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An empirical analysis of R&D expenditure in the Nordic countries

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Abstract:
In this paper we analyse the impact of public R&D on private sector output. It is argued that given away public R&D will increase the input supply of private R&D and accordingly enlarge business sector output. Testing the model on Nordic time series data over the period 1975 to 1995, the empirical evidence is mixed, however mainly in favour of the theory. A model based on panel data for all the five Nordic countries is estimated by an ML-procedure allowing for non-linear relationships and furthermore, the hypothesis is also tested within a cointegration methodology framework. Evidence was present concerning a positive influence of public R&D on private R&D in the Nordic countries, except Norway and Sweden.

Keywords: R&D spending, business sector productivity, impact of public R&D.
JEL Classification: O3,H5, D24

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1. Introduction

There is a widespread consensus among economists that a significant driving force behind increases in private productivity is R&D activity. Although the extensive amount of econometric literature on this issue gives the impression that private expenditure on R&D seems to increase the productivity of the private sector, it is also found that publicly funded R&D does not or does hardly contribute to private sector productivity R&D, see Capron & van Pottelsberghe (1997) for a survey on earlier empirical evidence.

A number of studies argue that the influence of public R&D is indirect via the influence on the productivity of other inputs. Thus, an increase in the amount of publicly funded R&D is expected to have a positive influence on the marginal product of other inputs, e.g. R&D financed by companies. As the amount of private R&D expenditure is positively correlated with increases in its own marginal product, a positive effect on company financed R&D expenditure is expected. However, the empirical evidence is mixed, see Capron & van Pottelsberghe (1997).

The aim of this study is to analyse the interaction between private and public R&D in the Nordic countries. More precisely, is it possible to detect any effects of government performed R&D on the productivity of the private sector in the short run as well as in the long run? Therefore, this paper does not focus on the funding of R&D, i.e. the stimulation effect of public funding on private sector R&D - which is the case for the majority of earlier studies. Instead, public R&D is defined as *R&D performed* within the public sector, i.e. at universities, public research institutes, research hospitals etc.

The impact of public R&D is via direct spreading of scientific knowledge to firms, knowledge embodied in students who graduate from universities and via collaboration between public research institutions and private enterprises. In addition, knowledge, initially based on R&D effort, will affect individual behaviour e.g. results from health science etc. Thus, besides the direct effect on the productive output of industries there are also indirect effects which tend to increase the effective input of other factors of production. It is of vital interest to ascertain whether public R&D has such positive effects on the economy when making policy decisions concerning public R&D expenditure.

In Denmark publicly performed R&D accounts for a relatively high share of the total national R&D expenditure. Thus, in 1995 more than 43 per cent of the total national R&D was performed at universities and other public R&D institutions which is relatively high compared to the other countries. The corresponding figures for Norway, Sweden, Finland

and Iceland are 43, 26, 37 and 67 per cent, respectively. In comparison, the OECD average level was 33% in 1995.

In the next section, the theoretical framework behind the analysis is presented. The analysis follows the arguments of Levy (1990), see below. The third section of the paper presents the data to be used in the empirical analysis. The impact of public R&D is analysed for the private sector as a whole and in section 4 the results from estimating a non-linear model by a maximum likelihood procedure are presented. The empirical specification of the model demands long time series of R&D figures and it is tested whether the data series are stationary in levels. Most of the time series used in the analysis seem to be non-stationary and hence, the existence of long-run cointegration relationships between publicly and privately performed R&D have been tested. The results from this analysis are reported in section 5. The final section concludes.

2. Theoretical arguments

According to Levy (1990) from the private firm point of view public R&D can be seen as a free good which can be employed without private costs to them. Assuming this, the production function of the firms can be written as

$$Q = AL^{\alpha}K^{\beta}BERD^{\gamma}PERD^{\eta} \qquad (1)$$

where Q is the firm output, L denotes labour input, K is ordinary capital, BERD stands for business R&D capital and PERD is public R&D.

