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by

David R Collie
Cardiff Business School, Cardiff University

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State Aid to Investment and R&D

David R Collie

Cardiff Business School, Cardiff University
Aberconway Building, Colum Drive
Cardiff CF10 3EU, United Kingdom
E-mail: Collie@Cardiff.ac.uk
Tel: +44(0)29 2087 6815
Fax: +44(0)29 2087 4419

Abstract

The prohibition of state aid to Investment and R&D in an integrated market such as the European Community is analysed in a Cournot oligopoly model where firms undertake investment or R&D to reduce their costs. Both strategic and non-strategic investment and R&D are considered. Governments in the member states give subsidies for investment and R&D, which are financed by distortionary taxation so the opportunity cost of government revenue exceeds unity. Prohibiting state aid to investment will always increase aggregate welfare. Prohibiting state aid to R&D will always increase aggregate welfare if spillovers from R&D are small. If spillovers from R&D are moderate then there exists a range of values for opportunity cost where governments give state aid and where the prohibition of state aid will increase aggregate welfare. Prohibiting state aid to R&D will reduce aggregate welfare if spillovers from R&D are large.

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1. Introduction

There has been scant attention paid to the economic analysis of state aid, and the rationale for the prohibition of state aid by the EC. My recent articles, Collie (2000, 2002a, 2002b), using a symmetric oligopoly model, have attempted to provide a rationale for state aid that explains why countries give state aid and why the EC would prohibit state aid. For simplicity, these articles model state aid as production subsidies even though operating aid is not generally permitted under EC state aid policy. These articles show that the profit-shifting motive identified by Brander and Spencer (1985) will lead member states to give state aid to their firms. When taxation is not distortionary and products are homogeneous, the Nash equilibrium in production subsidies will lead to an outcome where price is equal to marginal cost. Such an outcome is Pareto-efficient as the subsidies expand the output of the Cournot oligopoly to the efficient level. A similar result is obtained by Norman and Venables (2004) in an economic geography model of industrial clusters where subsidies again lead to a Pareto efficient outcome. Collie (2000) shows that adding distortionary taxation, an opportunity cost of government revenue greater than one, in a Cournot oligopoly model provides a rationale for the prohibition of state aid. Collie (2002a) shows how the results can be extended to differentiated products and Bertrand oligopoly. If products are sufficiently differentiated then the prohibition of state aid will not be beneficial as the subsidies of one country will have little effect on the profits of firms in other countries but will increase consumer surplus. Collie (2002b) introduces foreign competition into the analysis.

A criticism of these articles is that production subsidies are not permitted under EC state aid policy, and that subsides for investment and R&D are more relevant to actual state aid policy. Therefore, this paper extends the analysis to cover investment and R&D subsidies in a Cournot oligopoly model. Such subsidies are similar to production subsidies in that they reduce the marginal cost of production but they do it by expending real resources on investment or R&D. The analysis will consider strategic investment (with no spillovers) and non-strategic R&D (with spillovers), and it will turn out that the degree of spillovers is an important factor.

2. The Model

The model extends the analysis in Collie (2000, 2002a) by incorporating the investment or R&D decisions of firms, and introducing subsidies to investment or R&D given by the countries. For simplicity, the simplest possible functional forms will be employed such as linear demand and cost functions. There are M countries in an integrated market and it is assumed that in each country there is a single firm. The firms compete in a symmetric Cournot oligopoly where investment or R&D can be used to lower the marginal cost of production. Output of the *i*th firm is q_i and its investment or R&D is x_i. Demand for the homogeneous product in the integrated market is given by the linear inverse demand function:

$$P = \alpha - \beta \sum_i q_i = \alpha - \beta Q \tag{1}$$

The firms can use investment or R&D to reduce the marginal cost of production. For simplicity, the marginal cost of production for the *i*th firm is linear in investment or R&D:

$$c_i = \mu - \theta \left(x_i + \phi \sum_{j \neq i} x_j \right) \tag{2}$$

where θ is the cost reduction from investment or R&D, and ϕ is a measure of the degree of spillovers from R&D, with $0 < \phi < 1$. The cost of investment or R&D for the *i*th firm is quadratic:

$$r_i = \sigma x_i^2 / 2 \tag{3}$$

The government in the *i*th country gives state aid to its firm in the form of a subsidy, s_i, per unit of investment or R&D. Therefore, the profits of the *i*th firm are:

$$\pi_i = (P - c_i) q_i - \sigma x_i^2 / 2 + s_i x_i \tag{4}$$

Assuming that each country is only concerned about its own welfare, the welfare of the *i*th country is given by the sum of consumer surplus, producer surplus less the cost of the subsidies. If raising the tax revenue to pay the subsidy involves imposing a deadweight loss on taxpayers then the opportunity cost of government revenue is greater than one, $\lambda > 1$. Hence, the welfare of the *i*th country is:

$$\begin{aligned} W_i &= \frac{1}{M} \int_0^Q (\alpha - \beta Z) dZ - PQ + \pi_i - \lambda s_i x_i \\ &= \frac{1}{2M} \beta Q^2 + (P - c_i) q_i - \sigma x_i^2 / 2 - (\lambda - 1) s_i x_i \end{aligned} \tag{5}$$

where $(\lambda - 1) s_i x_i$ is the deadweight loss from taxation.

By definition, there are no spillovers from investment so $\phi = 0$, but there are spillovers from R&D so $\phi > 0$. Define the effectiveness of investment or R&D as:

$$\eta = \frac{\theta^2}{\beta \sigma} \tag{6}$$

There are two approaches to modelling investment or R&D that have been used in the literature:

Non-strategic investment or R&D: With non-strategic investment or R&D the firm sets x_i at the same time as setting output, q_i. In this case, the firms set investment or R&D to minimise the total cost of production.

Strategic investment or R&D: With *strategic* investment or R&D the firm sets x_i before it sets output, q_i. In this case, investment or R&D may give the firm a strategic advantage by reducing its costs before the other firms set their outputs, and thereby causing competitors to reduce their output.

