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How large is the Swedish 'academic' sector really? A critical analysis of the use of science and technology indicators

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Abstract

Sweden is perceived to be top ranking, and a 'role model', in terms of its volume of academic R&D. This perception is based on analyses using two standard indicators. We assess the validity of these and argue that institutional features skew the result in favour of a high ranking. Swedish academic R&D is more appropriately characterised as average, or below average, in terms of input and above average in terms of output. Science policy makers need to acknowledge this and devise policies that strengthen, rather than threaten the functioning of an efficient system.

Keywords: R&D; Bibliometrics; Indicators; Academic sector; Sweden

1. Introduction

Two areas in which Keith Pavitt excelled were science policy and indicators of scientific and technological activities. He also showed a keen interest in, and a remarkable knowledge of, the small Nordic country of Sweden. In this paper, we honour him and his exceptionally critical mind, by questioning the use of science and technology indicators to construct an image, indeed shared by himself, of Sweden as a top-ranking nation in terms of its volume of academic research (see e.g. Pavitt, 2001; Salter et al., 2000; Sörlin and Törnqvist, 2000).[1]

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This perception of Sweden has had two consequences. First, Sweden has sometimes been put forward as a 'role model' in terms of its investment in academic R&D (European Commission, 2003). Second, the perception has constituted the starting point for a discussion on how well that R&D is transformed into industrial, economic and societal gains. In particular, the apparent strength in terms of the volume of Swedish academic R&D is contrasted with a poor performance of Sweden in terms of a low share of R&D-intensive products, insufficient technology-based entrepreneurship and poor economic growth. Thus, to an even higher degree than in the European Union in general (Muldur and Soete, 1994), a paradox is perceived to exist between the apparent strength of the academic sector and the apparent poor use of this strength (Goldfarb and Henrekson, 2002; Henrekson and Rosenberg, 2000; Sörlin and Törnqvist, 2000).[2]

The notion of a paradox is widely spread in Sweden and could be said to constitute a 'dominant belief', or conventional wisdom. For instance, one of the main funders of academic research, VINNOVA, suggests that: "...the knowledge and results from research are not efficiently transformed into firm formation and growth" (Vinnova, 2003, p. 1, our translation).[3] As a dominant belief, it is probably essential in explaining recent trends in science policy towards emphasising 'useful' science, with 'useful' denoting science that can and will directly and visibly be implemented into, or in other ways be valuable to, industry and society at large. This belief and the present science policy are, thus, closely linked: with such a science policy, the strength of the academic sector can be better exploited and society will gain more from the (many) monies spent on academic research.[4]

However, the validity of this 'dominant belief', and the relevance of Sweden as a 'role model', rests on the accuracy of the two standard indicators used to measure the volume of academic R&D: academic R&D expenditure (an input measurement), and publications (an output measurement). On the input side, the Swedish *share of R&D in the higher educational sector as related to GDP* is the highest in the world (Pavitt, 2001; Salter et al., 2000, Table 5) and about *double* that of the average of the OECD countries (Henrekson and Rosenberg, 2000). Likewise, when it comes to output, Sweden ranks very high as regards the *number of scientific articles published* (in *science and engineering*) set in relation to GDP (Henrekson and Rosenberg, 2000; Vinnova, 2001).

The objective of this paper is to critically assess the validity of these indicators and, by implication, the image of Sweden as a top-ranking nation in terms of the volume of its academic R&D. Our contribution to the policy debate is therefore primarily focused on an analysis of the 'yardsticks' used to measure the volume of scientific activities, and not on scrutinizing the whole basis for the 'paradox'.[5] We will point to a set of problems in the use of these standard indicators, when these are applied without appropriate attention paid to institutional differences between countries.

We will argue that the conventional way of measuring input is inappropriate and skews the results in favour of a high Swedish ranking. Instead, using a measurement that takes into consideration institutional choices in Sweden, we show that the volume of R&D is not very different from that of other developed countries. In terms of the output indicator, we argue that high ranking in terms of number of publications per GDP is a reflection not only of a high scientific activity but also of institutional features. Tentatively, we suggest that there are three such features which may lead us to overestimate the volume of academic R&D in Sweden. However, by encouraging an international exposure of the results of the R&D, the very same insti-

[2] This discussion is part of a larger one on the 'Swedish Paradox' where a high ranking in terms of overall R&D expenditures, scientific publications and patenting is contrasted with a low ranking in terms of economic growth or some other variable (see e.g. Edquist and McKelvey, 1998; Andersson et al., 2002; Edquist, 2002).

[3] The citation refers not only to academic R&D but to all R&D. Other illustrative examples of this dominant belief can be found in an analysis of discourses on science by Sweden's strategic research bodies (Hellström and Jacob, 2004).

[4] The Swedish debate naturally links into a broader one in the OECD countries, where science is more and more expected to be of direct societal, industrial and economic use and where the academic sector is closely scrutinized in terms of its performance.

[5] A complete scrutiny of the 'paradox' would entail analysing not only (a) the strength of Swedish academic R&D, but also (b) what type of societal, industrial and economic gain academic output may lead to, and (c) how well Sweden—as compared to other countries—transforms academic results into such gains. As far as we know, there has been no such study.

tutional features are very likely to raise the value of that R&D. In sum, therefore, in an international perspective, Swedish academic R&D can be characterised as being average (or even below average) in terms of volume of inputs and above average in terms of value of output; it is, thus, not as large as conventionally believed, but it appears to be efficient.

To the extent that we are right, a great deal of reflection is required as regards the appropriateness of policies based on the belief that the volume of academic R&D is outstanding in Sweden, in particular on the input side. Science policy makers need to be aware of the risks that recent policies may jeopardize the functioning of a good system. An up-scaling of the volume of funding may be warranted, but perhaps most importantly, the attention of policy makers ought to be less focused on science policy and more on the broader innovation policy which defines the context in which science is exploited commercially.

A reflection is required not only by Swedish science policy makers but also by those who suggest that Sweden should be seen as a 'role model' for science policy makers in other countries. If at all, Sweden may act as a 'role' model in the manner in which the resources are used, i.e. in the nature of the institutional features that encourages an international exposure of the results of the R&D, but not in terms of the volume of the resources allocated to academic R&D.

