier work that if both factors are internationally immobile then we will once again obtain the Dixit-Grossman results implying that subsidies are unlikely to be beneficial. On the other hand if both factors are perfectly mobile internationally we will replicate the results of section 7.1.4, and a general sector-wide subsidy to R&D will be beneficial.

Suppose then that scientists are internationally mobile, with world wage $w$, while engineers are internationally immobile, with a wage $v$ in country 1 and $v'$ in country 2. Since the income of engineers nets out from the profits of the firms, social welfare is once again given by (11). If we think of the government introducing a subsidy which either lowers the wage of scientists (in all industries) by an amount $s$, or the wage of engineers by an amount $\sigma$, then the resource constraints become

$$\sum_{j=1}^{n}\Big\{\xi_j[w - s + \alpha_j(v - \sigma), w + \beta_j v'] + \eta_j[w - s + \alpha_j(v - \sigma), w + \beta_j v']\Big\} = S,$$

and

$$\sum_{j=1}^{n}\alpha_j \cdot \xi_j[w - s + \alpha_j(v - \sigma), w + \beta_j v'] = E,$$

where $S$ is the world supply of scientists, and $E$ is the supply of engineers in country 1.

If we just differentiate these two equations, it is easily seen that $dw/d\sigma = 0$ and $dv/d\sigma = 1$, so an attempt to subsidize the demand for engineers just drives up their wages to exactly offset the subsidy and has no welfare gain at all. Thus we get the Dixit-Grossman result again.

A subsidy to the use of scientists has more complex effects. However, one special case is where $a_j = a$ for all $j$. In this case $dw/ds = 0$ and $dv/ds = 1/\alpha$, so the wage of engineers rises to exactly offset the subsidy to scientists, and we once again get the Dixit-Grossman results. The intuition is clear. The mobility of scientists is irrelevant when faced with completely immobile engineers who are required in a fixed ratio to scientists.

When the $a_j$ are not uniform there will be some cases where a general subsidy to scientists is beneficial and some where it is not, but the information required to determine when these cases arise will be difficult to obtain. The general conclusion then is that policies of subsidy are not a good idea when there is some irremovable fixity of supply, however much flexibility there might be elsewhere.

### 7.1.7 Spillovers

In the literature on spillovers it is generally argued that the presence of spillovers is a reason why the private rate of return to R&D is less than the social rate of return, so there is a justification for policy intervention to encourage firms to undertake R&D. However, strictly speaking, this only applies to a closed economy. In terms of our model this could be interpreted as the case where the spillovers occur purely within each country, and, given that there is only one firm in each industry, these would then be pure interindustry spillovers. Since this case is familiar we will not analyze it formally here.

An alternative case that we *will* consider here is where the spillovers are purely intraindustry, but cut across national boundaries. As is intuitively obvious, and as we will show, such spillovers could provide a reason for *not* undertaking a policy of supporting domestic R&D, essentially because the country could free-ride on R&D being undertaken elsewhere. These two cases by no means exhaust all the possibilities, but it is clear that in general how far spillovers provide a rationale for supporting R&D is going to depend on the balance between internal and external spillovers.

We can capture the presence of intraindustry cross-national spillovers by assuming that now

(25) $\qquad a_j = a_j^0 - \phi_j(x_j + \beta_j \cdot y_j)$ and $b_j = b_j^0 - \psi_j(y_j + \beta_j \cdot x_j)$,

where $\beta_j$, $0 \leq \beta_j \leq 1$, is the degree of spillover in industry $j$.

We assume that spillovers are recognized by firms in each country, so that, for example, the first-order condition for choice of $x_j$ is now

$$-(r_{ja} \cdot \phi_j' + \beta_j \cdot r_{jb} \cdot \psi_j') = c_j, \tag{26}$$

with an analogous condition for the firm in country 2.

We assume that the cross-effects of the spillovers are not sufficiently strong to offset the direct effects, so that once again there are interior solutions for $x_j$ and $y_j$ and all the properties of the scientists' demand functions, $\xi_j(\cdot,\cdot)$ and $\eta_j(\cdot,\cdot)$, continue to hold.

Then it is easily seen that in the Brander and Spencer case the effect of introducing a subsidy to the $k$th industry in country 1 is given by

$$dW/ds_k = (\beta_k \cdot r_{ka} \cdot \psi_k' + r_{kb} \cdot \psi_k') \cdot \eta_{kc}. \tag{27}$$

Given our assumptions that own-effects dominate cross-effects then it is possible that for sufficiently large values of $\beta_k$ the term in parentheses in (27) could be zero or negative, thus negating even the basic Brander and Spencer argument for subsidies.

### 7.1.8 The Nature of Policies

So far we have talked rather vaguely about the government adopting a policy of subsidizing R&D in either one or all high-tech industries without its being very clear what the nature of this subsidy is. Formally we have treated it as something which just lowers the effective cost of scientists. It might be thought that this could encompass a number of different policies, such as allowing companies a more generous provision to write off R&D expenditures for tax purposes, explicit cooperative ventures with government, R&D expenditures by government that generates significant spillovers to the private high-tech sector, or a policy of generous grants to students to become scientists, thus lowering the costs of scientists to private industry. The point we wish to make here is that, while in a closed economy it probably does not matter very much which of these policies are adopted, in an open economy with mobile labor it matters a great deal. The essential point is that the fundamental market failure that generates the rationale for policy in all of these models is that, due to its imperfectly competitive nature, the private sector does not sufficiently expand its production. Consequently, it insufficiently expands its use of R&D and hence its demand for scientists. Fundamentally it is this lack of demand that has to be tackled.

While in a closed economy this lack of demand can be cured by reducing the cost of training scientists and hence encouraging firms to use more of them, in an open economy with mobile scientists this policy is disastrous because it simply lowers the cost of scientists to the rival country conferring to it all the benefit.

To demonstrate this more formally we need to extend our analysis to model more explicitly the decision to undergo training to become a scientist. Suppose then we have a pool of labor $L$. A worker in this pool can either remain an unskilled worker getting a wage of 1, or else become a scientist. To do this she has to spend a proportion $\pi$ of her working life in training, during which she earns nothing and incurs recurrent costs $c$, but then earns $w$ for the remaining proportion of her working life. Clearly this will be worthwhile only if $(1 - \pi)w - \pi c > 1$, that is, if $\pi < (w - 1)/(w + c)$.

We assume that people differ in their ability to become scientists, which we capture by their having different values of $\pi$, which we assume to be distributed in the population according to the density function $F(\cdot)$. Given $w$, the critical value of $\pi$ at which an individual is indifferent between becoming and not becoming a scientist is

$$\hat{\pi}(w) = (w - 1)/(w + c). \tag{28}$$

With these changes, then, assuming once again that scientists are perfectly mobile, social welfare becomes

$$W = L[1 - F(\hat{\pi})] - Lc\int_0^{\hat{\pi}} \pi dF + \sum_{j=1}^{n} r_j[a_j^0 - \phi_j(x_j), b_j^0 - \psi_j(y_j)].$$

If we consider first the case where there is a uniform subsidy $s$ to the *demand* for scientists, then the international wage of scientists is determined by the resource constraint

$$\sum_{j=1}^{n}[\xi_j(w - s, w) + \eta_j(w - s, w)] = L\int_0^{\hat{\pi}} (1 - \pi)dF + S_2(w), \tag{29}$$

where $S_2(w)$ is the supply of scientific manpower from country 2, and we assume $dS_2/dw \geq 0$.

Proceeding as before in section 7.1.4 we find that

$$dW/ds = \theta w dS_2/dw + (1 - \theta)\sum_{j=1}^{n}(r_{jb} \cdot \psi' + w)\eta_{jc} - \theta\sum_{j=1}^{n}(r_{jb} \cdot \psi' + w)\eta_{jd}.$$

If we compare this with (23) we see that the only difference from our previous analysis is that there is now an additional potential gain to country 1 from its subsidy policy, because the higher wage of scientists could induce additional supply from country 2. Although this also induces more supply from country 1, since the individuals who are affected were initially indifferent between becoming a scientist and not, this additional supply confers no welfare gain.