The impact of PERD is via direct spreading of scientific knowledge to firms, knowledge embodied in students who graduate from universities and via collaboration between public research institutions and private enterprises. In addition knowledge, initially based on R&D-effort, will affect individual behaviour e.g. results from health science etc. Further R&D-effort results in more efficient and better treatment of illness, e.g. at hospitals, thus reducing man-hours lost in production. More secure and stable infrastructure – which is, eventually, also a consequence of R&D-effort – will tend to make life more flexible for the individual and enlarge the effective labour force through increased mobility etc. Thus besides the direct effect on the productive output of industries, there are also indirect effects which tend to increase the effective input of other factors of production.

The second order derivative of Q with respect to BERD and PERD can be written as

$$\delta^2(Q)/\delta(BERD|PERD) = \gamma\eta AL^{\alpha}K^{\beta}BERD^{\gamma-1}PERD^{\eta-1} \quad (2)$$

Under the usual assumptions concerning the sign and magnitude of the parameters of the production function, i.e. A>0 and all other parameters between 0 and 1, the expression in 2, which is the marginal productivity of private R&D with respect to changes in public R&D, is positive. Hence, increases in public R&D tend to increase the marginal product of private R&D. If public R&D is freely provided, it will be demanded until its marginal product approaches zero because it contributes to increases in the marginal productivity of other inputs, e.g. private R&D capital. Accordingly, a positive relationship between public and private sector R&D is expected. Further, this relationship can be taken as an indication of positive impact of public R&D on private sector output and productivity.

The marginal product of public R&D capital can be computed as $\delta Q/\delta PERD = hAL^{\alpha}K^{\beta}BERD^{\gamma}PERD^{\eta-1} = hQ/PERD$. As noted by Levy (1990), estimating equation 1, directly knowing that public firms would use publicly supplied R&D at a zero price corresponding to zero marginal product in equilibrium, should by definition result in a h-value close to zero.

Some modifying comments should be made. Capron & van Pottelsberghe (1997) note that the assumption of zero costs in employing public R&D seems unrealistic. Firms have to lobby, seek information, formulate new projects, prepare R&D projects in order to get public funds or benefit from the results of public R&D. Of course, these costs are lower than if the firm had to produce all knowledge itself and this probably explains why some studies, when estimating equation 1 or similar forms directly, still come out with positive values of η. Further, the focus ought to be on total knowledge rather than knowledge based on publicly created R&D. Spillovers to other firms would probably not depend on the source of the performing sector or funding.

The estimation form in Levy (1990) is a Box-Cox transformed model with total private R&D expenditure as the endogenous variable and public contract R&D performed in industry plus GDP as exogenous variables. The model is estimated on pooled time series for 9 countries for 21 years. Allowing for spillover effects between Europe, USA and Japan, public R&D is found to contribute to private R&D (and accordingly to private sector productivity) in 5 countries[1]. However, in the UK and the Netherlands there is evidence of a negative contribution.

[1] USA, Japan, Germany, Sweden and France.

In Capron & van Pottelsberghe (1997) an empirical model is specified as changes in private productivity as a direct function of changes in the R&D capital/ouput ratio. R&D capital is either the total R&D capital or R&D capital split into private and public R&D capital. Using a balanced panel of 22 industries for the G7-countries, it is found that net rates of return of total R&D range from non-significant values to 272 per cent for Italy! Dividing R&D capital into private and public components, neither private nor public R&D comes out with a significant contribution to output growth. Only for France and Japan is there a high and significant contribution of private R&D to output growth. Hence, this study is not in favour of the conventional wisdom that private R&D stimulates business output growth.