The remaining parts of the paper are structured in the following way. In Section 2, we present the conventional wisdom of the size of the Swedish academic

Table 1
Expenditure on R&D as a percentage of GDP by different sectors around 2001, for all fields of science for a number of rich countries (ranking within parentheses)

Country	1 Gross domestic expenditure on R&D–GERD—as a percentage of GDP	2 Business enterprise expenditure on R&D–BERD—as a percentage of GDP	3 Higher education expenditure on R&D–HERD—as a percentage of GDP
Israel	4.81 (1)	3.52 (1)	0.82 (2)
Sweden	4.27 (2)	3.31 (2)	0.83 (1)
Finland	3.40 (3)	2.42 (3)	0.62 (3)
Japan	3.09 (4)	2.28 (4)	0.45
Iceland	3.06 (5)	1.80	0.58
Korea	2.96	2.25 (5)	0.31
United States	2.82	2.10	0.40
Switzerland (2000)	2.63	1.95	0.60 (4)
Germany	2.49	1.76	0.40
France	2.20	1.37	0.41
Denmark (1999)	2.19	1.42	0.43
Singapore	2.13	1.34	0.50
Belgium (1999)	1.96	1.40	0.47
Canada	1.94	1.11	0.59 (5)
Netherlands (2000)	1.94	1.11	0.57
Austria	1.90	–	–
United Kingdom	1.90	1.28	0.41
Norway	1.62	0.97	0.42
Australia (2000)	1.53	0.72	0.41
Ireland (2000)	1.15	0.83	0.23
Italy (2000)	1.07	0.53	0.33
New Zealand (1999)	1.03	0.31	0.35
Spain	0.96	0.50	0.30
European Union (2000)	1.89	1.22	0.40
Total OECD	2.33	1.62	0.40

Source: OECD (2003): *Main Science and Technology Indicators*, 2003:1, OECD. Missing data for Luxembourg, Japan (adj.).

sector. Section 3 contains a critical assessment of the validity of the two main indicators used in the literature. Section 4 contains our main conclusions and some suggestions for further research.

2. The 'conventional wisdom'

This section presents the 'conventional wisdom' of the size of Swedish academic R&D. At the end of the section, we will point to three main weaknesses in the indicators conventionally used, and these will then be further explored in section three.

Looking more broadly at Sweden, it ranks second in terms of the input measure 'gross domestic expenditure on R&D as related to GDP', with a figure of 4.27% in 2001 (see Table 1). Sweden has the same ranking when it comes to 'business enterprise expenditure on R&D', but is number one as regards R&D expenditure in the 'higher educational sector, as related to GDP'. For all of the three figures given, the Swedish figures are about *twice as high* as the averages of both OECD and EU.

On the output side, Table 2 contains data on the total number of scientific articles published for all types of organisations, set in relation to GDP in 1999. Counting all fields of science, Sweden ranks as number two (column 1) and the position is kept if restricted to publications in natural sciences, engineering and medicine (column 2).

As both the input and the output side tell the same story, the case for arguing that Sweden is outstanding in terms of the volume of academic R&D seems to rest on solid ground. However, by the very nature of indicators, they are partial and only imperfectly mirror what we are really after, in this case the volume of scientific activity in the academic sector. As with other indicators, there are weaknesses in these two, which justify further work to ascertain the validity of the 'conventional wisdom' of the size of Swedish academic R&D.

First, although it is clear that academic R&D (and publishing) is done not only in the higher educational sector but also in government laboratories and private non-profit organisations, most studies—and thus the conventional picture—use the figures above (see column 3 in Table 1) which only include the higher educational sector. As the relative distribution of work between these three types of organisations varies substantially between countries, analysing data for the higher educational sector only, may be misleading. Second, there are a number of potential problems associated with a monetary measure of the volume of R&D. We will point to some of these and use 'time-expenditure' as an alternative indicator. Third, using bibliometrics as an indicator of the volume of academic R&D in cross-country comparisons is fraught with problems (such as an English language bias) and we will discuss some of these.

Table 2
Number of published scientific articles for all types of organisations in a number of rich countries, set in relation to GDP[a] in 1999 (ranking within parentheses)

Country	1 Number of articles in all fields of science per GDP, 1999 ($\times 10^3$)	2 Number of articles in natural science, engineering and medicine[b], 1999 per GDP ($\times 10^3$)
Israel	42.9 (1)	39.3 (1)
Sweden	38.6 (2)	36.7 (2)
Switzerland	34.0 (3)	33.1 (3)
Finland	33.4 (4)	31.5 (4)
New Zealand	32.3 (5)	28.1 (5)
United Kingdom	28.6	25.4
Denmark	28.2	27.0
Australia	25.8	23.0
Netherlands	24.9	22.8
Canada	24.3	21.6
Singapore	20.6	19.4
France	19.7	19.1
Norway	19.5	17.8
Belgium	19.4	18.5
Germany	18.4	17.8
United States	17.7	15.5
Austria	17.2	16.6
Spain	16.3	15.9
Iceland	15.3	13.7
Japan	15.1	15.0
Ireland	12.7	11.8
Italy	12.4	12.2
South Korea	10.4	10.3
Luxembourg	1.5	1.2

Source: NSF (2002): *Science and Engineering Indicators*, National Science Foundation, USA, and OECD (2003), *Main Science and Technology Indicators*, 2003:1 for data on GDP.

[a] Given in Million current PPP$.

[b] *Natural Sciences, Engineering and Medicine* includes the following categories: clinical medicine, biomedical research, biology, chemistry, physics, earth & space, engineering & technology, mathematics.

3. A critical assessment of the validity of the indicators used

In this section the potential weaknesses outlined above will be explored in some detail. We will first broaden the range of actors measured, and then suggest an additional input indicator. We will then proceed to discuss weaknesses in the standard output indicator.

3.1. Broadening the range of actors performing ‘academic’ work

As already pointed out, academic R&D and publishing are undertaken in three types of organisations; higher educational organisations, government research bodies, and private non-profit organisations.[6] For instance, in Germany, both basic and applied academic work is done, and papers are published, by researchers working in the Max Planck and Fraunhofer societies, but these activities are classified under ‘government research bodies’ (Personal communication with Elena Bernaldo de Quirós, OECD, April 17, 2003). In the US, public laboratories, such as the defence related research lab DARPA, pursue research and are in many ways similar to university departments (Bozeman, 2000).

The organisation of scientific work carried out outside of industry varies greatly between countries. The example of R&D in solar cells may illustrate this in the cases of Germany and Sweden. In Germany, one of many universities that carry out R&D in this field is the University of Stuttgart (IPE), where basic R&D was undertaken for a particular thin-film design. When research had progressed to a point where the efficiency had reached a certain level, the design was transferred to a research institute (ZSW) funded by the Federal and Land Baden Wurtenberg governments as well as by firms. At this institute, the efforts were focussed on up-scaling the technology (i.e. making the solar cell larger, developing the required production technology and on commercialising the technology) (Jacobsson et al., 2004).

A nearly identical design approach was explored at the University of Uppsala in Sweden. In this instance it was, however, the same group within the University that undertook the basic research and the applied (up scaling) work, as well as the initial commercialisation efforts.[7] Hence, similar research and development were performed in Germany and Sweden but in *different organisational settings*. Clearly, to measure only the part of the work done in the German higher educational sector, and then to contrast this with the Swedish case, would greatly underestimate the size of the German R&D effort.

Of course, this case of R&D in solar cells is not unique. Substantial R&D activities are undertaken in government laboratories and in private non-profit organisations in a range of countries. Table 3 displays the distribution of R&D over higher educational organisations, government research bodies, and private non-profit organisations (henceforth jointly labelled ‘non-business’ R&D) around 2001. Several observations can be made.

First, while 56–60% of the ‘non-business’ R&D is on average performed by the higher educational organisations in the OECD and EU respectively, the corresponding figure was 87% for Sweden (column 1). Thus, Sweden shows an extreme concentration of such R&D to the higher educational sector. In other words, Sweden has a very different organisational set-up as compared to nearly all[8] other rich OECD countries, both larger, such as United States and Germany, and smaller countries, such as Finland and Denmark.