An alternative policy could be to subsidize the *supply* of scientists which we could interpret as a reduction in $c$. Thus, now

$$\hat{\pi} = (w - 1)/(w + c - s). \tag{30}$$

With an appropriate adjustment to the resource constraint (29) to take account of the fact that there is no longer a demand subsidy, we find

$$(31) \qquad dW/ds = dw/ds\left[w \cdot dS_2/dw - \sum_{j=1}^{n}(r_{jb} \cdot \psi' + w)(\eta_{jc} + \eta_{jd})\right].$$

Given our sign conventions the term in square brackets is unambiguously positive, but it is easy to see that $dw/ds < 0$, since encouraging supply lowers the wage, so the policy of subsidizing the supply of scientists is unambiguously harmful. It both reduces the supply of scientists from country 2 and lowers the cost of R&D for all the rival industries. Thus if scientists are internationally mobile, policies should be targeted at increasing demand for them, not their supply.

## 7.2 Tournament Models

### 7.2.1 The Basic Model

Here we just sketch the outlines of the model. The details are given in Beath, Katsoulacos, and Ulph (1989). Since the issues we wish to discuss in this section arise even if there is a single industry, we will confine attention to the case of a single industry and drop all subscripts. Thus the two firms in countries 1 and 2 (which we will call firms 1 and 2) have initial unit costs $a$ and $b$, respectively. They compete to discover a new technology with unit costs $c < \min(a, b)$. Whichever firm discovers this first obtains an infinitely lived and effective patent on this new technology, so there is a single prize to be won, which is what gives this model its tournament structure.

To discovery this new technology firms commit resources to R&D (hire scientists). Conditional on no one having discovered by $t$, the probability that a firm will discover in the time interval $(t, t + dt)$ depends on the flow rate of resources it devotes to R&D (number of scientists hired) at $t$—so there is no learning by doing. Thus the problem is stationary in that if one firm chooses to commit a constant flow rate of resources to R&D, the optimal response of the other is to also commit a constant flow rate. The constant flow rate of scientists hired by firm 1 will be denoted by $x$, that by firm 2 by $y$. For simplicity we will assume that the hazard rate corresponding to $x$ ($y$) is just $\sqrt{x}$ ($\sqrt{y}$), so there are diminishing returns to R&D.

There are two factors which completely determine the nature of firm 1's reaction function—optimal choice of $x$ for any given choice of $y$. The first is the *profit incentive.* This is the optimal choice of $x$ if $y$ is zero. Denote this by $x_0$. Since, if $y$ is zero, the only consideration affecting the choice of $x$ is balancing off the increased gain from bringing forward the likely date of discovery of the new technology against the increased costs, in terms of scientists, of doing so, the major factor determining the size of the profit incentive is the difference between profits from successfully obtaining the new technology and those currently being earned: $r(c,b) - r(a,b)$.

The second factor determining the nature of the reaction function is the amount of R&D firm 1 would do as $y \rightarrow \infty$. Denote this by $\bar{x}$. This factor we call the *competitive threat* since, as $y \rightarrow \infty$, firm 2 will almost surely innovate immediately. Given the inherently random nature of discovery, if firm 1 commits some resources to R&D there is still a chance that, even with $y \rightarrow \infty$, it could win the race. Balancing off the costs and benefits, it is clear that the major factor determining the amount of resources to spend on R&D is the difference between firm 1's rents if it successfully innovates first and those it would earn if firm 2 innovates first: $r(c, b) - r(a, c)$.

It turns out that in the absence of imitation or spillovers the competitive threat is typically greater than the profit incentive, giving rise to a reaction function for firm 1 like that shown in figure 7.1. There are two points to notice about this reaction function. The first is that $x$ is increasing in $y$, for if stopping firm 2 from winning is a more important objective than bringing forward the likely date of innovation, then clearly firm 1 will respond to an increase in firm 2's R&D spending by increasing its own. The second is that as we move along the reaction function, the expected present value of firm 1's profits are falling as $y$ (and hence $x$) increases. The amount $x_0$ effectively represents the profit-maximizing value of $x$ arrived at by balancing off the gains from having the new technology by a particular date against the costs of doing so. Thus moving along the reaction function from $x_0$ to $\bar{x}$ is to move further and further from the profit-maximizing position.

### 7.2.2 Brander and Spencer Revisited

To see the effects of introducing a subsidy to R&D costs in country 1, we first need to consider the reaction of country 2. Once again, in the absence of

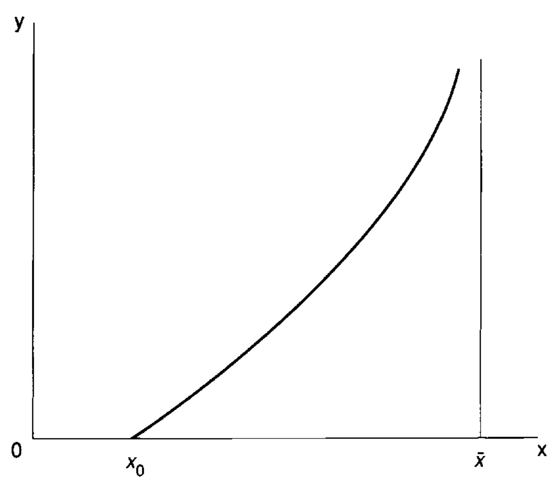


**Fig. 7.1 Reaction function of country 1**

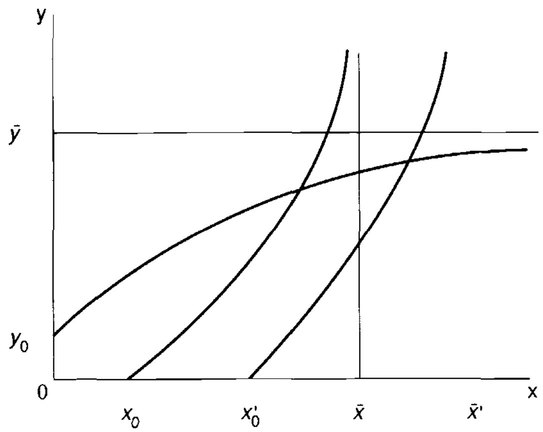


**Fig. 7.2 Effect of R&D subsidy in country 1**

imitation and spillovers, it is likely to have a greater competitive threat than profit incentive, and so to have a reaction function like that shown in figure 7.2.

Now a subsidy to R&D will shift country 1's reaction function out as shown in figure 7.2, leading to higher equilibrium values for $x$ and $y$, though, since the ratio of $x$ to $y$ has increased, firm 1 is relatively more likely to innovate first. However, since this subsidy is a pure internal transfer, the gain to the country from introducing it has to be evaluated using the iso-profit functions relevant to generating the initial reaction function for firm 1. Since the original choice of $x$ was profit-maximizing given the original equilibrium value of $y$, then, just as in Brander and Spencer, to first order the increase in the equilibrium value of $x$ has no welfare gain. The only effect of the subsidy comes from the induced impact on $y$, and since $y$ increases, and since we know profits fall as $y$ increases, the subsidy definitely harms country 1.

Essentially both countries are indulging in wasteful overinvestment in R&D in a bid to stop the other from innovating first, and all the subsidy does is intensify this wasteful competition. Thus in a wide class of cases even the standard Brander and Spencer result fails to go through. Since, as we saw, this effect enters the formulae in all the cases where the availability of scientists is an issue, the case for R&D subsidies is likely to be problematic in those cases, too, whenever innovation takes the tournament form of a race to be first.

### 7.2.3 Spillovers in a Tournament Model

The above results were based on a tournament model where there were no spillovers, and consequently competitive threats were likely to exceed profit incentives for both firms. When there are spillovers then the competitive threats and profit incentives facing firm 1 become:

competitive threat: $(1 - \beta)[r(c, b) - r(a, c)]$, and
profit incentive: $\{[r(c, b) + \beta \cdot (a, c)]/(1 + \beta)\} - r(a, b)$.

The intuition is as follows. Consider what happens as $\beta \rightarrow 1$. The fact that $y \rightarrow \infty$ is now likely to benefit firm 1 almost as much as firm 2, while any R&D undertaken by firm 1 will add effectively the same (infinitesimal) amount to the likely success of both firms. Firm 1 is therefore just as likely to innovate almost surely now as firm 2, whatever R&D it does, and therefore faces effectively no competitive threat and consequently finds it not worthwhile to do any R&D.