In this paper, the first approach will be used to model R&D and the second approach will be used to model investment. These two approaches are shown in table one:

Multi-Stage Game	Non-Strategic	Strategic
Stage One	Governments set investment or R&D subsidies.	Governments set investment or R&D subsidies.
Stage Two	Firms set output and investment or R&D given subsidies.	Firms set investment or R&D given subsidies.
Stage Three		Firms set output given investment or R&D.

Table 1: Multistage Games

3. Strategic Investment under Oligopoly

Firstly, consider investment where there are no spillovers and the investment decision can be used strategically by the firms. As usual the multistage game is solved by backwards induction to obtain a subgame perfect Nash equilibrium. At the final stage of the game, the firms set their outputs given the investment undertaken at the second stage so the first-order conditions for the Cournot equilibrium are:

$$\frac{\partial \pi_i}{\partial q_i} = \alpha - \beta Q - \beta q_i - \mu + \theta x_i = 0 \tag{7}$$

Solving for the Cournot equilibrium outputs yields:

$$q_i = \frac{(\alpha - \mu) + (M+1)\theta x_i - \theta \sum x_j}{(M+1)\beta} \tag{8}$$

The effect of an increase of investment by the *i*th firm on the its output and the output of its competitors is:

$$\frac{\partial q_i}{\partial x_i} = \frac{M\theta}{(M+1)\beta} > 0 \qquad \frac{\partial q_j}{\partial x_i} = \frac{-\theta}{(M+1)\beta} < 0 \tag{9}$$

Investment by the *i*th firm increases its output and reduces the outputs of its competitors. Clearly, investment gives the firm a strategic advantage in the final stage of the game.

At the second stage of the game, the firms make their investment decisions anticipating the effect that their investments will have on the Cournot equilibrium in the final stage of the game. Using (7), the profits of the *i*th firm can be written as:

$$\pi_i = \beta q_i^2 - \sigma x_i^2 / 2 + s_i x_i \tag{10}$$

Hence, with each firm independently and simultaneously setting investment, the first-order conditions for the Nash equilibrium in investments are:

$$\frac{\partial \pi_i}{\partial x_i} = 2\beta q_i \frac{\partial q_i}{\partial x_i} - \sigma x_i + s_i = 0 \tag{11}$$

Substituting (9) into the above and solving for the Nash equilibrium investments yields:

$$x_i = \frac{2MA\theta(\alpha - \mu) - 2M(M+1)\beta\theta^2 \sum s_j + (M+1)\Delta\beta s_i}{\Delta A} \tag{12}$$

where $\Delta \equiv (M+1)^2 \beta\sigma - 2M\theta^2 > 0$ and $A = (M+1)\beta\sigma - 2M\theta^2 > 0$ provided the effectiveness of investment is not too large $\eta \equiv \theta^2/\beta\sigma < (M+1)/2M$, which ensures uniqueness/stability. The effects of an investment subsidy from the *i*th government on investment undertaken by its firm and firms in other countries are:

$$\begin{aligned} \frac{\partial x_i}{\partial s_i} &= \frac{(M+1)\beta}{\Delta A}\left[(M+1)^2 \beta\sigma - 4M\theta^2\right] > 0 \\ \frac{\partial x_j}{\partial s_i} &= \frac{-2M(M+1)\beta\theta^2}{\Delta A} < 0 \end{aligned} \tag{13}$$

The subsidy by the government in the *i*th country increases investment by its firm but reduces investment by firms in the other countries. Therefore, the investment subsidy gives the firm in the *i*th country a strategic advantage and shifts profits from the other countries to the *i*th country.

Having obtained the Nash equilibrium investments and outputs, these can now be substituted into (5) to give welfare as a function of the subsidies in the first stage of the game when the governments set subsidies. The first-order conditions for the Nash equilibrium can be solved to get the symmetric Nash equilibrium subsidies and welfare:

$$\frac{\partial W_i}{\partial s_i} = 0 \quad \Rightarrow \quad s^N = s^N(\lambda, M, \eta) \tag{14}$$

Since the algebraic expression for the Nash equilibrium subsidy is very complicated, the results will be shown using numerical solutions in graphs. As the opportunity cost of government revenue increases the cost of using an investment subsidy increases and the Nash equilibrium subsidy will decrease until, for the critical value of opportunity cost λ^S, it is equal to zero. The critical value of opportunity cost, λ^S, such that the Nash equilibrium subsidy is equal to zero is defined by $s^N(\lambda^S) \equiv 0$. Figure 1 shows that as the number of countries/firms increases then the Nash equilibrium subsidy decreases as the profit margin and hence the incentive for strategic profit-shifting is reduced. Consequently, as shown in figure 2, the critical value of opportunity cost will decrease as the number of countries/firms increases. It can be shown that welfare is always higher when subsidies are prohibited than in the Nash equilibrium in subsidies, $W^P > W^N$. Figure 3 shows that as the effectiveness of investment increases then the Nash equilibrium subsidy increases as the investment subsidy has a greater strategic effect. Consequently, as shown in figure 4, the critical value of opportunity cost is increasing in the effectiveness of investment. These results lead to the following proposition:

Proposition 1: *The prohibition of state aid to investment will increase the welfare of all countries.*

When state aid to investment is allowed, the result is a subsidy war where governments use subsidies to give their firms a strategic advantage but the result is a prisoners' dilemma where all governments are worse off than if state aid was prohibited. The firms will over-invest in the Cournot oligopoly so the subsidies to investment will exacerbate this over-investment. Note that this result holds when the opportunity cost of government revenue is equal to one so lump-sum taxes are available whereas in Collie (2000) the outcome would be Pareto-efficient in this case as the production subsidies would drive price equal to marginal cost. The reason is that investment subsidies use real resources to reduce marginal cost but this is not the case with a production subsidy. From the point of view of economic efficiency, in contrast to EC state aid policy, a production subsidy may be superior to an investment subsidy.

When there are no spillovers from investment, the prohibition of state aid will increase welfare, but with spillovers from R&D there may be a case to allow state aid, and this will be considered in the next section.