The Swedish pattern is the result of a policy choice, which for decades has meant that the Universities, in particular, the Universities of Technology, have been responsible for sectoral R&D (Edqvist, 2003; Sörlin and Törnqvist, 2000). This sectoral R&D includes a great deal of applied work and some of it has been mission-oriented, for instance the very substantial funding of work in renewable energy technology (Johnson and Jacobsson, 2001).

Second, R&D in Government bodies is small in Sweden, about 12%. This is probably mainly military R&D, which is the exception to the rule of placing ‘non-business’ R&D in the higher educational sector (Edqvist, 2003). In other countries, the activities are more substantial, with an average of 34 and 38% for

[6] Publishing is also done by some researchers in private industry.

[7] A spin-off firm pursuing further commercialisation work has recently been established.

[8] Only Switzerland has a slightly higher share than Sweden.

Table 3
Distribution of 'non-business' gross domestic expenditure on R&D (GERD) over different types of organisations (for all fields of science and technology) for a number of rich countries, around 2001 (ranking within parentheses)

Country (around 2001)	1 Percentage of R&D expenditure by higher educational sector	2 Percentage of R&D expenditure by government sector	3 Percentage of R&D expenditure by private non-profit organisations[a,b]
Switzerland (2000)	87.74 (1)	4.98	7.28 (4)
Sweden	87.00 (2)	12.56	0.45
Belgium (1999)	84.15 (3)	11.62	4.23
Canada	71.29 (4)	28.00	0.71
Ireland (2000)	71.28 (5)	28.72	n.a.
Netherlands (2000)	67.91	30.23	1.86
United Kingdom	65.85	29.85	4.31
Spain	64.92	33.40	1.68
Singapore	64.13	35.87	n.a.
Norway	63.77	36.23	n.a.
Israel	63.43	23.13	13.43 (2)
Finland	62.63	35.29	2.08
Italy (2000)	62.12	37.88	n.a.
Denmark (1999)	55.43	41.43	3.14
United States	55.25	27.24	17.51 (1)
Japan	55.13	36.12	8.75 (3)
Germany	54.42	45.58 (5)	n.a.
Australia (2000)	51.13	43.58	5.28
France	49.20	47.07 (4)	3.72
New Zealand (1999)	48.79	51.21 (2)	n.a.
Iceland	45.63	48.79 (3)	5.58 (5)
Korea	43.70	52.10 (1)	4.20
Total OECD	56.91	34.21	8.88
EU (2000)	59.55	37.92	2.53

Source: OECD (2003), *Main Science and Technology Indicators* 2003-1, OECD.

[a] Data not available for the private non-profit organisations for Ireland, Singapore, Italy, New Zealand but assumed as negligible.

[b] For Germany and Norway data on the private non-profit organisations is not given by OECD. However, according to Bernaldo (Personal communication with Elena Bernaldo de Quirós, OECD–STI/EAS, April 17, 2003) and OECD (2000) the figures are included in the figures for the government sector.

OECD and EU, respectively (column 2). In some instances, about half of the 'non-business' R&D is undertaken in this organisational form (Korea, New Zealand, Iceland), while for the majority of the OECD countries the figure is 20–40%.

Third, private non-profit organisations are of some importance in a few countries and therefore need to be included in the analysis. This is particularly the case in US, Israel and Japan with a share of 8–17.5%. The average for EU is 2.5%, while it is 8.9% for the OECD. The Swedish share is low, less than 1%, along with countries such as New Zealand, Canada and Ireland.

Hence, while the higher educational sector plays a central role in most countries' 'non-business' R&D, it nevertheless varies in importance relative to government laboratories and private non-profit organisations. In a range of developed countries (e.g. Korea, Germany, New Zealand, France, Australia), about half of this R&D is carried out by government organisations and private non-profit organisations. In Sweden, on the other hand, this share is only about 13%. Thus, Sweden—along with Switzerland and Belgium—has an unusual way of *organising* 'non-business' R&D. In the Swedish case, the higher educational sector is charged not only with work of a fundamental nature but also with highly applied work, where much of it is directed by actors outside of academia (Sandström et al., 2004). The Swedish higher educational sector is, therefore, conducting enquiries, which, in other countries, are undertaken within different organisational forms.[9]

Another problem with focussing on the higher educational sector alone is that the procedure for classifying 'non-business' R&D varies between countries. This implies that the individual category does not always include comparable entities. As OECD notes, there are 'differences in the coverage of the Higher Education and Government sectors due to institutions at the "borderline" of the two' (OECD, 2003b, General methodology, p. 5). While in Germany, the Fraunhofer and Max Planck societies are classified as 'government research bodies', in France, the National Centre for Scientific Research is included in the higher educational sector, whereas in Italy, the corresponding organisation is included in the government sector. In Denmark, all research performed by university hospitals is included in the government sector and therefore the Danish R&D data for the higher educational sector is underestimated (OECD, 2003b, General methodology).[10]

For both these reasons, it is clear that if we are to compare the volume of academic R&D in different countries, a measurement that is limited to the higher educational sector is insufficient and inappropriate. *This is particularly important if the comparison involves Sweden since it has made a conscious decision to organise 'non-business' R&D differently from most other countries*. A valid indicator of the strength of 'academic' R&D (and of the competence base outside of industry) therefore has to include R&D undertaken in government and private non-profit organisations, in addition to the higher educational sector. We suggest, therefore, that the higher educational organisations, government research bodies, and private non-profit organisations are seen as three sub-sectors in an 'extended academic sector',[11] which then corresponds to 'non-business R&D'.

Widening the scope of analysis reveals a substantially different picture from that which comes out of an analysis of the higher educational sector alone (i.e. that conventionally used in the literature). Table 4 shows the expenditure on R&D as a percentage of GDP in the different parts of an 'extended academic sector' around 2001, for all fields of science. From the table (column 1), we can observe that as regards R&D in the higher educational sector— HERD—Sweden ranks first before Israel[12] and Finland (as expected—see Table 1).

However, this advantage is substantially reduced (column 4) if we also include the other two types of organisations in the analysis. Indeed, for the total 'extended academic sector' expenditure on R&D—AERD—as a percentage of GDP, Sweden not only drops to fourth place but, most importantly, the ratio between Sweden and the average for the OECD and EU is reduced from about 2 (in column 1) to about 1.3–1.4 (in column 4). Thus, allowing for *different organisational choices* with respect to undertaking research in an 'extended academic sector' greatly alters the picture.

In Table 4, the data covers all fields of science, including social sciences. For the fields of greatest importance to the generation of economic growth—the natural sciences, engineering and medical fields—data is, unfortunately, only available for a smaller number of countries (see Table 5). In particular, it is important to note that two of the countries, which are ranked above Sweden in Table 4—Israel and Finland—are not included due to missing data. Even so, two main observations can be made from Table 5.