On the other hand, if $y = 0$, then, as $\beta \rightarrow 1$, any R&D done by firm 1 will not just bring forward the expected date of innovation, but is as likely to make firm 2 the winner as firm 1. Thus the likely gain it gets from bringing forward the date of innovation is the difference between the average of the profits it gets if it wins and if it loses and its current profits.

Thus profit incentives and competitive threats are affected in an asymmetric fashion by the presence of spillovers. To see the implications of this, consider the case where firm 1 is currently very far behind firm 2, and there is a new innovation which gives a moderate advantage over the technology currently employed by firm 2. Indeed assume that firm 1 is so far behind that its current profits and those it gets if it loses are zero. However, if it wins it will face reasonably intense competition from firm 2, but will still make positive profits. Essentially then the profits that enter the determination of its competitive threat are $(1 - \beta)\cdot r(c, b)$, while those that affect its profit incentive are $[r(c, b)/(1 + \beta)]$. As long as $\beta$ is large enough, its profit incentive exceeds its competitive threat, while, as long as $\beta < 1$, both are positive. Its reaction function is now as shown in figure 7.3.

The important points to notice about this are: (i) now the larger $y$ is, the smaller the amount of R&D firm 1 does, since it can use the spillovers to free-ride on firm 2's R&D effort, and (ii) now the expected present value of profits made by firm 1 are increasing in $y$ as we move along the reaction function from $x_0$ to $\bar{x}$—again because it can substitute firm 2's R&D spending for its own while keeping the likely date of innovation more or less constant.

Consider firm 2. It too will have a positive competitive threat since it stands to lose its monopoly position if firm 1 innovates ahead of it. However, since the innovation is fairly moderate, its profits from winning may not greatly exceed its current profits, while given the large amount of competition it will face if firm 1 innovates ahead of it, its profits if it loses may be considerably less than its current profits. Thus if $\beta$ is large enough, the profits that enter the calculation of its profit incentive could be very small, if not zero or negative. In any event, it is likely to have a competitive threat that exceeds its profit incentive, as is illustrated in figure 7.3. But now an R&D subsidy to firm 1 is beneficial, for it once again expands the equilibrium values of $x$ and $y$, and, while the expansion in $x$ has, to first order, no effect on country 1's welfare, the expansion in $y$ is, as we have seen, now positively beneficial, since it allows country 1 to free-ride on country 2's R&D effort. Thus with tournament models, and with initially very asymmetric firms, large spillovers can actually be a

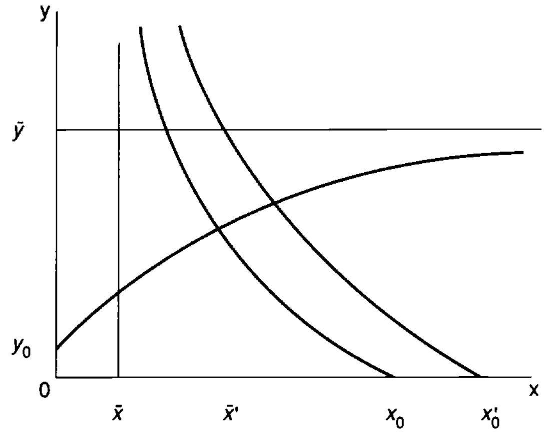


**Fig. 7.3 Effect of R&D subsidy in country 1 with spillovers**

reason for R&D subsidies. Thus arguments about the desirability of R&D subsidies depend rather crucially on the kind of innovation that takes place in any given industry.

Note that while the analysis in this section bears some resemblance to the contrast in policy conclusions one obtains when policy is conducted in the context of a Cournot model (with downward-sloping reaction functions) as against a Bertrand model (upward-sloping reaction functions), what this analysis shows is that policy depends on more than just knowing whether reaction curves are upward-sloping or downward-sloping. We also need to know how profits move along the relevant curves. Thus here subsidies are harmful whenever reaction curves have the *same* slope—whatever that is.

## 7.3 Measuring the Gains to R&D Policy

In this section we show how the model proposed in section 7.1 can be used to quantify the gains to R&D policy. We concentrate on the case where scientists are completely mobile and the government introduces a uniform R&D subsidy. As we saw there, the effects of such a subsidy are obtained by summing the effects on each industry, so there is no loss of generality if, to simplify the discussion, we concentrate on the case where the high-tech sector comprises a single representative or average industry.

However, for reasons that will become apparent, it is important that we generalize the model in section 7.1 to allow the possibility that there are $n$ different countries or firms competing in this industry. We also focus throughout on the case where initially the industry is in a symmetric equilibrium, and one government introduces a subsidy. This is because all the elasticities we need become far more complex in asymmetric equilibria, and, although we could probably perform all the calculations using numerical methods, we simply do not have enough data to calculate them.

### 7.3.1 The Model

Suppose we have a single industry where demand is given by

$$p = A \cdot Q^{\varepsilon}, \tag{32}$$

where

$$Q = \sum_{i=1}^{n} q_i. \tag{33}$$

Here $A > 0$ is a parameter measuring the size of the market, $q_i$ is the output of firm $i$, and $\varepsilon > 0$ is the inverse elasticity of demand. For the moment we will assume that since this is an imperfectly competitive industry $\varepsilon < 1$.

Although the initial equilibrium is symmetric we need to explore the consequences of having an asymmetry introduced via government policy pursued in country 1 which could give the firm there an R&D and hence a production cost advantage. Let us assume therefore that unit costs are $a$ in firm 1 and $b$ in firms 2 to $n$. For an interior solution we have the following first-order conditions for profit maximization:

$$A \cdot Q^{-\varepsilon} - A \cdot \varepsilon \cdot q_1 \cdot Q^{-(1+\varepsilon)} - a = 0, \tag{34}$$

and

$$A \cdot Q^{-\varepsilon} - A \cdot \varepsilon \cdot q_i \cdot Q^{-(1+\varepsilon)} - b = 0, i = 2, \ldots, n. \tag{35}$$

Adding gives

$$(n - \varepsilon)A \cdot Q^{-\varepsilon} = a + (n - 1) \cdot b. \tag{36}$$

Now the profits of firm 1, $r$, are

$$r = (A \cdot Q^{-\varepsilon} - a) \cdot q_1.$$

So, from (36), the profits to sale ratio,

$$r/(p \cdot q_1) = (p - a)/p = [(n - 1) \cdot (b - a) + a\varepsilon]/[a + (n - 1)b], \tag{37}$$

which, in a symmetric equilibrium, gives

$$r/(p \cdot q_1) = \varepsilon/n. \tag{38}$$

If we now introduce the notation

$$B = (1/\varepsilon) \cdot A^{1/\varepsilon} \cdot (n - \varepsilon)^{(1/\varepsilon)-1}, \tag{39}$$

then it is easy to show that the profits of firm 1, $r$, are given by

$$r = B \cdot [(n - 1) \cdot b - (n - 1 - \varepsilon) \cdot a]^2 \cdot [a + (n - 1) \cdot b]^{-(1+\varepsilon)/\varepsilon}. \tag{40}$$

From this we get

$$\frac{\partial ra}{\partial ar} = -a\left\{[2(n-1-\varepsilon)]/[(n-1)b-(n-1-\varepsilon)a] + \right.$$

$$\text{(41)} \qquad \left.(1+\varepsilon)/\{\varepsilon[a+(n-1)b]\}\right\} < 0,$$

$$= -\{[2(n-1)n+1]-(2n-1)\varepsilon\}/n\varepsilon, \text{ when } a = b,$$

and

$$\frac{\partial rb}{\partial br} = b \cdot \left\{2/[(n-1)b-(n-1-\varepsilon)a] - \right.$$

$$\text{(42)} \qquad \left.(1+\varepsilon)/\{\varepsilon[a+(n-1)b]\}\right\}$$

$$= [2n-1-\varepsilon]/n\varepsilon, \text{ when } a = b.$$

Here the interpretation of $\partial r/\partial b$ is the increase in firm 1's profits if the unit costs of *one* of the remaining $n - 1$ firms were to increase. If they all increased then we would simply multiply the above formulae by $n - 1$.