4. Non-Strategic R&D under Oligopoly

The analysis of R&D with spillovers will assume that it is non-strategic so as to reduce the complexity of the problem. As usual the multistage game is solved by backwards induction for the subgame perfect equilibrium. The firms are assumed to set output and R&D simultaneously and independently in the final stage of the game given the R&D subsidies set by the governments. The first order conditions for the Nash equilibrium are:

$$\begin{aligned} \frac{\partial \pi_i}{\partial q_i} &= \alpha - \beta Q - \beta q_i - \mu + \theta(1-\phi)x_i + \theta\phi X = 0 \\ \frac{\partial \pi_i}{\partial x_i} &= \theta q_i - \sigma x_i + s_i = 0 \end{aligned} \tag{15}$$

Summing these first-order conditions over all the firms yields the Nash equilibrium aggregate output and R&D:

$$X = \frac{\theta Q + \sum s_i}{\sigma} \qquad Q = \frac{\sigma M(\alpha - \mu) + \theta\left(1 + (M-1)\phi\right)\sum s_i}{(M+1)\beta\sigma - \theta^2\left(1 + (M-1)\phi\right)} \tag{16}$$

The R&D subsidy increases the total amount of R&D and increases total output, which also increases total R&D. These can then be used to solve for the Nash equilibrium output and R&D of each firm:

$$x_i = \frac{\theta q_i + s_i}{\sigma} \qquad q_i = \frac{\sigma\left((\alpha - \mu) - \beta Q - \phi\theta X\right) + (1-\phi)\theta s_i}{\sigma\beta - (1-\phi)\theta^2} \tag{17}$$

Having obtained the Nash equilibrium investments and outputs, these can now be substituted into (5) to give welfare as a function of the subsidies in the first stage of the game. The first-order conditions for the Nash equilibrium can be solved to get the symmetric Nash equilibrium subsidies and welfare:

$$\frac{\partial W_i}{\partial s_i} = 0 \quad \Rightarrow \quad s^N = s^N\left(\lambda, \phi, \eta, M\right) \tag{18}$$

The Nash equilibrium R&D subsidy is a function of the opportunity cost of government revenue, λ; the degree of spillovers, ϕ; the effectiveness of R&D, η; and the number of countries/firms, M. As with investment, there is a critical value of the opportunity cost, λ^S, such that the Nash equilibrium R&D subsidy is zero so $s^N\left(\lambda^S\right) \equiv 0$. The Nash equilibrium R&D subsidy will be positive (negative) when the opportunity cost is less (greater) than the critical value, λ^S.

Welfare when state aid is prohibited can be obtained by setting the R&D subsidies of all countries equal to zero to obtain: W^P, while welfare in the Nash equilibrium in R&D subsidies is given by: $W^N\left(\lambda\right)$. There is a critical value of opportunity cost, λ^P, such that welfare in the Nash equilibrium is equal to welfare when state aid is prohibited, $W^N\left(\lambda^P\right) \equiv W^P$. Welfare when state aid is prohibited will be greater (less) than welfare in the Nash equilibrium if the opportunity cost of government revenue is greater (less) than the critical value of opportunity cost, λ^P.

Again given the complexity of the algebraic expressions, the results will be presented using numerical solutions shown in graphs. Figure 5 shows the Nash equilibrium R&D subsidy as a function of the degree of spillovers and it can be seen that the subsidy is decreasing in spillovers when spillovers are small and increasing when spillovers are large.

Initially, spillovers reduce the strategic advantage obtained from an R&D subsidy but when the spillovers are large the gain to consumers becomes the dominant factor. Figure 6 shows how the critical values of opportunity cost vary with the degree of spillovers. It can be seen that λ^S is decreasing in the degree of spillovers whereas λ^P is increasing in the degree of spillovers. When the degree of spillovers is low, $\phi < 0 \cdot 05$ in the graph, welfare when state aid is prohibited is always greater than welfare in the Nash equilibrium. When the degree of spillovers is moderate, $0 \cdot 05 < \phi < 0 \cdot 14$ in the graph, welfare when state aid is prohibited is greater (less) than welfare in the Nash equilibrium if opportunity cost is greater than λ^P, which is increasing in the degree of spillovers. When the degree of spillovers is large, $\phi > 0 \cdot 14$ in the graph, welfare when state aid is prohibited is less than welfare in the Nash equilibrium. These results lead to the following proposition:

Proposition 2: *Prohibiting state aid to R&D will always increase aggregate welfare if degree of spillovers from R&D is low. If the degree of spillovers from R&D is moderate then there exists a range of values for opportunity cost where governments give state aid and where the prohibition of state aid will increase aggregate welfare. Prohibiting state aid to R&D will reduce aggregate welfare if the degree of spillovers from R&D is large.*

When the spillovers from R&D are small, as with investment where there are no spillovers, the prohibition of state aid will increase welfare whatever the opportunity cost of government revenue. When spillovers from R&D are large, the prohibition of state aid will reduce welfare whatever the opportunity cost of government revenue. In both cases, the policy implications are clear. However, when spillovers from R&D are moderate, whether the prohibition of state aid will increase or decrease welfare will depend upon the opportunity cost of government revenue.

Figure 7 shows that the Nash equilibrium R&D subsidy increases as the effectiveness of R&D increases, and figure 8 shows that the range of values for opportunity cost where the prohibition of state aid is beneficial increases as the effectiveness of R&D increases. Figure 9 shows that the Nash equilibrium subsidy decreases as the number of countries/firms increases, and figure 10 shows that the range of values where the prohibition of state aid is beneficial decreases as the number of countries/firms increases.

5. Conclusions

This paper has extended the analysis of Collie (2000, 2002a) to consider investment and R&D subsidies rather than production subsidies, as operating aid is not generally permitted under EC state aid policy whereas state aid to investment and R&D is permitted. Obviously, this required the analsysis to be extended to cover the investment or R&D decisions of the firms. It has been shown that the prohibition of state aid to investment (where there are no spillovers) will increase welfare. Similarly, the prohibition of state aid to R&D where spillovers are low will increase welfare. When spillovers to R&D are moderate, whether the the prohibition of state aid to R&D will increase or decrease welfare depends upon the opportunity cost of government revenue. The prohibition of state aid will always reduce welfare when the spillovers from R&D are sufficiently large.