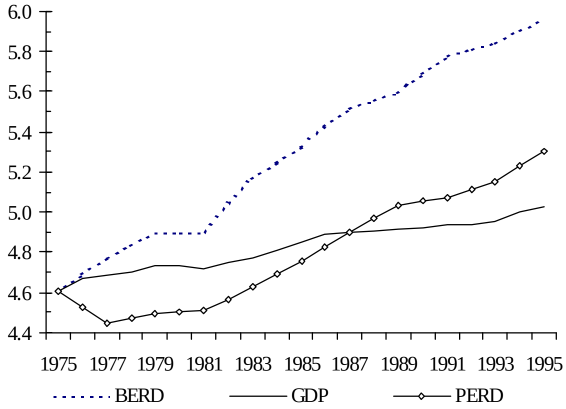
Next, Capron & van Pottelsberghe (1997) specify a model which is more in accordance with the ideas of Levy (1990). Thus, a regression equation is specified for private R&D as a function of its value added and the total R&D subsidies.Testing the model on a number of industries in the G7-countries, the empirical evidence is, however, rather mixed. R&D subsidies may stimulate or discourage private R&D investment, depending on industry and country.

3. Data

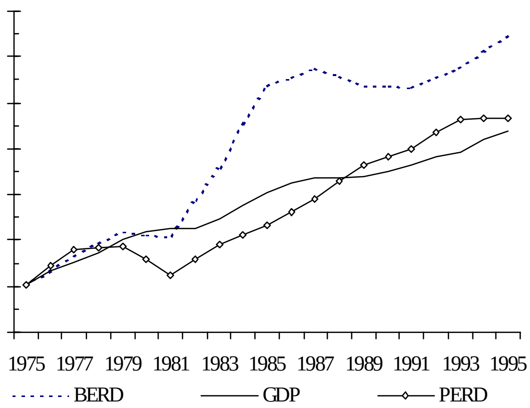
The data used in the analysis derive from the official R&D statistics. At the empirical level the R&D concept comprises *creative work undertaken on a systematic basis in order to increase the stock of knowledge of man and society, and the use of this stock in order to device new applications*, see the Frascati–manual p. 29, OECD(1993). Thus, the R&D concept includes basic and applied research plus experimental development. The business enterprise expenditure on R&D is defined as BERD, see OECD (MSTI, various issues). In the analysis below the public R&D expenditure is denoted as PERD. Hence, the empirical analysis is based on expenditure data and the notation from part 2 is maintained due to notational simplicity. Public R&D is the sum of GOVERD and HERD from the OECD statistics, i.e. government intramural R&D plus Higher education expenditure on R&D. The main source of data is "The Nordic statistics for R&D and Government Budget Appropriations or Outlays for R&D". Data are also available in the MSTI publication of OECD. As the R&D statistics are biannual, data have been interpolated for the non-survey years. Finally, data on value added GDP derive from the National Accounting Systems. The data set covers the period from 1975 to 1995 and is presented in figure 1.

Figure 1. Business sector R&D expenditure, value added and public R&D expenditure in the Nordic countries, 1975-1995 (Log values of fixed price indices).