First, the Swedish ranking remains first for the higher educational sector (column 1), and fourth for the widened definition of the academic sector (column 2). However, given the substantial advantage of both Israel and Finland over Sweden in Table 4, it is probable that the Swedish ranking would have been

[9] We do not in this paper assess or discuss whether or not the Swedish choice of organisation set-up is beneficial, or if it had been preferable to select a different mix between the three organisational forms.

[10] Also, in Switzerland publicly owned firms are included in the government sector, rather than in the industry sector (OECD, 2003a).

[11] We are aware that there are some risks involved in this extension and we would suggest that further work is done on this issue. In particular, we would suggest that work is done to see the effects of including highly mission and applied government laboratories in the 'extended academic sector'. Whereas, we have argued that such work, with the exception of military applications, is done in the higher educational sector in Sweden, we are not familiar with how its magnitude differs between countries. Nor do we know to what extent Bozeman's (2000) observation that there is a small difference only between universities and government laboratories holds for other countries.

[12] Interestingly, one of the referees suggests that the R&D expenditures for Israel is 'vastly inflated, with up to 1/5 of them practically invented'.

Table 4
Expenditure on R&D as a percentage of GDP in the different parts of an 'extended academic sector' around 2001, for all fields of science (ranking within parentheses)

Country	1 Higher education expenditure on R&D–HERD—as a percentage of GDP	2 Government sector expenditure on R&D–GOVERD—as a percentage of GDP	3 Private non-profit sector expenditure on R&D–NERD—as a percentage of GDP*,**	4 Total 'extended academic sector' expenditure on R&D–AERD—as a percentage of GDP
Israel	0.82 (2)	0.30	0.17 (1)	1.29 (1)
Iceland	0.58	0.62 (1)	0.07 (3)	1.26 (2)
Finland	0.62 (3)	0.35 (5)	0.02	0.98 (3)
Sweden	0.83 (1)	0.12	0.00	0.95 (4)
Netherlands (2000)	0.57	0.25	0.02	0.83 (5)
France	0.41	0.39 (2)	0.03	0.83
Canada	0.59 (5)	0.23	0.01	0.82
Japan	0.45	0.29	0.07 (4)	0.81
Australia (2000)	0.42	0.35	0.04	0.81
Singapore	0.50	0.28	0.00	0.78
Denmark (1999)	0.42	0.32	0.02	0.77
Germany	0.40	0.33	0.00	0.73
United States	0.40	0.20	0.13 (2)	0.72
New Zealand (1999)	0.35	0.37 (3)	0.00	0.72
Korea	0.31	0.37 (4)	0.03	0.70
Switzerland (2000)	0.60 (4)	0.03	0.05 (5)	0.69
Norway	0.42	0.24	0.00	0.66
Austria (1998)	0.53	0.11	0.01	0.65
United Kingdom	0.41	0.18	0.03	0.62
Belgium (1999)	0.47	0.06	0.02	0.56
Italy (2000)	0.33	0.20	0.00	0.53
Spain	0.30	0.15	0.01	0.45
Ireland (2000)	0.23	0.09	0.00	0.32
Total OECD	0.40	0.24	0.06	0.71
EU (2000)	0.40	0.26	0.02	0.67

Source: OECD (2003), *Main Science and Technology Indicators* 2003:1, OECD. (*) Data not available for NERD for Ireland, Singapore, Italy, New Zealand but assumed as negligible. (**) For Germany and Norway data on the private non-profit organisations is not given by OECD but are included in the figures for the government sector (Bernaldo, 2003; OECD, 2000).

sixth had data not been missing for these two countries. Second, and most importantly, the ratio between the Swedish figure for the 'extended academic sector', and the average for all countries is only 1.2 whereas it is 1.8 if we only include R&D in the higher educational sector.

In sum, it is clear that all three sub-sectors within an 'extended academic sector' need to be included in order to compare the volume of Swedish 'academic' R&D with that of other countries. This reveals a quite different picture from that portrayed by 'conventional wisdom'—the monetary resources allocated to 'academic' R&D in Sweden are broadly in parity with other OECD countries.

3.2. *Using time as an alternative indicator of input to R&D*

In order to assess the volume of input to the academic sector, the common gauge is R&D expenditure as related to GDP, but the volume of input could be measured in alternative ways. Indeed, even though the indicator 'R&D expenditure' is commonly used, there are a number of potential problems associated with a monetary measure. This section will point to a few such weaknesses and compare the monetary indicator to that of 'time-expenditure'.

Some problems with a monetary measure are due to differences in reporting procedures between coun-

Table 5
R&D in Natural Sciences[a] and Engineering divided by GDP (10^{-3}) in the 'extended academic sector' in a set of countries, about 1995 (R&D expenditure given in monetary terms) (ranking within parentheses)

Country	1 Higher educational sector (HES)	2 Total 'extended academic sector' (HES, government and private non-profit)	3 Share of HES in total
Iceland (1995)	3.70 (4)	9.38 (1)	0.39
Japan[b] (1995)	3.88 (3)	7.85 (2)	0.49
Australia (1996)	3.25	7.43 (3)	0.44
Sweden[c,d,e] (1995)	6.11 (1)	7.24 (4)	0.84 (1)
Denmark (1995)	3.40 (5)	6.43 (5)	0.53
Germany (1995)[d,f]	3.26	6.39	0.51
Canada (1995)[g]	2.62	5.21	0.50
Norway (1995)[h]	3.04	5.17	0.59 (4)
Austria (1993)	3.94 (2)	4.85	0.81 (2)
Spain (1995)	2.11	3.67	0.57 (5)
Ireland (1994)	2.06	3.12	0.66 (3)
Finland	n.a.	n.a.	n.a.
Korea	n.a.	n.a.	n.a.
Average of countries included in the table	3.40	6.07	0.58

Sources: elaboration on OECD (2000): *Basic Science and Technology Statistics*, Table 7, 1999 edition, Paris, France and OECD (2000a): *Main Science and Technology Indicators* 1999, number 1, Paris, France. If not otherwise indicated, the footnotes are based on the general methodology in OECD (2000) and a list provided by Elena Bernaldo of the OECD.

[a] Natural, medical and agricultural sciences.

[b] Overestimated or based on overestimated data. Until and including 1995, data is overestimated by international standards but the OECD has adjusted the figures downwards.

[c] Higher educational sector excludes most or all capital expenditure.

[d] The sum of the breakdown does not add to the total.

[e] Data are not available for private non profit sector. According to personal communication with Peter Skatt. Swedish Central Bureau of Statistics, April 14, 2003, many of the activities in this sector were reclassified in 1995 and moved to private industry and to government. R&D expenditure was therefore reduced from 330 million SEK in 1993 to 93 million SEK in 1995 in total. Three hundred and thirty million SEK represented 2.3% of total R&D in Government, Higher education and Private non-profit in 1993.

[f] According to Bernaldo (2003) the institutional coverage of the Government sector includes research institutes of federal Länderna and local governments e.g. the national research centres, the Max-Planck and Fraunhofer societies, Blue list institutions, scientific museums and libraries.

[g] Unrevised breakdown not adding to the revised total.