The analysis in this paper could be extended in a number of ways that may affect the results. Firstly, adding product differentiation may imply that the prohibition of state aid will not be beneficial when products are sufficiently differentiated as shown in Collie (2002a) for production subsidies. Secondly, with Bertrand rather than Cournot oligopoly the strategic incentives for investment or R&D may be altered but it should be noted that Bagwell and Staiger (1994) have shown that the argument for R&D subsidies is not generally affected by whether there is Cournot or Bertrand oligopoly unlike the argument for export subsidies, see Eaton and Grossman (1986). Therefore, introducing Bertand oligopoly as in Collie (2002a) may not affect the results in any qualitative way.

References

Bagwell, Kyle & Staiger, Robert W. (1994). 'The sensitivity of strategic and corrective R&D policy in oligopolistic industries', *Journal of International Economics*, Elsevier, vol. 36(1), pages 133-150

Besley, T. and P. Seabright (1999). 'The Effects and Policy Implications of State Aids to Industry: An Economic Analysis', *Economic Policy*, **28**, 14-53.

Brander, J.A. and B.J. Spencer (1985). 'Export Subsidies and International Market Share Rivalry', *Journal of International Economics*, **18**, 83-100.

Collie, David R. (1997). 'Bilateralism is Good: Trade Blocs and Strategic Export Subsidies', *Oxford Economic Papers*, **49**, 504-20.

Collie, David R. (2000). 'State Aid in the European Union: The Prohibition of Subsidies in an Integrated Market', *International Journal of Industrial Organisation*, **18**, 867-884.

Collie, David R. (2002a), 'Prohibiting State Aid in an Integrated Market: Cournot and Bertrand Oligopolies with Differentiated Products', *Journal of Industry, Competition and Trade*, Vol 2, pp. 215-231.

Collie, David R. (2002b), 'Trade Liberalization and State Aid in the European Union', in Chris Milner and Robert Read (editors), ***Trade Liberalization, Competition and the WTO***, Edward Elgar, Aldershot, pp. 190-206.

Commission of the European Communities (1999). 'State Aid and the Single Market', *European Economy, Reports and Studies*, No. 3, Office for Official Publications of the European Communities, Luxembourg.

Eaton, J. and G. Grossman (1986). 'Optimal Trade and Industrial Policy under Oligopoly', *Quarterly Journal of Economics*, **101**, 383-406.

Gilchrist, J. and D. Deacon (1990). 'Curbing Subsidies' in P. Montagnon (editor), *European Competition Policy*, London: Royal Institute of International Affairs/Pinter Publishers.

Neary, J.P. (1994). 'Cost Asymmetries in International Subsidy Games: Should Governments Help Winners or Losers?', *Journal of International Economics*, **37**, 197-218.

Norman, Victor D. and Anthony J. Venables (2004), 'Industrial Clusters: equilibrium, welfare and policy', *Economica*, Vol71, pp. 543-558.

Snow, A. and R.S. Warren (1996). 'The Marginal Cost of Funds: Theory and Evidence', *Journal of Public Economics*, **61**, 289-305.