For later purposes it is also worth reporting that, when $a = b$, then

$$\text{(43)} \quad a \cdot r_{aa}/r_a = -(1/\varepsilon) \cdot \left\{(n-1-\varepsilon) + [(1+2\varepsilon)/n] + \right.$$

$$\left.[(n-1-\varepsilon)(1-\varepsilon)]/[2(n-1)(n-\varepsilon)+(1-\varepsilon)]\right\},$$

and

$$\text{(44)} \qquad b \cdot r_{ba}/r_a = (1/\varepsilon) \cdot \left\{1 - [(1+2\varepsilon)/n] + [1+\varepsilon(2n-1)\right.$$

$$\left.-2\varepsilon^2]/[2(n-\varepsilon)(n-1)+(1-\varepsilon)]\right\}.$$

Note that, from (43), $r_{aa} > 0$, so that, at least in the neighborhood of a symmetric equilibrium, $r$ is convex in $a$. Of course it has to be convex at some point in its range, since profits decrease to zero at a finite value of $a$. But this means that the more that is spent on R&D to lower costs, the more worthwhile it becomes to further lower them. Nor is this a peculiarity of the particular model we have employed, but must be true of any model where firm 1's profits go to zero if its costs get too far out of line with those of the other firms. This implies that to get a well-defined story of R&D spending we are going to have to make the R&D costs of lowering production costs rise very fast. So let us assume

$$\text{(45)} \qquad a = a^0 \cdot x^{-\gamma},$$

where $x$ is the amount of R&D done by firm 1. This functional form is used in much of the empirical literature on estimating the effects of R&D on output and productivity. Later we will call on this literature for an estimate of $\gamma$. If the price of R&D for firm 1 is $c$, then the cost of achieving unit production costs $a$ is

$$C(a) = c \cdot (a^0/a)^{1/\gamma}. \tag{46}$$

If we now think of firm 1 taking $b$ as given and choosing $a$ to maximize

$$r(a,b) - C(a)$$

then this produces the first-order condition

$$-\partial r/\partial a = (c/\gamma) \cdot (a^0)^{1/\gamma} \cdot a^{-(1+1/\gamma)}. \tag{47}$$

It is easy to check that in order to have the second-order conditions for a maximum satisfied we need

$$\alpha \equiv 1 + (1/\gamma) + (a \cdot r_{aa}/r_a) > 0. \tag{48}$$

From (43) it follows that this will not be true for any arbitrary positive value of $\gamma$ and that we will need $\gamma$ to be suitably small, as we would have expected from the previous discussion.

It is easy to check that if (48) holds then

$$\partial a/\partial b < 0, \text{ and} \tag{49}$$

$$\partial a/\partial c > 0, \tag{50}$$

so that, from (49) an increase in R&D by one of the other firms, which lowers its unit costs, causes firm 1 to cut back on its R&D, giving it higher unit costs, while, from (50), an increase in the price firm 1 has to pay for its science causes it to do less R&D and so have higher unit costs.

We assume now that firms 2 to $n$ have the same R&D cost function, the same initial costs $a^0$, and all face the same price, $d$, for science. Initially we will start with $c = d$, so that we will indeed have a symmetric equilibrium, and we will examine the effects of policies that lower $c$.

To examine the effects of such a policy let us introduce the notation

$$\beta = b \cdot r_{ba}/r_a, \tag{51}$$

and

$$\Delta = (n - 2)\alpha\beta + \alpha^2 - (n - 1)\beta^2. \tag{52}$$

It is easily checked that a sufficient condition for the reaction functions to intersect in the right way and produce a stable (symmetric) equilibrium is that

$$\Delta > 0, \text{ or, equivalently, } \alpha > \beta. \tag{53}$$

It is also easily verified that

$$\frac{\partial a}{\partial c}\frac{c}{a} = [(n - 2)\beta + \alpha]/\Delta > 0, \tag{54}$$

and

$$\frac{\partial b}{\partial c}\frac{c}{b} = -\beta/\Delta < 0. \tag{55}$$

Thus in the full Nash equilibrium it is still the case that a rise in the price of firm 1's science causes it to do less R&D and so have higher unit costs, while it causes firms 2 to $n$ to do more R&D and so have lower unit costs. By symmetry the effect of an increase in $d$ on $b$ is the same as the effect of $c$ on $a$, while the effect of an increase in $d$ on $a$ is the same as the effect of $c$ on $b$.

### 7.3.2 Calibrating the Effects of Policy

The policy effects we want to calibrate are those arising from the mobile-scientists case, assuming that there is just one industry, but allowing now for $n$ firms in the industry.

We know that when there are just two firms the effect of introducing a small subsidy is given by

$$\frac{dW}{ds} = -(1-\theta)\left(\frac{\partial r}{\partial a}\cdot\frac{\partial a}{\partial c} + \frac{\partial r}{\partial b}\cdot\frac{\partial b}{\partial c}\right) + \theta\left(\frac{\partial r}{\partial a}\cdot\frac{\partial a}{\partial d} + \frac{\partial r}{\partial b}\cdot\frac{\partial b}{\partial d}\right),$$

where $\theta = dw/ds$. More generally we have

$$\frac{dW}{ds} = -(1-\theta)\left[\frac{\partial r}{\partial a}\cdot\frac{\partial a}{\partial c} + (n-1)\frac{\partial r}{\partial b}\cdot\frac{\partial b}{\partial c}\right] +$$
$$\theta\left\{(n-1)\frac{\partial r}{\partial a}\cdot\frac{\partial a}{\partial d} + (n-1)\frac{\partial r}{\partial b}\cdot\left[(n-2)\frac{\partial b}{\partial c} + \frac{\partial b}{\partial d}\right]\right\}.$$

Now it is easy to check that, given symmetry, $\theta = 1/n$. We also exploit symmetry to write $\partial a/\partial c = \partial b/\partial d$, $\partial b/\partial c = \partial a/\partial d$, and to evaluate everything at a symmetric equilibrium where $a = b$ and $c = d = w$, the wage of scientists. We then get, after some rearranging

$$w\cdot\frac{dW}{ds}\cdot\frac{1}{W} = \frac{r}{W}\cdot\frac{(n-1)}{n}\cdot\left(\frac{\partial r}{\partial b}\cdot\frac{b}{r} - \frac{\partial r}{\partial a}\cdot\frac{a}{r}\right)\cdot\left(\frac{\partial a}{\partial c}\cdot\frac{c}{a} - \frac{\partial b}{\partial c}\cdot\frac{c}{b}\right). \tag{56}$$

If, instead of a uniform absolute subsidy $s$, we had thought of a proportional subsidy, $\tilde{\sigma}$, where $s = \tilde{\sigma}\cdot w$, then the left-hand side of (56) is just the percentage change in GNP brought about by a unit increase in $\tilde{\sigma}$, i.e., from introducing a 100 percent subsidy to the cost of R&D. The term $(r/W)$ on the right-hand side of (56) is just the share of profits from the high-tech sector in GNP. We can write

$$r/W = (r/pq)\cdot(pq/W) = (\varepsilon/n)\cdot\Sigma, \tag{57}$$

where $\Sigma \equiv (pq/W)$ is the share of the output of the high-tech sector in GNP.

From (56) and (57) it is clear that the effects of R&D subsidies on GNP will be proportional to the size of the high-tech sector. However if we want to measure the power of the policy of subsidizing R&D it makes sense to measure the effects of policy relative to the size of the sector to which they are applied. Thus we should divide (56) by $\Sigma$.

Finally, if we wish to know the effectiveness of a 1 percent subsidy to R&D costs we have to divide (56) by 100. Thus if we let $\tilde{\sigma} = 100 \cdot \sigma$ then $dW/d\sigma \cdot 1/W$ will measure (relative to the initial size of the high-tech sector) the percentage effect on GNP of a 1 percent R&D subsidy. From our above discussion, we can rewrite (56) to obtain

$$(58) \qquad \frac{dW}{d\sigma} \cdot \frac{1}{W} = \frac{\varepsilon}{n} \cdot \frac{(n-1)}{n} \cdot \left[\frac{\partial r}{\partial b} \cdot \frac{b}{r} + \left(\frac{-\partial r}{\partial a} \cdot \frac{a}{r}\right)\right] \cdot \left[\frac{\partial a}{\partial c} \cdot \frac{c}{a} + \left(\frac{-\partial b}{\partial c} \cdot \frac{c}{b}\right)\right] / 100.$$

Estimates of this measure of the effectiveness of R&D subsidies will be presented in tables 7.1 and 7.2 below.