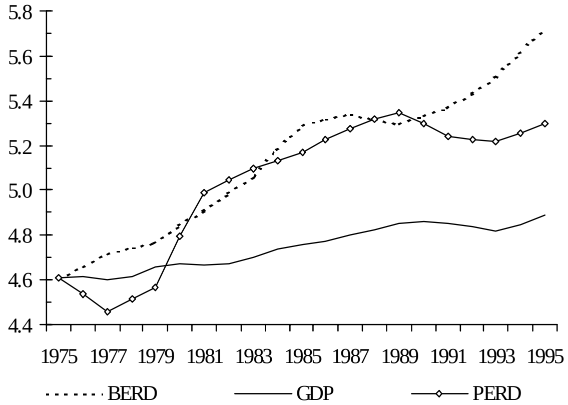
Denmark



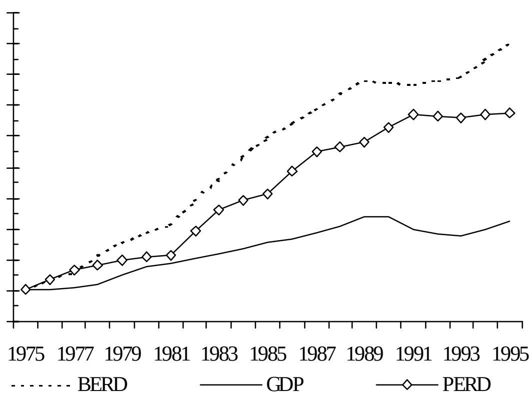
Norway



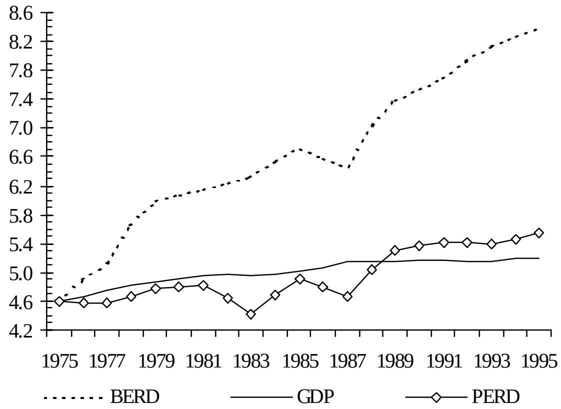
Sweden



Finland



Iceland



4. Estimation procedure and empirical results

In this study, the empirical model is in accordance with the approach in Levy (1990). The main point of interest is measuring the impact of public R&D on the private sector. Public R&D is specified as the total R&D performed in the public sector irrespective of funding, see above, and this specification is in line with the argument of Capron & van Pottelsberghe (1997) who argue that 'a dollar is a dollar' in discussing the usefulness of dividing R&D based on source of funding.

The basic model to be estimated on pooled time series data for the five Nordic countries is as presented in part 2. The sample period is 1975-1995 which results in 105 observations and using dummy variables the empirical model to be estimated is given by (3)[2]

$$BERD^{BC}_{nt} = \alpha+\beta\ GDP^{BC}_{nt} + \gamma\ PERD^{BC}_{nt} + \alpha_i D_i + \beta_i D_i\ GDP^{BC}_{nt} + \gamma_i D_i\ PERD^{BC}_{nt} + \varepsilon_{nt} \quad (3)$$

Where t = 1, ... ,21 (1975-1995)
n = Denmark, Norway, Sweden, Finland, Iceland
i = 2, . . ., 5

D_i is a dummy variable taking a unit value for Norway (2), Sweden (3), Finland (4) and Iceland (5), respectively. Due to this normalization the α, β and γ parameters represent the Danish case. All variables are subjected to the Box-Cox transformation

$$X^{BC} = \frac{X^{\lambda}-1}{\lambda} \qquad \left(X^{BC} = \log X for \lambda = 0 \right)$$