Figure 1: Nash equilibrium subsidy vs number of countries/firms

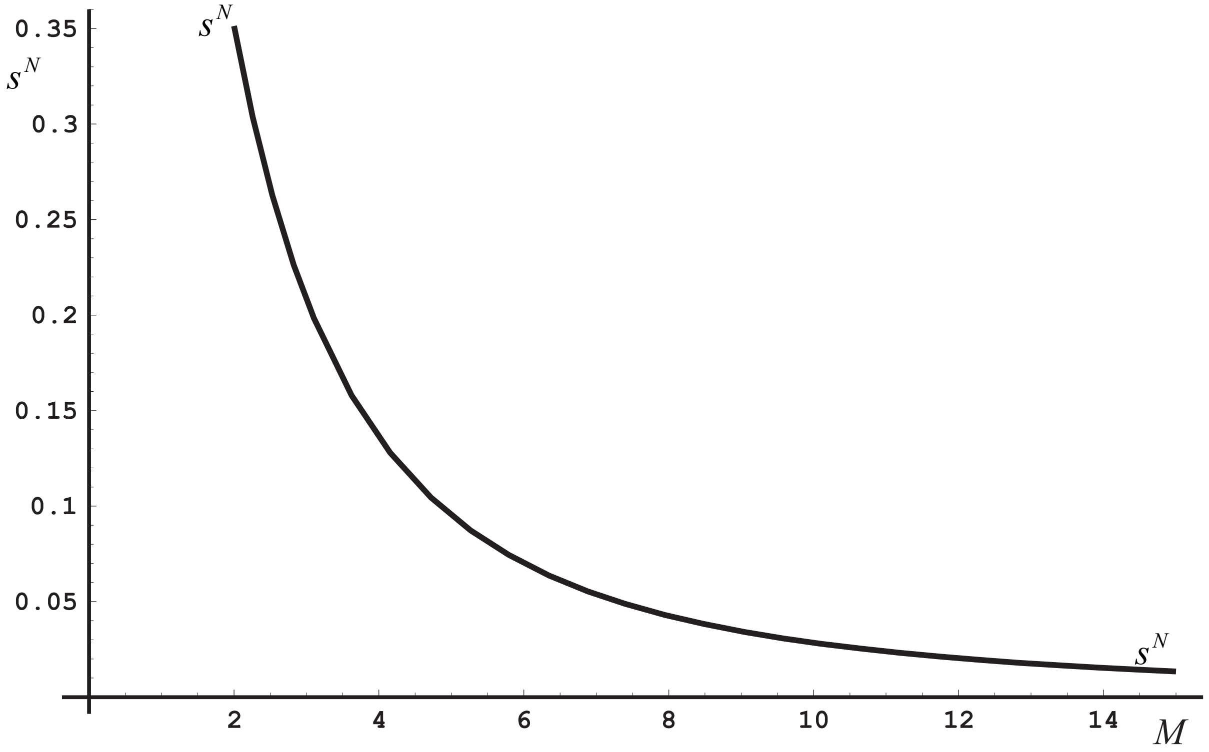

Figure 2: Critical value of opportunity cost vs number of countries/firms

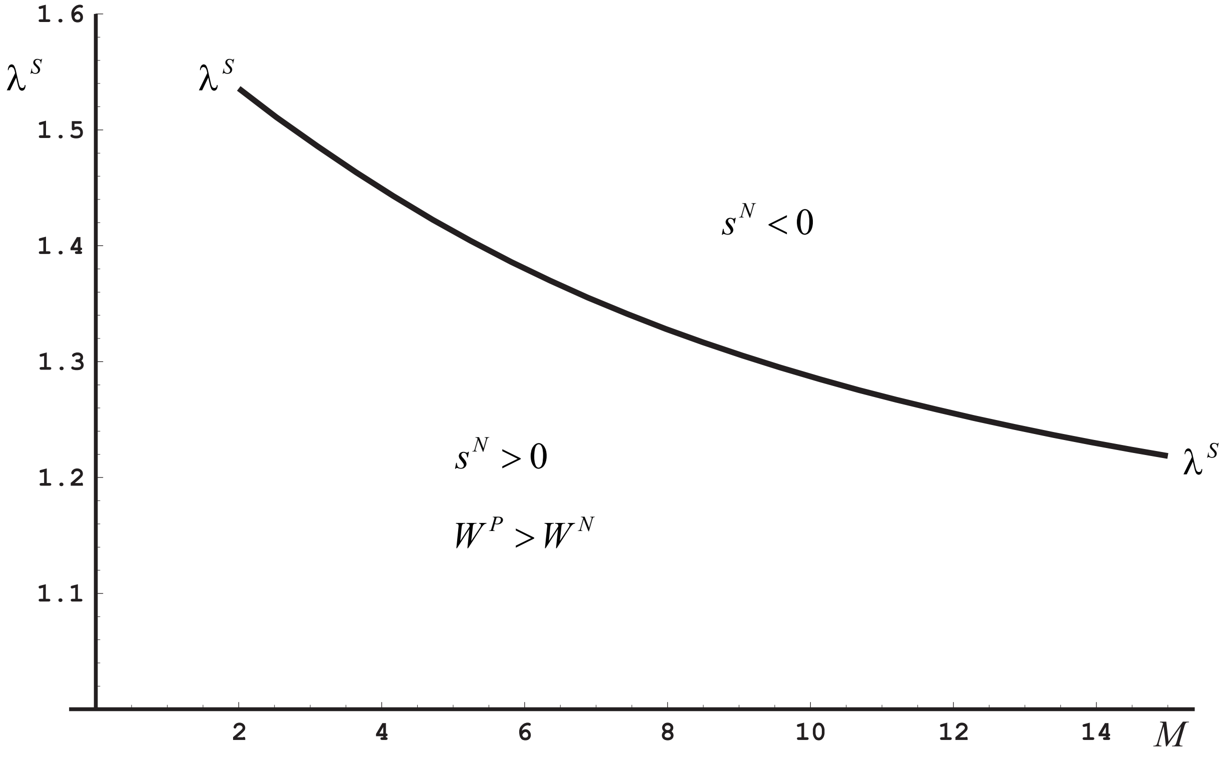

Figure 3: Nash equilibrium subsidy vs effectiveness of investment