One problem with this measure is that how powerful a 1 percent subsidy is depends in part on what percentage of a firm's expenditure is represented by R&D. Thus, if R&D represents a relatively small part of a firm's expenditure, a 1 percent subsidy might not have as much impact as, say, a 1 percent production subsidy, but on the other hand the amount of money given by way of the subsidy will also be smaller. This suggests an alternative measure of the effectiveness of an R&D subsidy which is the increases in GNP it induces relative to the amount of the subsidy. We will refer to this as the "policy multiplier." This will be a particularly useful measure to employ when comparing the effectiveness of different kinds of policy.

Now the expenditure involved in implementing the subsidy is

$$E = s\xi(w - s, w),$$

so, evaluated at the initial zero-subsidy position, we have

$$(59) \qquad w \cdot \frac{dE}{ds} = w \cdot \xi.$$

Hence if we divide (56) by (59) we get

$$(60) \qquad \frac{dW}{dE} = \frac{r}{w\xi} \cdot \frac{(n-1)}{n} \cdot \left(\frac{\partial r}{\partial b} \cdot \frac{b}{r} - \frac{\partial r}{\partial a} \cdot \frac{a}{r}\right) \cdot \left(\frac{\partial a}{\partial c} \cdot \frac{c}{a} - \frac{\partial b}{\partial c} \cdot \frac{c}{b}\right),$$

where $dW/dE$ is the increase in GNP brought about per unit amount of resources transferred as a subsidy to R&D—i.e., the policy multiplier. Note that this measure is independent of the size of the sector.

It is easily checked from (47) that the ratio of $r$ to the costs of doing R&D is

$$(61) \qquad \frac{r}{w\xi} = \frac{r}{C(a)} = 1/\left[g \cdot \left(\frac{-\partial r}{\partial a} \cdot \frac{a}{r}\right)\right].$$

We can therefore rewrite (60) as

$$(62) \qquad \frac{dW}{dE} = \left\{1/\left[\gamma \cdot \left(\frac{-\partial r}{\partial a} \cdot \frac{a}{r}\right)\right]\right\} \cdot \frac{(n-1)}{n} \cdot \left(\frac{\partial r}{\partial b} \cdot \frac{b}{r} - \frac{\partial r}{\partial a} \cdot \frac{a}{r}\right) \cdot \left(\frac{\partial a}{\partial c} \cdot \frac{c}{a} - \frac{\partial b}{\partial c} \cdot \frac{c}{b}\right).$$

Estimates of this measure of the effectiveness of R&D subsidies will be presented in tables 7.3 and 7.4 below.

We have estimates of $\gamma$ from empirical studies. So given values for $n$ and $\varepsilon$, we can perform all the necessary calculations of both measures. The next subsection sets out the details and the results.

### 7.3.3 The Results

Estimates of $\gamma$ vary both across different studies and, within studies, across different industries. Thus early studies using U.S. data by Mansfield (1968), Terleckyj (1974), Miniasian (1969), and Griliches (1980) found estimates of $\gamma$ in the range 0.1–0.12. Griliches and Mairesse (1984) and Cuneo and Mairesse (1984) look further at the relationship of firms' R&D spending to productivity performance for the United States and France, respectively. They find estimates of $\gamma$ in the range 0.08–0.15, with higher values for science-based firms—confirming a similar finding by Griliches (1980) that R&D-intensive industries have higher values of $\gamma$. There is therefore some consensus that $\gamma$ lies in the range 0.1–0.15, with the more technologically advanced industries having higher values. Accordingly we have undertaken calculations with three different values of $\gamma$: 0.1, 0.125, and 0.15. We have also allowed $n$ to take the three values 2, 3, and 4.

The most problematic parameter to obtain estimates for was $\varepsilon$. Baldwin and Krugman (1988a) suggest the price elasticity for wide-bodied jets lies in the range 1.57–2.57 ($\varepsilon = 0.39$–$0.64$). Baldwin and Krugman (1988b) report a price elasticity for 16K chips of 1.8 ($\varepsilon = 0.56$). Based on this evidence we performed two separate exercises. The first was to simply calculate the welfare gains using values of $\varepsilon$ ranging from 0.35 to 0.75. This encompasses all of the values for various high-tech sectors reported above. In table 7.1 we report the results of this exercise when the measure of welfare gain is the percentage increase in GNP (relative to the size of the high-tech sector) brought about by a 1 percent R&D subsidy. In table 7.3 we report the results using as our measure $dW/dE$—the size of the gain relative to the resources transferred as a subsidy.

An implication of this exercise is that, from (38), the price/cost margin (or, equivalently, the markup of price over cost) will vary quite sharply with the number of firms. Accordingly in our second exercise we fixed the price/cost markup, $m$, where

$$(63) \qquad m/(1 + m) = (p - c)/p = \varepsilon/n,$$

and then used (63) to determine $\varepsilon$. The values of $m$ we chose were 0.15, 0.2, and 0.25. Empirical evidence suggests that markups of this order are fairly typical. The results of this exercise are reported in table 7.2, using as a measure of the gains the increase in GNP (relative to the size of the high-tech sector) from a 1 percent subsidy, and in table 7.4 where we use as our measure the increase in GNP relative to the amount of resources transferred by way of a subsidy.

Incidentally, if we take $n = 3$, then the implied value of $\varepsilon$ from a markup of 20 percent is approximately 0.55. In what follows we will therefore take 0.55 as our central estimate of $\varepsilon$, and 0.2 as our central estimate of $m$.

Let us turn then to look at the results in the tables. From table 7.1 a number of points emerge. The first is that while the figures are fairly sensitive to the underlying parameters, the majority of parameter values produce percentage gains of less than 1 percent, and values greater than 1 percent only seem to arise for extreme parameter values.

The second feature is that while, as expected, the effects of subsidies are greater the larger $\gamma$ is, they are also greater the more competitive the market is—the larger $n$ is and the smaller $\varepsilon$. The reason is that the gains from policy arise from expansion of the home firms and more particularly from contraction of the overseas opposition. These are greater, the more elastic demand and the larger the number of other firms that will be affected by policy.

Table 7.2 presents essentially similar results for the magnitude of effects. Once again policies are more effective the more competitive the market is, as reflected by a smaller value of $m$. However the effects of variations in $n$ are less clear-cut, because now there are associated variations in $\varepsilon$ as well.

While the relatively small size of the effects of policy shown in tables 7.1 and 7.2 are in line with others' findings on the magnitudes of the effects of strategic trade policy, there are some crucial differences in the nature of the policies and in the underlying models which make a straight comparison rather difficult. The first is that trade policy affects both consumer surplus and producer surplus (rents), and in some calculations more than half the gain comes from consumer surplus. We have ignored this on the assumption that most of the gains from price reductions accrue outside the country.

**Table 7.1** **Percentage Increase in GNP from 1% Subsidy to R&D Costs**

| | $\gamma$=0.1 | | | $\gamma$=0.125 | | | $\gamma$=0.15 | | |
|---|---|---|---|---|---|---|---|---|---|
| $\varepsilon$ | $n$=2 | $n$=3 | $n$=4 | $n$=2 | $n$=3 | $n$=4 | $n$=2 | $n$=3 | $n$=4 |
| 0.35 | 0.18 | 0.47 | — | 0.31 | 2.26 | — | 0.62 | — | — |
| 0.45 | 0.13 | 0.25 | 0.51 | 0.19 | 0.44 | 2.27 | 0.27 | 0.92 | — |
| 0.55 | 0.10 | 0.19 | 0.30 | 0.14 | 0.28 | 0.57 | 0.19 | 0.43 | 1.38 |
| 0.65 | 0.09 | 0.15 | 0.23 | 0.12 | 0.22 | 0.37 | 0.15 | 0.30 | 0.60 |
| 0.75 | 0.08 | 0.13 | 0.19 | 0.10 | 0.18 | 0.28 | 0.13 | 0.24 | 0.41 |

*Note:* Cells without entries indicate that for these parameter values the model has no stable solution.

**Table 7.2** **Percentage Increase in GNP from 1% Subsidy to R&D Costs**

| | $\gamma$=0.1 | | | $\gamma$=0.125 | | | $\gamma$=0.15 | | |
|---|---|---|---|---|---|---|---|---|---|
| $m$ | $n$=2 | $n$=3 | $n$=4 | $n$=2 | $n$=3 | $n$=4 | $n$=2 | $n$=3 | $n$=4 |
| 0.15 | 0.37 | 0.33 | 0.34 | 2.56 | 0.78 | 0.70 | — | 7.24 | 2.49 |
| 0.20 | 0.19 | 0.21 | 0.22 | 0.36 | 0.34 | 0.35 | 0.83 | 0.57 | 0.55 |
| 0.25 | 0.14 | 0.17 | 0.18 | 0.23 | 0.24 | 0.26 | 0.36 | 0.35 | 0.36 |

*Note:* See note to table 7.1.