[h] Private non-profit is included in government.

tries. For instance, in the Swedish case, OECD (2000) notes that capital costs for the academic sector were partially excluded in the 1995 data. On the other hand, the sum spent on R&D is exaggerated as it includes some expenditure for education. To these problems, which are well known, we would like to add two additional ones; institutional differences in terms of how PhD students are funded and the use of fixed funding (block funding) for activities other than research.[13]

First, PhD students perform a substantial part of academic R&D. A measurement in monetary terms may then distort the comparison between countries where students are employed, and are paid salaries, and those countries where students are funded with grants.[14] In

[13] There are more problems which justify a scrutiny. One of those is how rents of facilities are handled in the accounting. In Sweden, rents are paid for by the Universities and account for a substantial part of the cost. For example, for Chalmers University of Technology, the figure was as high as 17% in 2002. Clearly, cross-country comparisons on the funds allocated to academic R&D may be marred by differences between countries in how rents for facilities are set and accounted for.

[14] The problem is broader than this. There is a great deal of uncertainty as to how much of the work done by PhD students is included in the data. In the UK, for example, we suspect that the work done by foreign students with their own income is not reported.

Sweden, PhD students accounted for as much as 44% of the person-years spent on R&D in engineering in 2001 (in the higher educational sub-sector) (SCB, 2003).[15] These students (at technical universities) are normally paid salaries.[16]

In 2003, an average PhD student would cost about 333,000 SEK annually in salary costs alone (on top of this, a great deal of overhead costs are added). This can be compared to, for instance, the case of the UK where PhD students may receive a grant of 6,000–9,000 pounds (Salter, 2003, personal communication at Imperial College, September 4), which is about SEK 84,000–126,000. This is, at most, one third of the salary cost of a Swedish PhD student in engineering.

If we for the Swedish case take the number of (employed) PhD students in engineering (2001)—2,511 (SCB, 2003 Table 11)—and assume an annual salary cost of SEK 333,000, we end up with an annual cost of SEK 836 million. If these students were paid a grant of about 7,500 pounds (the average figure) instead, the total cost would drop to about SEK 264 million. The discrepancy is as much as SEK 572 million. Total (current) R&D expenditures in engineering in the higher educational sector amounted to 4,067 million in the same year for Sweden (SCB, 2003, Table 19). Five hundred and seventy two million is in that context a large sum, 14%. Institutional differences of this kind can, thus, have a significant influence on inter-country comparisons.

Second, it is normally assumed[17] that the fixed (block) funding to Universities in Sweden can be used for research and it is fully included in the OECD R&D statistics. Much of that funding is, however, used for other purposes. These include the cost of teaching PhD students and the cost of PhD students attending courses (in the technical faculty this amounts to 20% of the students' time, for which they are paid a salary) as well as time for teachers to upgrade their knowledge. In 2001, and limiting ourselves to the faculty of engineering, of the 1,312 million SEK received in the form of fixed funding, about 500 was estimated to remain for research.[18] This means that out of the total sum available for R&D of about 4.1 billion SEK (current costs, including external funding of about 2.6 billion SEK, see SCB, 2003, Table 19), as much as about 800 million were estimated to be used for other purposes than R&D. While it remains to be seen if this use of block funding is unique to Sweden, these figures nevertheless suggest the possibility that the monetary indicator may well overestimate the Swedish volume of academic R&D.

An alternative indicator of the volume of R&D input is the number of person-years spent in R&D set in relation to population, i.e. a measure of R&D in terms of *time expenditure*. This indicator has, of course, also weaknesses. In particular, the problem of separating research from teaching would be the same as for the indicator using monetary values, but we would get away from the problem of different ways of funding PhD student work and the use of block funding for other purposes than R&D.

Data are given in Table 6 for a number of rich countries.[19] Four observations can be made. First, Sweden (with Austria) is again confirmed to be an unusual country when it comes to the share of the higher educational sector in total 'extended academic R&D' (column 3). Second, including only the higher educational sector (column 1) Sweden ranks high, but drops from number 1 to number 3, after Finland and Iceland, and is closely followed by Australia. Third, when we include

[15] This figure is a result of an elaboration on SCB (2003), Table 13. Moreover, as is seen in SCB (2003), Table 2, the number of employed PhD students (as opposed to those living on grants) increased greatly in the period 1989/90 to 2001.

[16] This is also true for some students at other types of universities.

[17] See, for instance, Civilingjörsförbundet (2004).

[18] This is a rough estimate, but it provides us with the right order of magnitude. We have limited ourselves to four personnel categories where data is available in terms of full time equivalents (SCB, 2003, Table 11): full professors (626), lecturers (940), PhD students with a salary (2511) and those without a salary (575). We made the following assumptions: (1) 20% of professors' time and 15% of lecturers' go to work to support teaching, e.g. keep up with the literature, (2) 20% of the PhD students' time goes to take PhD courses (we have assumed no costs for the 575 students without a post), (3) half of the supervision time ($0.5 \times 7.5\%$ of professor's time per student) is paid for by external funding, (4) there are 10 PhD students per course and each take two courses per year which leaves us with about 600 courses given per year. Each course is assumed to cost 10% of a professor's time, (5) 50 million SEK goes to examination of PhD students. The total sum amounts to 807 million SEK. We have assumed the following average salaries in SEK: PhDs, 18,000; lecturers, 36,000; professors, 44,000. We have left out costs for administration and for upgrading the knowledge of teachers without a PhD, which means that our calculation is conservative.

[19] Unfortunately, data for Israel are not available but as the data include a number of OECD countries, a cross-country comparison is still useful.

Table 6
Number of person years spent on R&D in Natural Sciences[a] and Engineering per million inhabitants, in selected countries around 1999 (R&D expenditure given in terms of time) (ranking within parentheses)

Country	1 Higher educational sector (HES)	2 Total 'extended academic sector' (HES, government and private non-profit)	3 HES/total
Iceland	1989 (2)	4271 (1)	0.47
Finland[b]	2107 (1)	3475 (2)	0.61 (6)
Australia (1998)	1468 (4)	2489 (3)	0.59 (8)
Denmark	1035 (7)	2126 (4)	0.49
Japan[c]	1231 (5)	1870 (5)	0.66 (4)
Norway[d]	1075 (6)	1806 (6)	0.60 (7)
Sweden[e]	1485 (3)	1769 (7)	0.84 (2)
Germany	955	1716	0.56
Spain	778	1317	0.59
Canada[f]	727	1287	0.56
Korea	757	1114	0.68 (3)
Austria (1998)[g]	813	950	0.86 (1)
Ireland	n.a.	n.a.	n.a.
Average of countries included in the table	1202	2016	0.63

Sources: OECD (2003a), R&D Database, kindly made available to us by Mr. Rolf Nilsson, Vinnova and CIA (2003) for population data. The population data is for 2003. If not otherwise indicated, the footnotes are based on the general methodology in OECD (2000) and a list provided by Elena Bernaldo of the OECD.

[a] Natural, medical and agricultural sciences.

[b] Private non-profit is included in the government sector.

[c] See Table 5, footnote a.

[d] Private non-profit is included in the government sector.