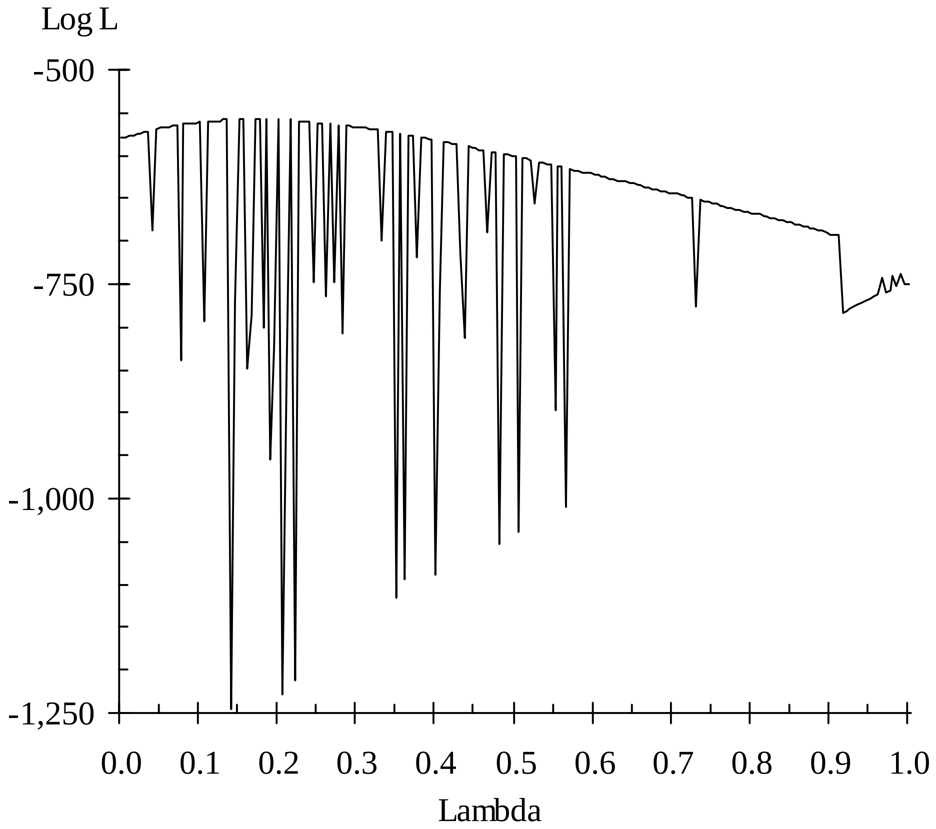
The following estimation procedure is followed. The model is estimated by a maximum likelihood procedure allowing all variables to be Box-Cox transformed as the expression in (2) may involve a non-linear relationship. In connection with this, we also allow the λ parameter in the BC transformation to vary when maximizing the likelihood function. Additionally, we have estimated (3) by the ML-procedure solving for λ values in the interval between 0 and 1 with 0.005 increments. A λ value of 0 corresponds to the log-linear version of (3) and for λ=1 a linear model is obtained. When first restricting λ to the [0;1] interval the log likelihood function values are calculated for each run of the model and the result is exhibited in figure 2.

[2] It is planned to integrate international spillovers in a future version of the model.

It is evident from figure 2 that the ML-procedure may be sensitive to the value of λ as the Log L suddenly 'dives' at some local extrema (minimum values). A global maximum of the Log L function seems to be in this [0;1] interval and relatively close to zero, which also indicates that a log-linear version of (3) might be a reasonable model to choose.

The next step is to re-estimate the model but with no restrictions on λ, which means that this variable is to be estimated simultaneously with the other parameters in (3). The results are reported in table 1.

Figure 2. Values of the log likelihood function, 0 ≤ λ ≤1



Notes: Log likelihood function values of model (3) as estimated by ML. The starting values for each set of ML-iterations were the parameter estimates obtained from an OLS regression of (3).

The estimate of the λ parameter is 0.1702 which is extremely close to the global maximum in figure 2 (λ=0.175) and hence, the estimates presented in table 1 are assumed to be valid regarding the ML-procedure. Nearly all the estimated coefficients are found to be highly significant which is very similar to the results in Levy (1990) for the OECD countries. The PERD variable is positive and significant indicating a positive relationship from public R&D spending to private R&D spending for Denmark. The negative values of D_2·PERD and D_3·PERD may indicate no such relationship for Norway and Sweden, but for Finland and Iceland the corresponding parameter estimates are expected to differ significantly from zero.

Table 1. Maximum Likelihood Parameter Estimates, Model (3).

Variable	Coefficient	Standard Error	t-value
Intercept	-23.4155	4.7863	-4.8921
GDP	4.5674	0.5796	7.8799
PERD	0.4540	0.1205	3.7665
D_2	17.6768	3.2792	5.3905
D_3	0.0624	3.5537	0.0176
D_4	12.8934	3.6860	3.4980
D_5	2.8203	4.8111	0.5862
D_2·GDP	-0.8536	0.4712	-1.8118
D_3·GDP	1.2654	0.6810	1.8581
D_4·GDP	-2.7324	0.7339	-3.7233
D_5·GDP	-2.3441	0.8116	-2.8882
D_2·PERD	-0.7445	0.2170	-3.4309
D_3·PERD	-0.2500	0.0973	-2.5686
D_4·PERD	0.4302	0.1894	2.2710
D_5·PERD	0.7157	0.1919	3.7300
λ	0.1702	0.0336	5.0579

Notes:The number of observations is 105 which means 88 degrees of freedom in the ML-procedure. All estimated coefficients are significant (min. 5% level), except in the following cases (variables): D_3, D_5, D_2·GDP, D_3·GDP. The statistical program RATS is used for the calculations.