**Table 7.3** **Policy Multiplier**

| | $\gamma$=0.1 | | | $\gamma$=0.125 | | | $\gamma$=0.15 | | |
|---|---|---|---|---|---|---|---|---|---|
| $\varepsilon$ | $n$=2 | $n$=3 | $n$=4 | $n$=2 | $n$=3 | $n$=4 | $n$=2 | $n$=3 | $n$=4 |
| 0.35 | 1.79 | 3.74 | — | 2.50 | 14.50 | — | 4.15 | — | — |
| 0.45 | 1.37 | 2.08 | 3.77 | 1.62 | 2.95 | 13.27 | 1.98 | 5.12 | — |
| 0.55 | 1.21 | 1.63 | 2.29 | 1.35 | 1.98 | 3.45 | 1.51 | 2.51 | 6.98 |
| 0.65 | 1.14 | 1.42 | 1.81 | 1.22 | 1.62 | 2.29 | 1.32 | 1.87 | 3.12 |
| 0.75 | 1.10 | 1.31 | 1.57 | 1.16 | 1.43 | 1.84 | 1.23 | 1.58 | 2.23 |

*Note:* See note to table 7.1.

The second difference is that strategic trade policy considers policies such as export or production subsidies which are potentially very powerful, because they represent subsidies to a large part of a firm's activities. Since, even in the high-tech sector R&D accounts for a small fraction of all costs, a 1 percent R&D subsidy may not represent a very significant subsidy. For this reason it is worth looking at our second measure of the effectiveness of R&D policy—the increase in GNP relative to the amount given as a subsidy. Figures for this are given in tables 7.3 and 7.4.

Thus if we take as our central case the values $\gamma = 0.15$ (the "high-tech" end of the spectrum), $\varepsilon = 0.55$, and $n = 3$, we see that the gain in GNP relative to the size of the subsidy is 2.5. Thus if the government raises £1 billion in taxes and then gives this in the form of an R&D subsidy to firms in the high-tech sector, then GNP would rise by £2.5 billion. Therefore while a 1 percent subsidy to R&D may not have much of an impact on GNP, because it is a rather weak stimulus, in terms of pounds spent, it offers a potentially very high rate of return.

Of course, in a fuller and more careful evaluation of policy, account would have to be taken of any deadweight loss the transfer would impose. Also it must be recalled that we have considered the most favorable case, where scientists are fully mobile, and these results would have to be scaled down to reflect the degree of immobility that exists in practice. However, offsetting this is the fact that we have also ignored any beneficial spillover effects within the economy.

Table 7.4 Policy Multiplier

| | $\gamma$=0.1 | | | $\gamma$=0.125 | | | $\gamma$=0.15 | | |
|---|---|---|---|---|---|---|---|---|---|
| *m* | *n*=2 | *n*=3 | *n*=4 | *n*=2 | *n*=3 | *n*=4 | *n*=2 | *n*=3 | *n*=4 |
| 0.15 | 3.52 | 2.70 | 2.53 | 19.39 | 5.06 | 4.21 | — | 39.34 | 12.42 |
| 0.20 | 1.92 | 1.80 | 1.76 | 2.86 | 2.32 | 2.19 | 5.56 | 3.25 | 2.91 |
| 0.25 | 1.52 | 1.51 | 1.49 | 1.91 | 1.76 | 1.71 | 2.56 | 2.11 | 2.00 |

*Note:* See note to table 7.1.

In addition, account would also have to be taken of the effects of policy on terms of trade, on consumer surplus, and on the policy choices of rival governments. While these are all important issues, a serious treatment lies well beyond the scope of this paper. Nevertheless the conclusion seems to emerge that giving R&D support to the high-tech sector is potentially an extremely powerful and important policy.

## 7.4 Empirical Evidence

The preceding sections identified four issues critical to the application of strategic trade policy: (i) the mobility of scientists, (ii) the mobility of science, (iii) the existence of spillovers, and (iv) tournament versus nontournament R&D environments.

Although recent theoretical work on R&D races has focused rather heavily on tournament models, the requirements an R&D environment must satisfy to be of a tournament kind are very restrictive. Effectively, the requirements are a single product or process that firms are competing to introduce, and just one central idea or technique lying behind the product or process so that whoever develops and successfully patents this technique first can prevent rivals from using the new technology. No formal tests exist of what proportions of R&D activity may reasonably be classified as tournament and nontournament. Clearly even within a given industry some R&D activity may fall in one category and some in the other. Impressionistically, however, pharmaceuticals is an industry where some of its R&D exhibits many of the features of tournament models, while aerospace is more representative of the nontournament case. Our view is that the nontournament model describes a sufficiently large part of R&D activity to make the policy implications of sections 7.1 and 7.3 worth taking seriously. Since these depend crucially on the degree of mobility and the extent of spillovers, the rest of this section will examine the evidence on these issues.

### 7.4.1 The Mobility of Scientists

Any degree of international mobility of scientists is sufficient to undermine the Dixit and Grossman result, and there is obviously some such mobility. For policy purposes, however, the important issue is to measure it, because the scope for improving welfare by general or arbitrary R&D subsidies must be balanced against factors such as the probabilities of retaliation, the costs of financing subsidies, and the dangers of a subsidy policy being captured by interest groups. All of these trade-offs require quantification. This subsection therefore surveys the evidence on the extent of migration by scientists and engineers. It concludes that migration does occur in response to economic factors in the long run and finds that, for the United States, the principal conduit is the higher education system. The effects of migration are felt throughout the economy, however, because, within specialisms, there is a fairly free flow of scientists between sectors.

The evidence on migration is based on three principal sources: the National Science Foundation (NSF 1986, 1973), the Office of Scientific and Engineering Personnel (OSEP 1988), both from the United States, and the Science and Engineering Policy Studies Unit (SEPSU 1987) from the United Kingdom. All three sources rely on survey data, although the NSF also makes use of immigration authority information. The NSF considers all scientists and engineers (referred to as S/Es below) while OSEP refers mainly to trained engineers working as engineers (Es). SEPSU deals with just five disciplines—biochemistry, chemistry, earth sciences, physics, and electronic engineering—and is cautious about extrapolation to the population of all scientists and engineers.

The principal conclusion from these studies is that there is an international market for S/Es, but that it is far from perfect. International flows are small relative to total stocks of S/Es: SEPSU, for example, finds that U.K. annual immigration and emigration are both about 2 percent of total S/Es over 1976–85. Stocks of nonnational scientists, on the other hand, can be significant: NSF (1986) reports that, in 1982, while only 3.5 percent of S/Es in the United States were noncitizens, a further 13.5 percent were of foreign origin but had taken U.S. citizenship. Migration is more significant among better-qualified S/Es. The OSEP shows that over one-third of doctorate-level engineers in the United States are of non-U.S. origin (OSEP 1988, table A-2) and that in 1982 over one-third of labor force entrants holding Ph.D.s were noncitizens (OSEP 1988, table D-2).

The most obvious institutional feature of the international market for scientists is immigration control; virtually every industrial nation now controls immigration to try to ensure that available jobs go to suitably qualified local residents. In the United States, for example, overall immigration quotas are imposed, and the secretary of labor has to certify that each act of permanent immigration "will not adversely affect the wages or working conditions of similarly employed labor" (NSF 1986). Places are granted to would-be immigrants on the basis of shortages of skills, and OSEP reports that, across broad subject areas, Ph.D.-level immigration is positively correlated with reported skill shortages (OSEP 1988, 95). The connection is less clear within the S/E group, however, although foreign-born S/Es account for relatively high proportions of researchers in fields that were previously unfashionable in the United States but are now of high commercial significance (OSEP 1988, 3). Thus it appears that immigration does serve to alleviate crucial skill shortages, especially at high levels.