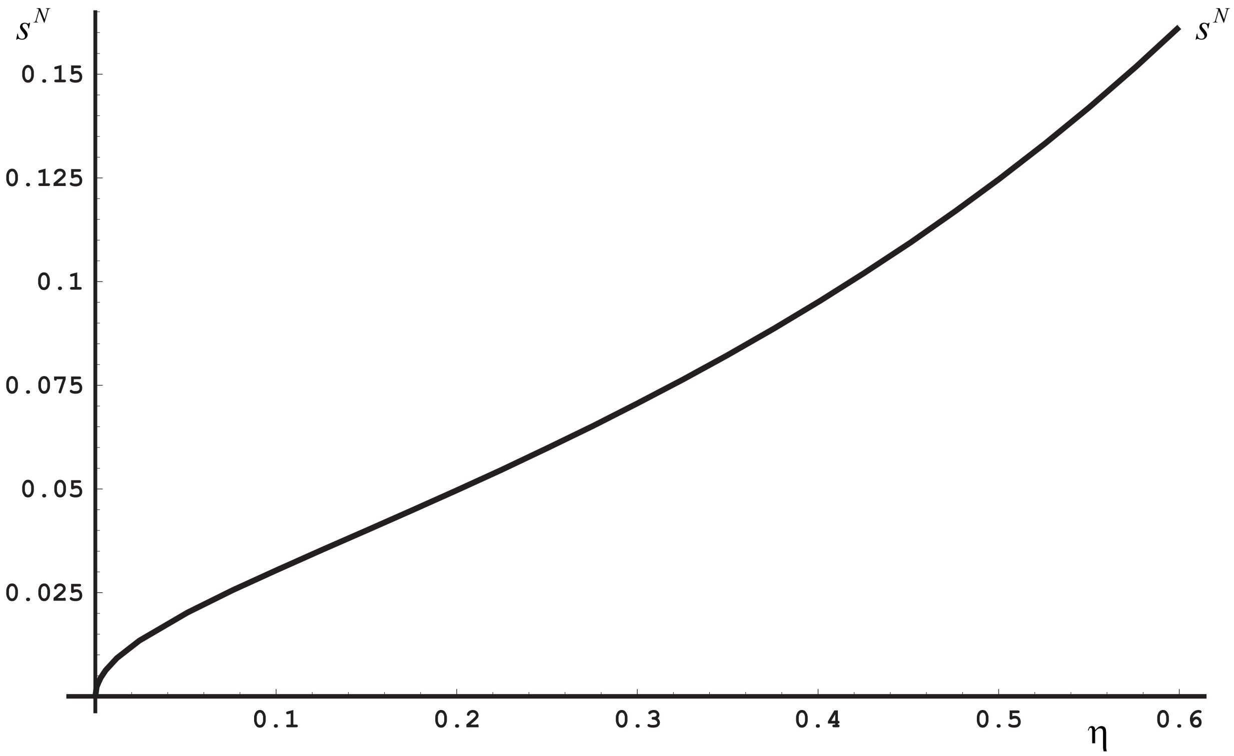

Figure 4: Critical value of opportunity cost vs effectiveness of investment

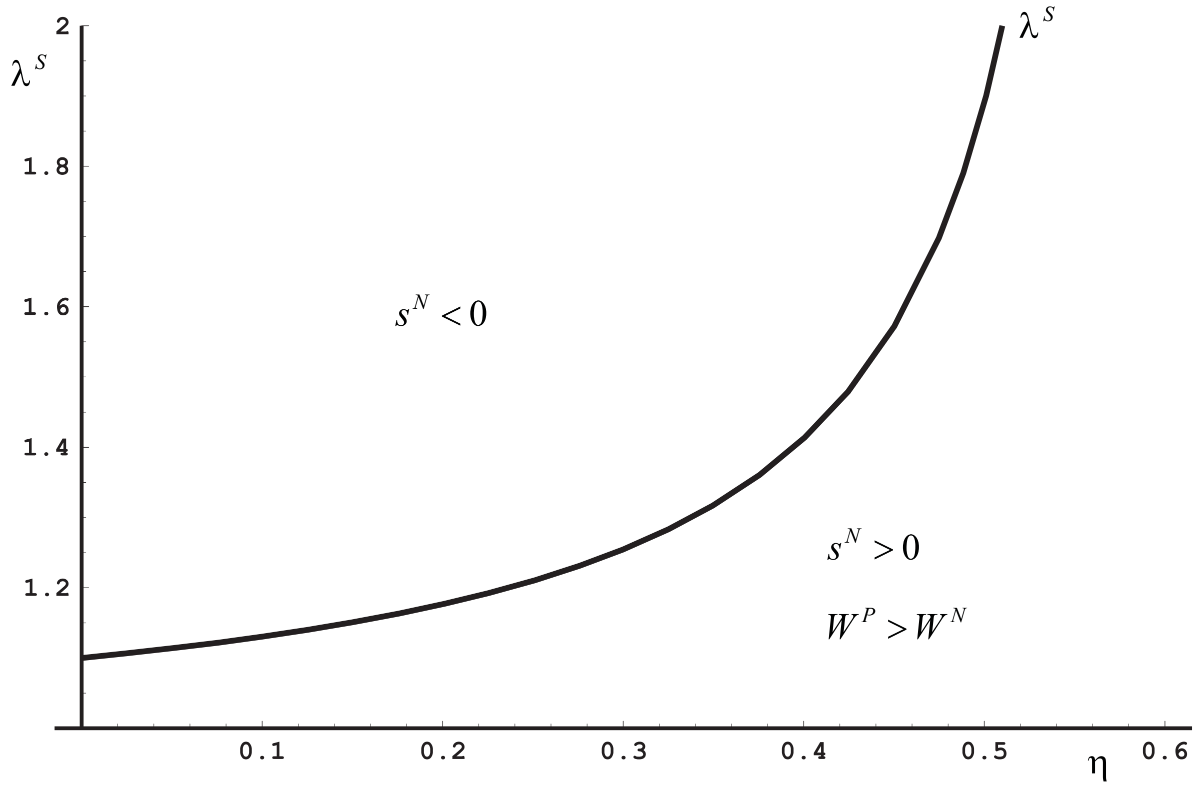

Figure 5: Nash equilibrium subsidy vs spillovers