In order to investigate these hypothesis formally, the necessary linear restrictions are imposed on the model which is then reestimated. The results are presented in table 2 which also reports on two other associated restrictions concerning the public R&D variable.

The conclusions from table 2 are that public R&D expenditure has a positive influence on private R&D in all countries, except Norway where the null of a zero PERD parameter estimate is not rejected. For Sweden the rejection level is 6% which is acceptable taking the relatively small number of observations into consideration.

Table 2.Test values of linear restrictions in model (3).

Restriction I: The significance level of the public R&D variable (PERD)		
Ho: PERD parameter estimate is zero		
Test results:		
Norway	$\chi^2(1) = 2.09$	(p = 0.15)
Sweden	$\chi^2(1) = 3.66$	(p = 0.06)
Finland	$\chi^2(1) = 36.91$	(p = 0.00)
Iceland	$\chi^2(1) = 63.96$	(p = 0.00)
Restriction II: Equal PERD parameter estimates across all countries		
Ho: PERD parameter estimate = D_i · PERD parameter estimate (i = 2, 3, 4, 5)		
Test result:	$\chi^2(4) = 72.23$	(p = 0.00)
Restriction III: Equal PERD parameter in Denmark, Finland and Iceland		
Ho: PERD parameter estimate = D_i · PERD parameter estimate (i = 4, 5)		
Test result:	$\chi^2(2) = 2.06$	(p = 0.36)

Note: A high p value indicates that the null hypothesis is rejected.

The conclusion from testing restriction II is, that the PERD variable differs across the Nordic countries which also justifies the inclusion of the dummy variables in model (3). Contrary to this, the last restriction III is not rejected which means that the value of the PERD coefficient may be equal for Denmark, Finland and Iceland.

5. Cointegration analysis

The starting point of this part of the empirical analysis is to test the series for their order of integration. Accordingly, industry R&D expenditure, public R&D expenditure and value added are tested by performing the Dickey-Fuller and Phillips-Perron unit root test. The test statistics are shown in table 3.

Table 3 clearly shows that all variables are non-stationary – except for one case where the test statistic indicates a trend stationary variable (The Danish PERD variable, according to the PP test statistic). In addition, the first difference of the variables turns out to be stationary which means that all series are most likely I(1) (test values not shown). Accordingly, if the variables are to be used in a regression analysis it needs to be verified that the variables cointegrate, i.e. that they form a stable long-run relationship.

Table 3. Unit root tests of R&D expenditure variables.

	Log BERD		Log PERD	
	ADF{}	PP(1)	ADF{}	PP(1)
Denmark	-2.67{1}	-1.78	-3.35{1}	-5.38
Norway	-2.59{1}	-1.38	-2.67{1}	-1.60
Sweden	-2.92{1}	-1.61	-2.20{1}	-1.10
Finland	-2.22{1}	-1.13	-1.67{1}	-1.11
Iceland	-3.06{1}	-2.62	-2.62{1}	-2.39

Notes: Critical value at the 5% level of significance is –3.67, based onMacKinnon (1991). Log values are used in all tests. {} denotes the number of included lags in the DF/ADF test. The Phillips-Perron test has been computed using correction for 1st order autocorrelation. A linear trend has been included in all tests in order to give strenght to a hypothesis of trend stationarity.

Many of the previous studies do not distinguish between short-run and long-run effects. As the effects of public R&D on the private sector are expected to be at work in the long run, the empirical approach used is the standard procedure of a multivariate cointegration analysis.