Two exceptions make it relatively straightforward for S/Es to immigrate even if, at the time of entry, they are not highly qualified or experienced. First, temporary work visas of one year's duration are granted liberally to S/Es and without quota limits (NSF 1986). Moreover, these visas are renewable and in many cases can be translated into permanent visas and eventually into naturalization without great difficulty. Temporary visas are automatically granted to foreign engineering students on graduation in order that they may obtain practical training in the United States. The temporary visa system brings several benefits to the functioning of U.S. skilled labor markets. First, it permits short-run adjustment to shortages; for example, in 1978, the latest year recorded, 30 percent of foreign S/Es admitted were on temporary visas (NSF 1986). Second, the temporary visa system offers an effective screening mechanism of candidates' ability, motivation, and the like; permanent immigration will be possible only if they find a sponsor/employer and so will require some minimal standard of performance. Such screening clearly enhances immigration as a means of increasing and improving the labor force.

The second fast track through immigration formalities is the education system—especially at the second-degree level. Foreigners on temporary visas accounted for 40 percent of engineering enrollments in U.S. doctorate-giving institutions and 41 percent of Ph.D.s awarded by U.S. engineering schools in 1985; in 1982, 62 percent of foreign S/E Ph.D. recipients stayed in the United States. Two-thirds of engineering postdoctorates were foreign (noncitizen) in 1985, rising to four-fifths in metallurgy/materials engineering, and half of all engineering assistant professors under 35 years of age were foreign. Around 80 percent of non–U.S. origin S/Es employed in the United States in 1982 had received U.S. training and 80 percent had entered the United States after the age of 15, presumably for the express purpose of work or training. Most of the growth of employment of S/Es of foreign-origin since 1972 has been among naturalized citizens, not aliens. Thus it would hardly be an exaggeration to say that a principal function of the U.S. higher education system has been to supply the U.S. economy with S/Es from abroad on a fairly permanent basis.

Although there are few discernible patterns in the specialisms of U.S. foreign S/Es, there are patterns in their occupations. Foreign-origin S/Es are underrepresented in the defense and government sectors relative to industry as a whole and relatively overrepresented in education and the hospital/nonprofit sectors (NSF 1986). They are concentrated in research and development/design tasks and are underrepresented in general management (though not the management of R&D). This research concentration also explains the high proportion of foreign-origin staff in education—they are not overrepresented in teaching. The OSEP suggests that foreign and foreign-born engineers earn the same wages as indigenous engineers once allowance is made for qualifications, age, field, experience, and so forth. This suggests that within skill and subject groups, foreign and domestic S/Es are good substitutes. U.K. evidence also suggests fairly high mobility between sectors (university, industry, government), so that overall we may conclude that for each specialism there is a single fairly well functioning market for S/Es.

Two sources present direct evidence on the motives for migration among S/Es. The NSF (1973) found that economic and job factors were the most significant considerations for U.S. immigrants from industrial countries, while SEPSU found that for U.K. emigrants relative career opportunities at home and abroad predominated, followed by rates of pay, research facilities, and the desire for experience. Higher pay was particularly important to emigrants from the university sector. While both sources listed many other motives for migration, they both leave an overwhelming impression that the economic resources devoted to science matter most of all: S/Es do seem to be attracted to areas of high net rewards.

The evidence presented in this section is open to at least one coherent interpretation that has profound policy implications, not least in the area of strategic trade policy. The international migration of S/Es is a long-run phenomenon but is, nonetheless, subject to market forces. It takes time for market signals to build up and be acted upon, but migration, once undertaken, tends to be permanent. A principal medium for migration is the university system, in which there are relatively few cultural barriers to international movement. Most liberal is the system of educating foreign students. At least for migrants to the United States, S/E doctoral studies are more often than not the first step on an American S/E career. Obviously this is not universally true, and it is particularly difficult to identify how many foreign S/Es return home after several years' employment in the United States, but the evidence suggests that the education system is a primary route through which U.S. industry recruits foreign talent. The universities and research foundations also provide a good medium for postdoctoral migration, attracting, for example, about half of U.K. S/E emigrants and providing work for a relatively high proportion of the foreign S/Es in the United States.

That a high proportion of migration occurs via universities does not mean, however, that its principal effects lie in that sector. As students graduate, they mostly pass out into noneducation sectors. Moreover, mobility between university faculties and other employers of S/Es means that the ability of universities to recruit immigrants for teaching and research releases manpower for other sectors. It is true that foreign-origin S/Es are strongly represented in industrial research and development activities, but again, the ability of U.S. industry to have R&D done by foreign S/Es releases indigenous S/Es for management posts. Thus even if foreign-origin S/Es are not well represented in the commanding heights of U.S. industry, their availability somewhere in the system makes a fundamental contribution to the U.S. economy.

The policy implications in the context of strategic trade policy is as follows. In the short run, a country's stock of S/Es is probably fairly rigid. This gravitates away from activist trade policies for the reasons set out by Dixit and Grossman (1986). On the other hand, a long-term commitment to the employment of and provision for S/Es may reap benefits in terms of increased net immigration. However, given the intersectoral mobility of S/Es, the requirement is more for general scientific facilities than for industry or project-specific subsidies.

The evidence above suggests a close connection between U.S. training for S/Es and U.S. employment, but it did not identify the direction of causation. Given the strong economic motives among qualified scientists and the high stay-on intentions expressed by U.S. S/E students (NSF 1986), we suspect that students seek U.S. education as an entry ticket to U.S. employment rather than seek U.S. employment as a result of obtaining a U.S. education. In other words, it is likely that stimulating the demand for scientists is more effective than stimulating the supply.

In terms of the model considered in section 7.1 and calibrated in section 7.3 there seems to be a significant amount of mobility, which could help justify policies of support for the high-tech sector. Moreover the degree of mobility among engineers seems to be as high as among scientists, so it is possible that the problems alluded to in section 7.1.6 would not arise. However this depends on our ad hoc designation of the key workers in the development process as engineers, and it is possible that there are yet other strategically important but immobile factors that we have ignored.

### 7.4.2 The Mobility of Science

If scientists are immobile, it may still be possible to import their services by subcontracting R&D abroad. As we saw above, "mobile science" is, broadly speaking, a substitute for mobile scientists, although its implications for policy are rather different. It is easy to conceive of research problems being contracted out to foreign researchers—indeed, this paper is an example—so again the important issue is quantitative rather than qualitative.

The most detailed data and analyses of offshore R&D refer to multinational corporations (MNCs). Crude data suggest that around 70 percent of technological royalties and fees paid by residents of industrial countries represent transfers between related organizations—see, for example, Ledic and Silberston (1984). Although these data may exaggerate the proportion of "affiliated" transfers—for example, royalties offer more scope for transfer pricing than do goods flows (Hirschey and Caves 1981), and nonaffiliated transactions are more likely to include other means of payment for technology, such as tie-in sales, purchases of inputs, and the like (Bond 1981)—the importance of the

MNCs in technology transfer is undeniable. The difficulty of interpreting these data for our purposes is that they include both R&D that is a substitute for local, home-country, effort and R&D that must necessarily be conducted abroad because it is complementary to foreign sales or production. The former is "footloose" and a legitimate component of mobile science: the latter is not.

Three sets of studies suggest the importance of production and sales activities in determining the location of the R&D that MNCs do locate abroad. First, foreign-based R&D is biased toward development and adaptation rather than basic or applied research—Creamer et al. (1976), Hood and Young (1976), and Mansfield et al. (1979). The last found that around three-quarters of U.S. MNCs restricted their overseas R&D activities to improvements or modifications of products or processes rather than allowing them to work on entirely new cases. The proportion of domestic laboratories so limited was much smaller. Firms also reported that some third of overseas R&D expenditure contributed nothing to their U.S. operations, and fewer than one-half of firms attempted to integrate all their laboratories into a single worldwide research program.

The second set of evidence comes from Teece (1976). He offers direct evidence that foreign technology cannot be imported and applied costlessly, but rather that it requires significant inputs of both local and foreign skilled labor and scientists to exploit it. Although generalization is difficult, Teece notes a number of common features of technology transfer. First, transfer costs are lower the larger, more experienced in production, and more R&D intensive is the transferee organization. Second, transfer costs are lower the more times the technology has been transferred previously and the greater the production experience with the technology. Except in a small subset of his 26 instances, Teece found that transfer prior to any production experience was very expensive. This last result bodes ill for transferring fundamental research.