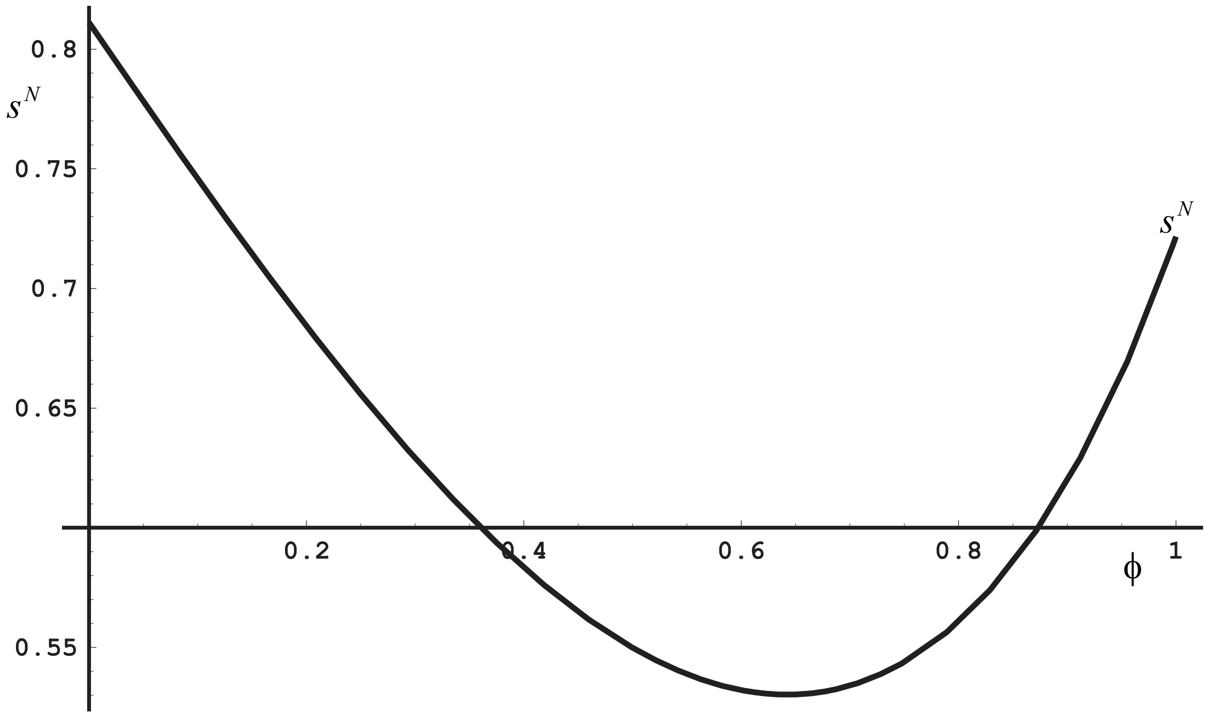

Figure 6: Critical values of opportunity cost vs spillovers

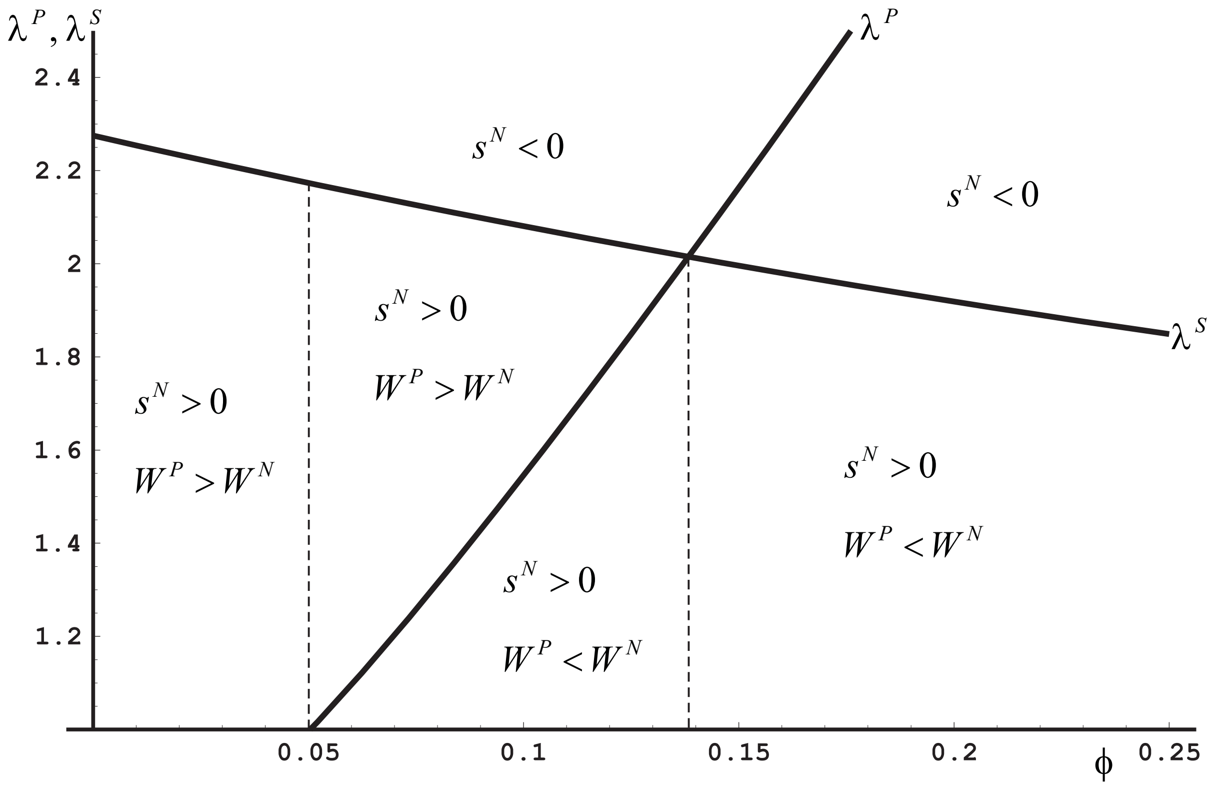

Figure 7: Nash equilibrium subsidy vs effectiveness of R&D

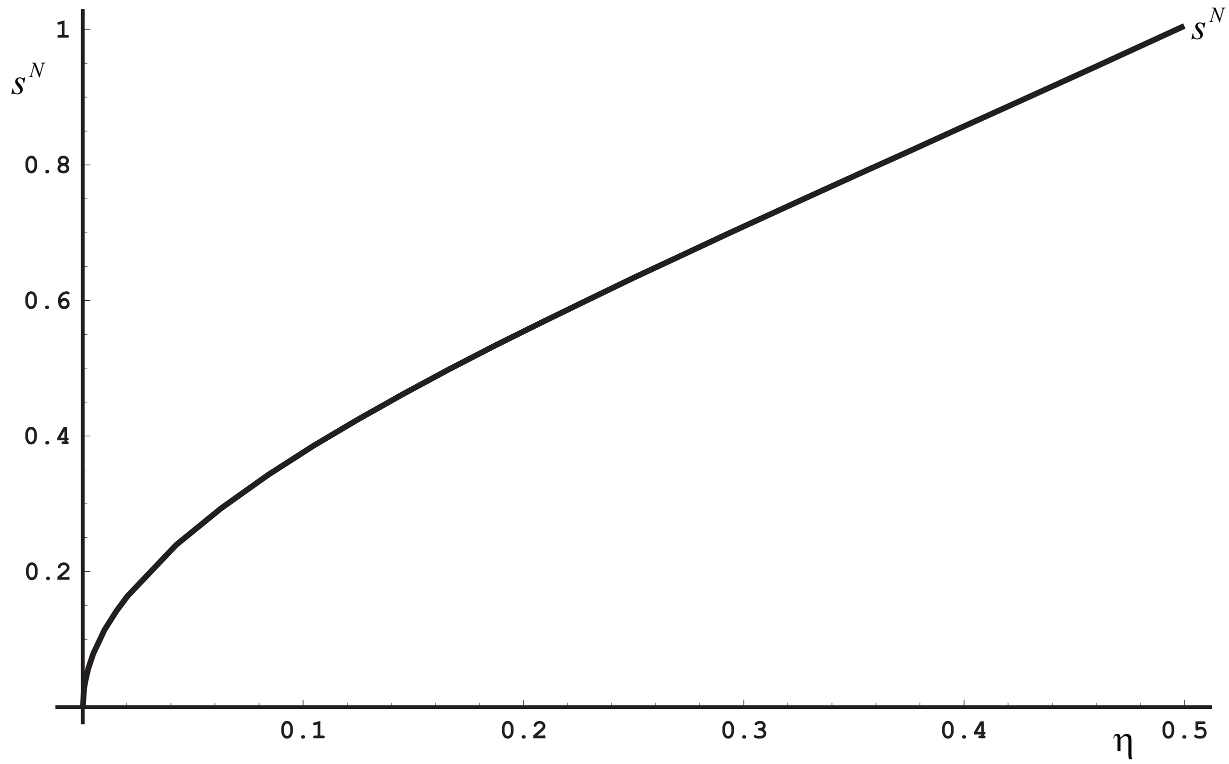