[e] OECD does not give Swedish data on R&D in government so we supplemented OECD with data from SCB (2001, Table 2 and Fig. 1). Data for the private non-profit sector is not given either but as was noted in footnote e in Table 5, the sum is negligible. Data for government is underestimated since it includes only central government units. This seems to be a general problem however (OECD, 2000, p. 494).

[f] National estimate or projection for the higher educational sector is adjusted, if necessary, by the Secretariat to meet OECD norms. Provisional data for the government sector.

[g] Only those post graduate students on the payroll of the university are included in R&D personnel in the higher educational sector.

all three sub-sectors (column 2), Sweden drops to 7th place (and if Israel were included, the ranking might even be as low as 8). Fourth, and most importantly, Sweden spent 1,769 person-years per million inhabitants whereas the average for the countries included in the table was higher, 2,016 person-years per million inhabitants.[20]

Hence, with the alternative indicator, 'time expenditure', the Swedish ranking is considerably lower than if we use money as the basis of the indicator, and, most importantly, the Swedish figure is lower than for the average of a group of rich OECD countries.

In Fig. 1, we compare, for a set of countries, the two indicators (a) R&D divided by GDP and (b) the number of person-years spent on R&D per million inhabitants, within natural sciences and engineering in the 'extended academic sector'. We can note that there is a clear trend line but that Sweden is placed well below that line. Although we would be very hesitant to draw strong conclusions from that observation, the weaker position of Sweden using time instead of money as the basis for measuring the volume of R&D in the 'extended academic sector' is at least consistent with the idea that there may be factors at work (such as the valuation of efforts by PhD students) that distort the results in favour of a stronger Swedish position. Further research is, however, required to check the validity and reliability of these data, and we would welcome such work.

To summarize, so far, and assuming that the data are reasonably accurate, the overall conclusion from both these indicators is clear: *rather than seeing Sweden as a top-ranking country, we should regard it as one out*

[20] Even if we exclude Iceland, the average figure for the remaining countries—1,811 person-years per million inhabitants—is larger than the figure for Sweden.

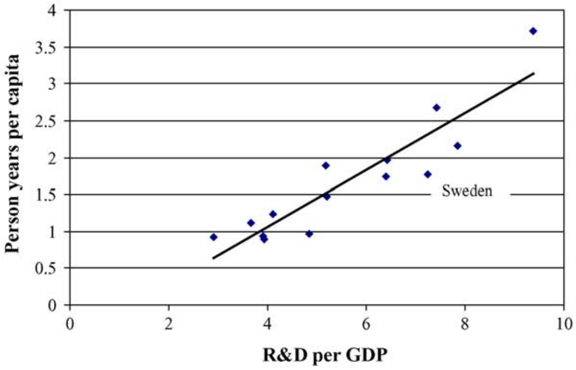

Fig. 1. Relationship between R&D divided by GDP and number of person years per capita spent on R&D within natural sciences and engineering in total 'extended academic sector' for 14 countries, about 1995. Note: (*) the diagram contains data from 14 countries (Australia, Austria, Canada, Czech Rep, Denmark, Germany, Hungary, Iceland, Japan, Norway, Poland, Portugal, Spain and Sweden). Sources: Elaboration on OECD (2000): *Basic Science and Technology Statistics* (Table 7, 1999 Edition, Paris, France); OECD (2000a): *Main Science and Technology Indicators* 1999 (number 1, Paris, France); OECD (2003a), R&D Database; and CIA (2003) for population data.

of many rich OECD countries in terms of allocation of resources to academic R&D. Sweden differs only in the manner in which that work is organised.

3.3. The measurement of output from the academic sector

The most common indicator of the volume of output from academic R&D is the number of publications as related to GDP.[21] Sweden ranks very high here (see Table 2), a standing which is intriguing considering that we have found that the allocation of funds and time to the 'extended academic sector' is similar to that of many other rich OECD countries. For instance, as seen in earlier tables, Sweden and Germany have, in relative terms, broadly the same input volume of R&D in the 'extended academic sector' (this is true both if we use monetary value or time (see Tables 4–6). However, in terms of output indicated by the number of published articles (set in relation to GDP, see Table 2) the Swedish figure is twice as high as that of Germany.

A combination of average (or below average) volume of input and above average volume of output in terms of publications is suggestive of an efficient academic sector. In addition, for two reasons, [22] extensive international publishing is likely to positively influence the *value* of that R&D, improving further the efficiency of the system. First, publishing in an international (in particular an English language) journal increases the scope of the audience, which means that the chances are greater for a particular finding to be used. Second, being exposed to the standards used in the international scientific community probably raises the level of research. Competition is greater—especially for a paper to be accepted in an English language journal, it has to compete with papers from all over the world—and the reviewer pool is larger and, on average, we would expect their comments to be more useful.[23]

Yet, whereas the extent of international publishing is an indicator of value of academic R&D, there are a number of potential problems in using publications as an indicator of the *volume* (not value) of scientific activity in cross-country comparisons. We will argue that Swedish institutional features make it likely that the high Swedish publication figures exaggerate, to an extent, the volume of 'academic' scientific activity.

First, whereas we would expect researchers in the entire 'extended academic sector' to publish, it is plausible that those in higher educational organisations do so to a greater extent simply because it matters more to them. For instance, Sörlin and Törnkvist (2000, p. 88) suggest that, in the case of Sweden: ". . .sectoral research was in practice taken over by the universities and came to an increasing extent to be conducted according to the norms of academia. . .this contributes to explain. . .Sweden's good performance in terms of scientific publishing" (our translation).

Bozeman (2000, p. 634) discusses in a similar way but also points to a rather small difference between universities and government laboratories in this respect:

[21] We are aware that this output indicator is limited and that there are other ways by which the results of academic R&D can be made socially useful, e.g. by spinning off firms. See Salter and Martin (2001) and Jacobsson (2002) on this point.

[22] We are grateful to two of the anonymous referees for pointing this out to us.

[23] The quality of Swedish academic R&D, as indicated by how often articles are cited, is ranked second in the world (Lattimore and Revesz, 1996; Vinnova, 2001; Pavitt, 2001). Clearly, this is another indicator of an academic sector, which generates above average value.

Table 7
The regression models tested to explain number of publications per GDP[a]

Model	Unstandardized coefficients		Standardized coefficients	T	Adjusted R^2	Sign.
	B	Standard error	β			
AERD	34	4.2	0.763	5.9	0.565	0.000
RDABS	46	7.4	0.784	6.3	0.599	0.000
RDABS + dummy	41	7.3	0.691	5.7	0.656	0.000[b]
	5.0	2.2	0.277	2.3		

[a] The models include analysis of 26 countries.
[b] RDABS is significant at 0.000 level and dummy is significant at 0.033 level.

"...in both university and the larger government laboratories, the reward system is largely based on scientific publications", but "University laboratories devote 44% of their activity to publishing scientific research, compared to 36% in government labs". As Sweden is unusual in terms of the organization of research (with a very heavy emphasis on the higher educational sector), this organisational difference may contribute to the high volume of output of scientific publications.