The model describing the long-run effect of public R&D is specified in accordance with (3) but this time the log-linear model is preferred as the cointegration analysis is a matter of stable linear relationships in the long run. For each of the Nordic countries a pure time series model, (4), is estimated.

$$\log BERD_t = \alpha + \beta \log GNP_t + \gamma \log PERD_t + \varepsilon_t \quad (4)$$

The terminology is the same as above, i.e. $BERD_t$ and $PERD_t$ are the annual expenditure of private R&D and public R&D, respectively. Finally, ε_t is an error term. The sign of β and γ are both expected to be positive because higher economic activity andpublicly performed R&D have a positive effect on private R&D in the long run. This was also among the main findings from the ML-estimations, cf table 2. The Engle-Granger two-step cointegration methodology is applied to (4) and, as this is based on OLS regressions, the estimated cointegration vectors - if there are any - may be expected to come close to the corresponding single-country estimates in table 2.

Table 4. EG 2-step cointegration regressions. Dependent variable: BERD

	Denmark	Norway	Sweden	Finland	Iceland
Intercept	-8.07	-0.32	-4.86	-4.10	-20.21
GDP	2.79	2.15	2.62	1.21	3.63
PERD	0.37	-0.26	0.21	0.82	1.29
R^2	0.99	0.93	0.92	0.99	0.95
DW	0.95	0.40	0.46	0.69	0.69
ADF{lags}	-3.84{1}	-2.19{1}	-4.00{1}	-2.67{1}	-2.70{1}

Notes: Log values of the variables used in the analyses. The 5% critical value is -4.18 and the 10% critical value is -3.79, MacKinnon (1991).

Table 4 summarizes the estimation results using the Engle-Granger 2-step procedure. The parameter estimates can be interpreted as long run elasticities because of the double log formulation of (4), e.g. for Denmark the elasticity is found to be 0.37 between $PERD_t$ and $BERD_t$. Thus, the ADF test value is far below even the 10% critical value in the case of Norway, Finland and Iceland. Only for Denmark and Sweden is there evidence of a cointegration relationship in terms of model (4) - at least at the 10% level of significance. This is somewhat surprising as the value of the PERD coefficient is relatively high for Finland and Iceland, but the results may also be caused by biassed parameter estimates which is usually experienced when applying this methodology to very small samples like we do here.

Therefore, the Johansen (1991) multivariate ML-approach to cointegration analysis has also been applied to the Nordic data set. Besides modelling short-run dynamics and long-run relationship simultaneously the Johansen procedure also tests for the number cointegrating vectors and does not share most of the drawbacks the characterize the OLS-procedure. From a statistical point of view the method comes up with reasonable results as (exactly) one cointegration vector is found in each of the countries, but only in the case of Finland do the parameter values have a sensible economic interpretation (with values close to the result from table 4) which is why no results are reported here.

Consequently, the conclusions from this cointegration analysis are (only) partly in accordance with the ML-procedure in part 4 as a relationship between $PERD_t$ and $BERD_t$ still seems to be the case for Denmark, Sweden and Finland - according to either the EG/OLS-procedure or the Johansen-procedure for cointegration analysis.

Recently, Pedroni (1997, 1998) has shown how to conduct cointegration tests in nonstationary panels with multiple regressors where heterogeneity in the long run cointegration vectors among panel members is allowed. In Pedroni (1998) the method of testing the null of no cointegration in such a panel data set is described and also the computation of critical values for these tests are provided. This methodology is well suited to the problem in the present paper and, therefore, we submit the Nordic R&D data set to this panel cointegration test.[3]

As explained in the first part of the paper the R&D data are only collected on an biannual basis, so all observations in equal years (1976, 1978, etc...) are computed as simple averages of the published data in the official statistics. Conducting cointegration analysis usually requires a reasonable amount of observations hopefully covering at least a couple of decades. Therefore, as we have a panel data set comprising 5 countries and a sample period of 21 years we restrict the data to the original - or primary - observations covering only uneven years form 1975 to 1995. This leaves 55 observations available for the panel cointegration test which seems reasonable as also the time span is of some length[4].