Figure 8: Critical values of opportunity cost vs effectiveness of R&D

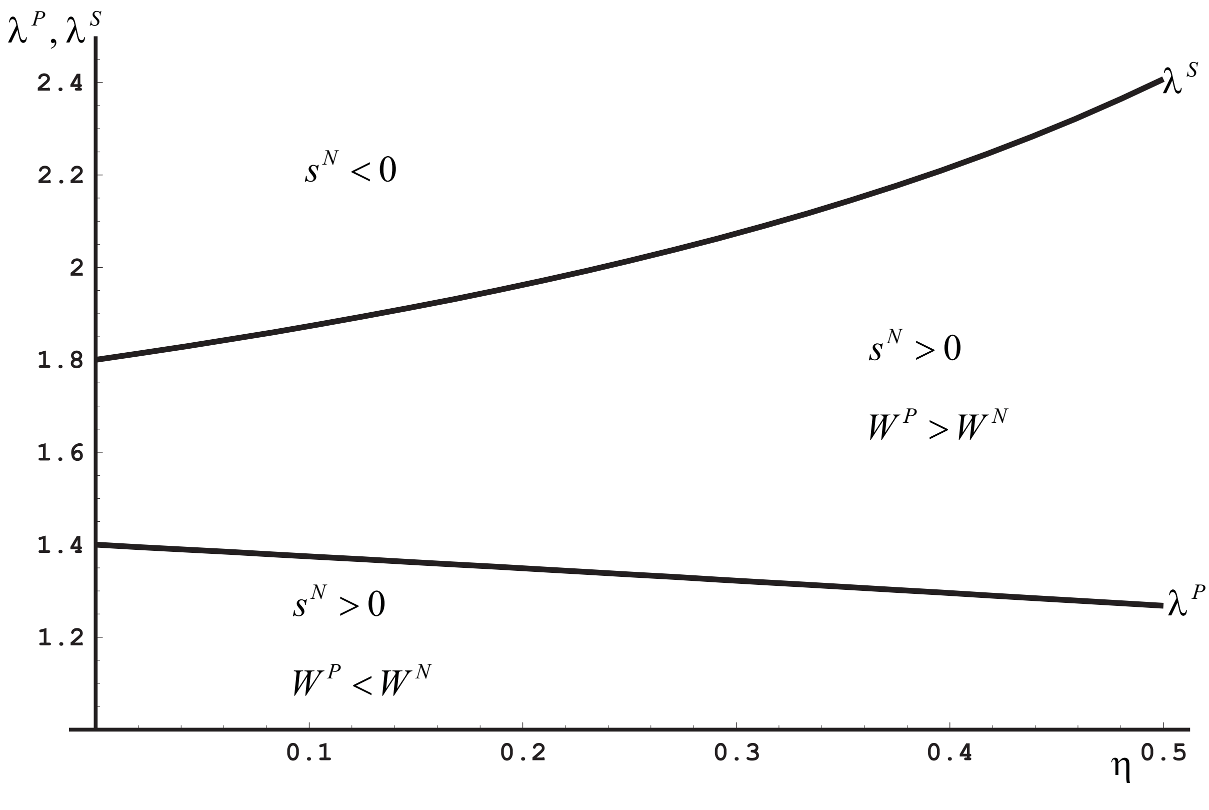

Figure 9: Nash equilibrium subsidy vs number of countries/firms

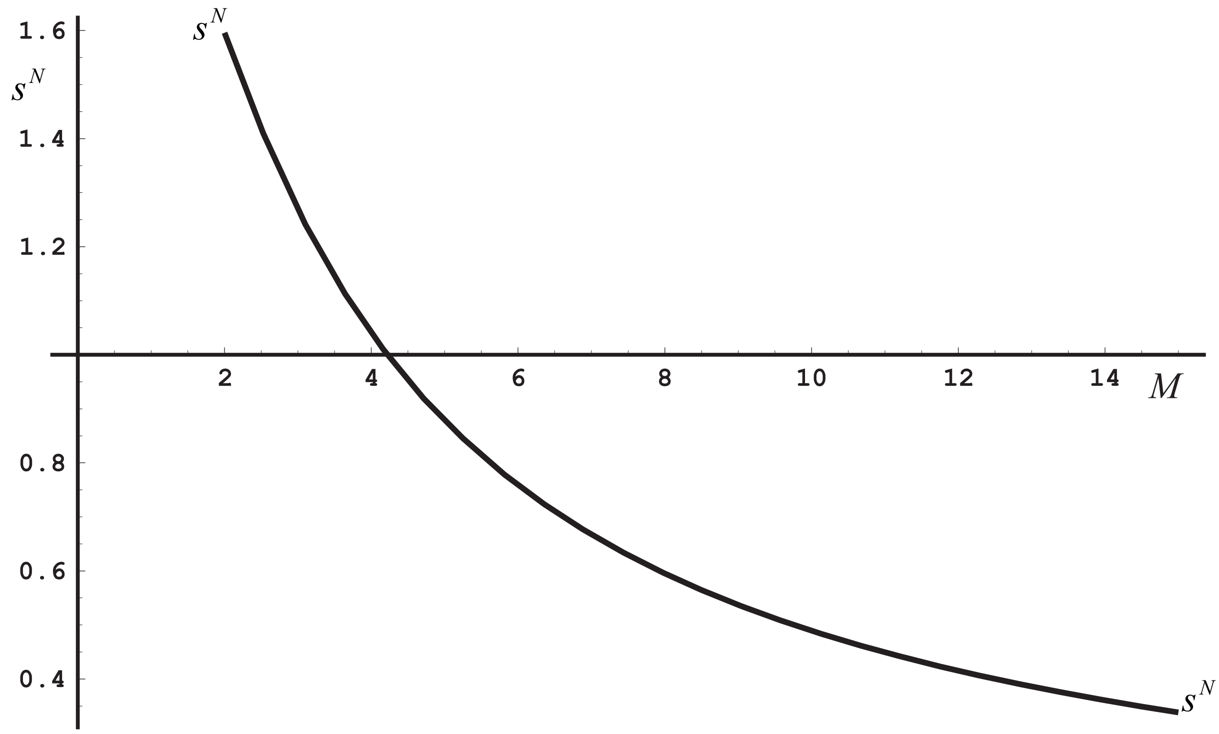

Figure 10: Critical values of opportunity cost vs number of countries/firms