For a range of countries, we have tested to what extent output (the number of scientific publications, in all fields, per GDP adjusted for Purchasing Power Parity) is explained by the monetary input into the academic sector set in relation to GDP. We distinguish between the 'extended academic sector' (AERD) and the higher educational sector (RDABS).[24] In Table 7 (see Appendix 1 for a correlation matrix), we can see that the share of GDP that is allocated to research in the higher educational sector (RDABS) explains slightly more than the share, which is allocated to R&D in the 'extended academic sector' (AERD) (adjusted R^2 is 0.599 and 0.565, respectively).[25] Hence, a marginally better 'fit' is achieved, but the data also suggests that Sörlin and Törnqvist (2000) may overrate the importance of the size of the higher educational sector in explaining publishing patterns.[26]

Second, there is an English language bias in the journals represented in bibliometric databases (Pavitt, 1998). Publications in other languages than English may not be fully accounted for in such databases, resulting in an underestimation of the output for countries where publishing is made in other languages. This bias is reported to be strong.[27]

Many smaller countries may not even have scientific journals in their native language so researchers are referred to publishing in foreign journals.[28] Swedish researchers largely choose to do so in English-language journals. English is, of course, not the first language in Sweden, but Swedish researchers have adopted English as one of two working languages. This has been simplified by a generally strong Anglo-Saxon cultural orientation. In Sweden—as in other small Anglo-Saxon oriented countries such as the other Scandinavian countries, Netherlands and Israel—researchers are expected to be more likely to publish in English language journals than researchers from larger, non-English speaking countries such as Germany, Japan, Italy and France where domestic scientific journals exist to a greater extent. Indeed, in Sweden, it is not very common to find a PhD thesis at a technical university that is written in any other language than English. This suggests that 'an English language bias' in the databases is to be expected to influence the measured number of publications not only for those countries where English is the main mother tongue but also for some other smaller nations where English is, practically speaking, the main professional language for academics.

[24] We are grateful to Linus Dahlander, Chalmers University of Technology, for help with the statistical analysis.

[25] Hence, these two indicators of the volume of academic R&D are not fully consistent. In part, this is so by the very nature of indicators. For a study of three indicators of technological activities in Swedish industry, see Jacobsson et al. (1996).

[26] Crespi and Geuna, 2004 also find that the proportion of 'non-business' R&D that is undertaken outside of the higher educational sector has a negative effect on the production of publications, but that the effect is rather weak.

[27] A 50% increase in the propensity to publish have been reported to have been seen in countries which have English as the first language (Pavitt, 1998; citing Lattimore and Revesz, 1996).

[28] If a local journal exists, it is likely to be of lesser quality than the English language journals simply because an English language journal may attract researchers from all over the world.

In Table 7, we have included a dummy together with RDABS, i.e. the share of GDP that is allocated to R&D in the higher educational sector. An 'English language bias' effect is assumed to operate not only for countries such as Great Britain, but also for Denmark, Israel, Netherlands, Norway and Sweden. Adjusted R^2 increases to 0.656 and both RDABS and dummy are highly significant. Indeed, the standardized coefficient of the dummy is as high as 0.277, which means that over one quarter of the contribution of the two variables comes from the dummy.[29]

The adjusted R^2 has, thus, increased from 0.565 to 0.656, i.e. the inclusion of two new dependent variables, reflecting Swedish institutional peculiarities, has explained about a quarter of the initial unexplained variance.

Third, whereas we have not, at this point, added more independent variables to the regressions, we would suggest that the list does not end here. In a tentative way, we would like to point to a further institutional feature of Sweden, which makes it plausible that the *propensity to publish* in the higher educational sector is higher than in many other countries.

In Sweden, PhD students in engineering, natural science and medicine normally collect a set of papers into a thesis instead of writing a monograph. Some, or most, of the papers need to have been published (or accepted) before the thesis is defended (and the papers are normally published in an English language journal). In some other countries, PhD students may not publish, or do so only occasionally.[30]

To conclude, the number of publications per GDP is an indicator that is influenced by institutional features of the countries measured. Whereas, our analysis is still tentative, we suggest that three institutional features—a focus on the higher educational sector, publications in English, and publishing patterns of PhDs—may make us overestimate the volume of Swedish academic R&D (while at the same time increasing the value of the same R&D). Clearly, in cross-country comparisons, we need to take such institutional disparities into account if we are concerned with using bibliometrics as an indicator of the volume of scientific activities.

4. Conclusions and some suggestions for further research

In order to contribute to the debate over a 'Swedish paradox', we have critically assessed the validity of two indicators used in analyses which have driven the widely spread perception of Sweden as a leading country in terms of the volume of academic research. These indicators reflected monetary input into, as well as output of R&D. We have also added a second input indicator, 'time expenditure'.

In terms of the input indicators, we have argued that since Sweden has chosen to organise its 'non-business' R&D in an unusual way, the appropriate information to use is that related to an 'extended academic sector', i.e. in addition to the higher educational sector the analysis must include R&D undertaken in government research bodies and in private non-profit organisations. Assessing the strength of such research—both in terms of monetary values (set in relation to GDP) and in terms of person years (set in relation to population)—gives a picture of Sweden as not an unusual country but as one of many other developed nations.

Indeed, we could point to a potential problem of an *under-dimensioned* 'extended academic sector'.[31] We can refer to the assessment of time-expenditure on academic R&D (see Table 6), where, in fact, as regards person years per million inhabitants, Sweden spends *less* and not more than other rich OECD countries on academic R&D in this extended sense. At the same time, the academic sector is charged with the role of

[29] Adding countries like we have done to those with English as the dominant first language is, of course, a bit dangerous. We are well aware that it may be arbitrary which countries to include but we would nevertheless argue that it is more relevant with an enlarged group of countries than a narrow one with only those included where English is the dominant first language. It is, however, noteworthy that the top five performers in terms of publishing (see Table 2) are small countries, which may indicate that size is of relevance. More work is required on this issue.

[30] Different scientific fields have different 'propensities to publish' and research in medicine is supposed to yield most publications. Using NSF data on publications and OECD data on the number of person-years allocated to R&D, we analysed whether the structure of Swedish academic R&D had any explanatory power. To our surprise, it did not. Although Sweden places great emphasis on medical R&D, and to an extent on engineering, this is done at the expense of R&D in natural sciences where there is also a high propensity to publish. The analysis was, however, limited to the 11 countries for which data was available at this detailed level.

[31] See Rickne (2002) for a discussion of this problem of an under-dimensioned volume of research within the field of biomaterials.

supporting a very large R&D effort in industry (see Table 1). There is a significant correlation between expenditure on academic R&D in the extended sense and business R&D ($r = 0.705$, significant at the 0.01 level, $n = 22$),[32] i.e. the volume of academic work bears a relationship with that in business. Yet, as is seen in Appendix, Table 2, Sweden ranks last in the OECD in terms of the share of the extended academic sector in total R&D. On both these accounts, an *up-scaling* of academic R&D may well be warranted.