The test statistics are based on the residuals from the cointegration regression (5).

$$\log BERD_{nt} = \alpha_n + \beta_n \log GDP_{nt} + \gamma_n \log PERD_{nt} + \varepsilon_{nt} \qquad (5)$$

where t = 1975, 1977, ... , 1995
n = Denmark, Norway, Sweden, Finland and Iceland

The same notation as in (3) is used. Both the slope coefficients and the country specific intercepts are allowed to vary across the countries. Pedroni (1998) derives seven different test statistics where four of these are denoted *panel statistics* and three are referred to as *group statistics* (based on the 'within-dimension' and the 'between-dimension', respectively). In table 5 four of these tests are reported where the nonparametric tests are analogous to the Phillips-Perron *t*-statistic (as applied in table 3) and the parametric tests are the ADF-type of cointegration test. Following the results from the former analysis we have also made two subsamples and subjected these to the same panel cointegration test procedure. A two-member panel consisting of Norway and Sweden (no-cointegration likely) and the other three countries forming a panel where the no-cointegration hypothesis is more likely to be rejected.

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[3] Acknowledgement: Thanks to Peter Pedroni (Indiana University, US) who kindly supplied us with the RATS codes for the computation of the critical values and thus made the panel cointegration tests available in the present analysis.

[4] This procedure would not be allowed in the former part testing for cointegration in the specific countries as only very few observations would then be available. Concerning the ML-procedure in part 4, we have also applied this to the reduced data set comprising 55 observations but the amendment does not influence fundamentally on the results formerly presented.

Table 5. Panel cointegration tests.

	Panel *t*-Statistic		Group *t*-Statistic	
	Nonpara-metric (T3)	Parametric (T4)	Nonpara-metric (T6)	Parametric (T7)
Panel:				
1) All countries	-0.83	-3.72*	-0.38	-5.02*
2) Norway, Sweden	-0.15	-1.00	0.28	-1.03
3) Denmark, Finland, Iceland	-1.02	-4.83*	-0.72	-5.64*

Notes: * significant at conventional levels, standard normal distribution. In the Pedroni-RATS code a value of 2 is chosen for the m lag option, but the conclusions concerning acceptance/rejection of the null of no-cointegration are not sensitive to the value of the lag truncation (mlag =1, 2 or 3). Biannual data for the period 1975-1995 used in the cointegration tests. T3, T4, T6 and T7 refer to the test numbers in Table I, Pedroni (1998).

The critical values are constructed in the Pedroni-tests in such a manner that the standard normal distribution can be applied directly concerning the hypothesis testing - where large negative values indicate the rejection of the null of no cointegration.

It is evident from the test-statistics from table 5 that only the ADF-types of test favour the rejection of no-cointegration and as expected most significantly for the subsample of Denmark, Finland and Iceland. Therefore, the conclusion seems to be that in accordance with the former results it is unlikely to find cointegration for Norway and Sweden, but for the other three Nordic countries there is some evidence in favour of the opposite conclusion.

6. Conclusion

The purpose of this paper has been to estimate the impact of public R&D on private sector R&D and hence also output. In accordance with Levy (1990) it is argued that given away public R&D will increase the input supply of private R&D and accordingly enlarge business sector output.

Testing the model on pooled Nordic time series data over the period 1975 to 1995, the empirical evidence is mainly in favour of the theory. According to the estimation results from a maximum likelihood procedure, all countries - except Norway - do seem to be characterized by the previously mentioned hypothesis concerning a positive relationship between private and public R&D expenditures.

The next step was to replicate the analyses at individual country levels and applying cointegration analysis to the data set. When using both the EG/OLS-procedure and the

Johansen-procedure at least in the cases of Denmark, Sweden and Finland the hypothesis seems to be confirmed.

Finally, a very recently developed test procedure for panel cointegration, Pedroni (1997, 1998), is also applied to the Nordic data. The results from these tests are somewhat mixed, but the strongest evidence in favour of cointegration (only according to the ADF-type statistics) is found for a sub-sample consisting of Denmark, Finland and Iceland.

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