The third body of evidence is based on statistical models of the share of R&D undertaken abroad; see, for example, Mansfield et al. (1979), Lall (1979), Hirschey and Caves (1981), and Pearce (1988). All of these authors find that sales by foreign subsidiaries are positively related to the proportion of R&D undertaken abroad. Hirschey and Caves also find that overseas R&D increases with the need to adapt products to local market conditions and with the level of host country R&D.

All of these results suggest that a substantial proportion of MNC overseas R&D activity is determined by overseas production and sales requirements. However, the degrees of explanation that these studies attain are generally quite low; thus there still remains scope for further explanations, including that firms locate some footloose R&D in a cost-minimizing fashion. Only Mansfield et al. (1979) offer direct evidence on this. Based on admittedly very small samples, they suggest that laboratories devoted to minor adaptation could be efficient at a considerably smaller scale than those devoted to genuine research or development, which in turn could be smaller than research *and* development laboratories. Thus it is possible that the development activities noted by the various studies will form the basis of future research laboratories, or indeed, given the date of Mansfield et al.'s work, that they have already done so.

Mansfield et al. also found that Canada, Europe, and Japan had been considerably cheaper locations for R&D than the United States in 1965 (by 30 percent, 40 percent, and 20 percent, respectively) and in 1970, but that by 1975 the differentials had largely disappeared. Their respondents also suggested that over the decade 1965–75 the share of R&D done overseas had expanded rapidly, but that in the late-1970s it was expected to do so only slowly. This confirms evidence from Pearce (1986) that the proportion of R&D expenditures undertaken by U.S.-owned foreign affiliates in the total R&D spending of the corporate group rose from 6.6 percent in 1966 to 8.8 percent in 1982. This is at least consistent with firms responding to economic pressures to locate footloose R&D efficiently.

There is one further aspect of the MNC literature relevant to our hypothesis. Reddaway (1968) noted that U.K. foreign direct investment abroad generated significant back-flows of information from certain host countries—mainly the United States and West Germany. In part this was due to R&D undertaken by the foreign subsidiaries and is akin to the R&D that Mansfield et al. identified as being of relevance to the parent company. Reddaway, however, also writes of "informal know-how" and of the United States as a "source of general expertise" (1968, 322). This appears to entail U.K. firms benefiting by learning by doing abroad, and the implication seems to be that such knowledge is transferable back home. Further evidence of learning by doing abroad is quoted by Caves, who notes its role in certain Japanese companies' foreign investment (1982, 198).

Taken as a whole these results suggest that at least some footloose R&D can be located abroad, and thus that to some extent science can be brought in to overcome a local shortage of scientists. The results are not strong, however, and none of the studies really tackles the question of what proportion of foreign science was undertaken by home-country scientists. If this were high, it would reduce the role of offshore R&D in supplementing home efforts.

There are also direct but less comprehensive indicators of the existence of offshore R&D. For example, Porsche is reported to fund nearly 40 percent of its R&D laboratories' turnover with projects undertaken for other companies, including a complete car design for the Soviet firm Lada. Indeed it is suggested that most car producers in the world make some use of the Porsche laboratories (Note 324/88, Science and Technology Section, British Embassy, Bonn). In 1987, 3.1 percent of total German-funded R&D was conducted abroad, and 1.1 percent of German-conducted research was funded from abroad. While small, these figures were both the fastest growing elements of their respective aggregates (Federal Republic of Germany 1988). In the United Kingdom, some 13 percent of R&D performed by U.K. companies was funded from overseas, although how much of this was MNC developmental work is unknown.

On the output side of R&D, Cantwell (1989a, 1989b) and Pearce (1986) have analyzed data on patents taken out in the United States. This data has the advantage that it records both the nationality of the parent company and the location where the R&D leading to the patent was actually undertaken. Comparing the period 1963–70 with 1978–84, they find evidence that the link between the locus of production and the locus of R&D was weakening. Also, while the degree of concentration of research activity was much the same over the period, the pattern was actually different, suggesting that concentration of research activity was being driven by considerations other than the locus of production or the head office of the parent company.

The interpretation of these various snippets of information must be that it *is* possible to undertake R&D offshore and to a greater and growing level of sophistication than merely adapting home-country technology to local conditions. However, while such activity is growing rapidly, it still accounts for only a small share of R&D activity. Thus overall we suggest that offshore sourcing is not yet a practical means of significantly relaxing a domestic "science constraint." However, as this international mobility of science becomes increasingly important, so too do the conclusions of section 7.1.5. It will be recalled that while there was again support for policies that increased the demand for scientists, this was only unambiguously desirable for countries which had a sufficiently large stock as to make them net exporters, suggesting that supply policies could also be desirable.

### 7.4.3 Spillovers

There are now a number of studies that have investigated R&D spillovers and have calculated private and social rates of return to R&D, where the social rate of return takes into account the effect of spillovers. Griliches (1964) and Evenson and Kislev (1973) investigated the effects of R&D spillovers on U.S. agricultural production. They estimated the social rates of return on agricultural R&D projects were 150 to 300 percent greater than private rates of return. Mansfield et al. (1977) compared private to social rates of return on 17 innovations introduced in the United States. The variation in the private rates of return was from 214 percent to less than 0 percent with a median 25 percent rate of return. The social rates were calculated to range from 209 percent to less than 0 percent with a median rate of return of 56 percent.

Jaffe (1986) attempts to gauge the broad importance of spillovers by looking at the average effect that other firms' R&D has on the productivity of a firm's own R&D. He finds that firms whose research is in areas where there is much research by other firms have, on average, more patents per dollar of R&D and a higher return to R&D in terms of accounting profits or market value, though firms with very low own R&D suffer *lower* profits and market values if their neighbors are R&D-intensive. All of these effects remain after controlling for the possibility that the technological areas themselves are associated with variations in the productivity of R&D.

Levin and Reiss (1984) also dealt with a cross-section of U.S. firms and estimated that a 1 percent increase in R&D spillover caused average costs to decline by 0.05 percent. Bernstein and Nadiri (1989) estimated the effects of intraindustry spillovers for four U.S. industries. A firm's R&D spillover was defined as the sum of the R&D capital stocks of the firm's rivals. It was estimated that a 1 percent increase in the spillover decreased average cost in the long run by between 0.1 and 0.2 percent. It was also estimated that the social rate of return was up to twice the private rate. If we recall that, in section 7.3, a 1 percent increase in a firm's own R&D spending was estimated to reduce costs by 0.15 percent, these results by Bernstein and Nadiri seem to imply very large spillover effects. However, their methodology is very different from those used in the studies reported in section 7.3 to estimate the effects of R&D spending on costs, so the elasticities are not strictly comparable.

In all these studies the R&D spillover is defined as a single aggregate with individual industries not treated as separate spillover sources. Bernstein and Nadiri (1988) developed and estimated a model for five U.S. high-tech industries which allowed each one to be a distinct spillover source. The paper by Bernstein (1989) uses a variant of this framework and applies it to nine Canadian industries. The production cost of each industry is affected separately by the R&D capital of each of the other industries. He finds that, for each receiving industry, cost effects depend on the particular source of R&D spillover. Six industries were affected by multiple spillover sources. All nine industries were influenced by R&D spillovers, and the cost reductions attributable to these ranged from 0.005 percent for chemical products to 1.082 percent for electrical products. Private rates of return to R&D ranged from 24 to 47 percent, approximately 2 and one-half times the returns on physical capital. Social rates of return ranged from four times the private rate (for nonelectrical machinery) to twice the rate. Unfortunately, none of these studies deal with international R&D spillovers, so while there clearly is considerable knowledge diffusion between Europe, Japan, and the United States, we have no feel for its quantitative impact on technology and costs.

## 7.5 Conclusion

In this paper we have argued that the recent literature on strategic trade policy provides a natural framework in which to discuss some issues of manpower policy, while conversely, arguments about trade and industrial policies toward the high-tech sector depend critically on certain manpower issues. In particular we have shown that the view one takes of policy depends critically on whether it is scientific manpower or science itself which is mobile. We have also shown that, in an international context, spillovers can undermine rather than support the case for policy intervention as they are taken to do in a closed economy.

A calibration of our model suggests that the potential for beneficial policy is very great. However, a final conclusion on this depends on a number of elasticities to do with mobility and spillovers for which we just do not have data, though what evidence we have presented suggests mobility is significant and growing.

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