In terms of the output indicator, we argue that a high ranking in terms of number of publications per GDP is a reflection not only of a high volume of scientific activity in the academic sector but also of institutional features. In a tentative way, we pointed to three institutional factors which may lead us to overestimate the Swedish volume of R&D; the dominance of the higher educational sub-sector in the 'extended academic sector', an 'English language bias' effect and a high propensity to publish among PhD students.

Yet, the very same institutional features that probably make the use of bibliometrics overestimate the volume of academic R&D is likely to raise the *value* of that R&D. Therefore, a reasonable characterisation of Swedish academic R&D is one with average, or possibly below average, resources, but with above average value of output; it is efficient. If Sweden is to be seen as a 'role model' for academic R&D in Europe, its justification does not, therefore, lie in the volume of resources allocated to that activity but rather in the nature of the institutional features that encourages an international exposure of the results of the R&D.[33]

With respect to the Swedish debate on policy, we suggest that the 'left-hand' side of the 'paradox' referred to in the Introduction is not convincing as the main starting point for a policy discussion, in particular not on the input side. Institutional factors, as distinct from a genuinely high level of activity, appear to play a key role in generating the high Swedish ranking. The policy problem should, therefore, not be formulated as one where well funded and 'unruly scientists' need to be tamed into doing 'useful things' (Hellström and Jacob, 2004). Attention needs instead to be shifted from science policy to the broader innovation policy that sets the context for the economic exploitation of science.[34]

For the more limited area of science policy, the relevant issues for Swedish policy makers are probably best sought in how recent policies may do harm to an academic sector that has average, or below average resources, but which performs well.[35] In particular, we are concerned with a funding system that has gradually, simply by an erosion of the fixed funding, reduced the ability of senior researchers to establish the direction of their enquiries.[36] Much of that funding (erroneously regarded as 'free funding' by many observers) is spent on graduate education and on maintaining the competence of teachers.

In addition, a growing share of the external funding is directed and is expected to lead to useful results in the short term (Sandström et al., 2004). Indeed, in some circles, publishing in international journals is seen to be in conflict with being 'useful' in that way. This understanding is in stark contrast to research arguing that the US achievements in science-based technologies has drawn on research that is ranked highly by academic standards and where first class capabilities are generated (Pavitt, 2001).[37] Science policy makers should therefore be concerned with the risks of depletion of resources and of short-termism.

Finally, there are many methodological problems associated with the kind of analyses undertaken in this paper. These refer to both input and output indicators. First, the inclusion of government organizations and private non-profit organizations into an 'extended academic sector' has solved some inconsistencies, but may involve new ones. These need to be explored further. In

[32] $R = 0.711$ if we correlate R&D in the higher educational sector/GDP with business R&D/GDP.

[33] However, as we have concentrated on how volume is measured, further work is needed to draw implications as regards Sweden as a 'role model' in terms of value creation.

[34] See Goldfarb and Henrekson (2002) and Henrekson and Rosenberg (2000) for useful discussions of policy.

[35] Some of these risks are discussed in Geuna (2001) and Jacobsson (2002).

[36] There was a substantial expansion of teaching both at the undergraduate and graduate level in Sweden in the 1990s. In the period 1991–2002, the number of PhD students grew by 64%, the number of lectures by 33% and the number of professors by 60%. Yet, fixed funding grew only by 24% in real terms (SCB, 2003). See also footnote 18.

[37] Other authors underscore this view, e.g. Hicks et al. (2000) and McMillan et al. (2000) for the US and Faulkner and Senker (1994) for the UK. For instance, Hicks et al. (2000) show that a US scientific paper among the top 1% most highly cited papers is nine times more likely to be cited by a US patent than a randomly selected paper.

particular, we are concerned that there may be a great variation in the nature of the work undertaken in government R&D laboratories.

Second, there are substantial sources of uncertainty as regards the comparability of R&D expenditures (in monetary terms and in time) across nations. Indeed, the European Commission has acknowledged such difficulties and has developed composite indicators to meet this challenge (European Commission, 2003). One of the uncertainties highlighted in our study is the varying purpose for which block grants are used in different countries. As argued above, a substantial part of the Swedish block grants is used for purposes other than R&D.

Another uncertainty is to what extent the work of PhD students is included in data on monetary and time expenditures on R&D. In the UK, for instance, according to the OECD (Personal communication with Sharon Standish, OECD, August 27, 2003) only "…those post-graduate students who are on the payroll of the higher education institutes (HEI) are included", whereas in the case of Sweden "…all post-graduate students are counted as researchers in FTE, regardless of whether or not they are on the university payroll." Considering that most UK students are not on the pay roll but rely on grants and own funding, it is possible that the UK figures underestimate the volume of academic R&D compared to Sweden. These sources of uncertainty need to be explored further.

Third, the rationale for including certain countries into a group that may 'benefit' from an English language bias needs to be developed further. Fourth, we would like to suggest that work is undertaken with respect to the propensity to publish among PhD students (engineering, natural sciences and medicine) and that an assessment is made as to how differences between countries impact on aggregate data on the number of publications.

Appendix A. Appendix 1

See Table 8.

Appendix B. Appendix 2

See Table 9.

Table 8
Correlation matrix

	AERD	RDABS	DUMMY	PUBLPPP
AERD[a]	1.00	0.819**	0.378	0.763**
RDABS[b]	0.819**	1.00	0.337	0.784**
DUMMY[c]	0.378	0.337	1.00	0.509**
PUBLPPP[d]	0.763**	0.784**	0.509**	1.00

[a] AERD is the monetary input into R&D in the 'extended academic sector' divided by GDP/PPP.
[b] RDABS is the monetary input into R&D in the higher educational sector divided by GDP/PPP.
[c] Dummy stands for the following countries: Australia, Canada, Denmark, Ireland, Israel, Netherlands, New Zealand, Norway, Singapore, Sweden, United Kingdom, United States.
[d] PUBLPPP is the ratio between the number of scientific publications divided by GDP/PPP.
** Significant at the 1% level.

Table 9
Percentage of gross domestic expenditure on R&D (GERD) performed by different sectors in 1999 sorted by total GERD by academic sector

Country	1 Total percentage of GERD performed by the business enterprise sector	2 Total percentage of GERD performed by the extended academic sector
Portugal	22.7	77.3
Greece	28.5	71.5
New Zealand	29.7	70.3
Turkey	38.0	62.0
Poland	41.3	58.7
Iceland	46.7	53.3
Italy	49.3	50.7
Spain	52.0	48.0
Norway	56.0	44.0
Netherlands	56.4	43.6
Canada	57.0	43.0
France	63.2	36.8
Denmark	63.3	36.7
United Kingdom	66.8	33.2
Finland	68.2	31.8
Israel	69.0	31.0
Germany	69.7	30.3
Japan	70.7	29.3
Korea	71.4	28.6
Belgium	71.6	28.4
Ireland	72.9	27.1
United States	74.8	25.2
Sweden	75.1	24.9
Total OECD	69.3	30.7
EU	64.1	35.9

Source: OECD (2003), *Main Science and Technology Indicators*, 2003, OECD. Missing data for Australia, Austria, Japan (adj.), Luxembourg, Switzerland.

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