R&D-Induced Growth in the OECD?

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[1] [2] **Abstract**

I use aggregate and industry-level data for a group of OECD countries for the period 1973 to 1991 to estimate a system implied by a model of R&D-induced growth that relates R&D intensity, productivity, and output growth. I find evidence of positive long-run impact of R&D intensity on productivity and, ultimately, on the growth rate of output. The null hypothesis that growth is not induced by R&D is therefore rejected for this group of OECD countries. The estimation of the theoretically implied system of equations is more efficient and provides stronger results than the traditional estimation of individual equations in the microeconomic R&D literature. The results become stronger when using aggregate-level data suggesting spillovers from aggregate R&D.

Keywords: R&D-induced Growth, Technological Change, System Estimation.

JEL Classification: O4, O3, O5, C3, C52

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1 Introduction

During the second half of the last decade several papers have addressed the question of testing endogenous growth theory based on its implications about convergence (Evans 1996a), and the relation of output growth with government-related variables (Kocherlakota and Yi 1997), money (Evans 1996b), investment and R&D expenditures (Jones 1995a,b). With the exception of Kocherlakota and Yi (1997) the evidence from these papers appears to be against the empirical relevance of endogenous growth theory. Dinopoulos and Thompson (2000) perform a direct evaluation of and provide evidence for the empirical relevance of an augmented version of Romer's (1990) endogenous growth model.

In this paper, I implement tests of endogenous growth theory based on a simple model of R&D-induced growth from Aghion and Howitt (1998). This framework deals with most of the empirical critiques that have been raised to this date as explained in Howitt (1999), but implies testable relations between innovative activity, technological change, and output growth. Unlike the earlier version of endogenous growth models which implied scale effects, this framework remedies the problem and implies a relation between R&D intensity[1] and economic growth rather than between R&D expenditure levels and economic growth.

Part of the value added of my approach to the existing literature is that I consider a theoretically implied system which incorporates the lags between R&D and productivity, and productivity and output growth, in the chain of events giving rise to economic growth. Thus, the current analysis differs from previous work on R&D in two respects. First, by considering a system of equa-

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[1] R&D intensity is given by the fraction of GDP that is attributed to research and development expenditures.

tions implied by a theoretical model it achieves efficiency gains relative to the single equation estimation suggested by partial equilibrium analysis. Second, the current analysis allows for lags between R&D, productivity, and the growth rate of output. This goes a long way towards remedying the problem of reverse causality characterizing much of the previous literature with its focus on contemporaneous relationships.

R&D-induced growth has been shown to be consistent with U.S. experience. The extent to which this conclusion is specific to the U.S. which happens to be the technological leader or can be applied to a broader group of countries close to the technological frontier is a main focus of this paper.

I use OECD data to estimate a system implied by a model of R&D-induced growth that relates R&D intensity, productivity, and economic growth. The OECD accounts for ninety percent of R&D expenditures in the world. The rest of the world can thus be best thought of as importers and imitators of technologies developed in a handful of OECD countries. R&D-induced growth in the OECD would then be indirectly conducive to productivity and output growth for developing countries, to the extent that OECD-developed technologies are locally appropriate. Bayoumi, Coe, and Helpman (1999) provide simulation results suggesting the importance of such R&D spillovers for developing countries.

The relation between R&D and productivity has been studied extensively in the microeconomic literature. Such studies include Griliches (1980a,b), Mansfield (1988), and Griliches and Mairesse (1990).[2] Griliches (1980a) uses a panel of 3-digit manufacturing industry data in the U.S. and finds that the estimate of the R&D coefficient is sensitive to the time period under study; for the period

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[2] These authors use a Cobb-Douglas production function that includes R&D stock as one of three inputs, to derive a relation between productivity and R&D.

1959 to 1968 he estimates a positive and significant coefficient whereas for the period 1969 to 1977 the estimated R&D coefficient is close to zero. Griliches (1980b) uses a short time series between 1957 and 1963 for a large cross-section of U.S. firms and finds a positive relationship between company productivity and R&D intensity. Mansfield (1988) uses a cross-section of industries averaging the data for the period 1960 to 1979 for Japan and for the period 1948 to 1966 for the Unites States. He finds a high positive coefficient for applied R&D in Japan but a negative and statistically insignificant coefficient for basic research. In the U.S., the coefficients for applied and basic research are both positive with the former coefficient being much smaller than the latter. Finally, Griliches and Mairesse (1990) use a cross-section of firms for the U.S. and Japan for the short time period 1973 to 1980 and report mixed results; for a number of firms R&D-intensity coefficients are negative, for some firms this same coefficient is between zero and 0.05, and for other firms this is greater than 0.05. A review of this literature is found in Nadiri (1993).

More recently, Keller (1999) uses a panel of industries and countries to study the role of interindustry and international technology flows in the OECD. Griffith, Redding, and Van Reenen (2000) look at the role of R&D in stimulating innovation and enhancing technology transfer in a panel of OECD industries.

I perform the statistical analysis using aggregate data across thirteen OECD countries, and two-digit manufacturing industry data for seven OECD countries for the period 1973 to 1991. The comparison between the aggregate data results and the industry-level results from the R&D-intensive manufacturing sector can be instructive about the economywide relevance of studies of the manufacturing sector.

If models of R&D-induced growth are empirically relevant, then regressing productivity growth on lags of R&D intensity, and output growth on lags of productivity growth should give nonzero sums of the slope coefficients. A zero sum of slope coefficients for either of the two relations would imply that the null hypothesis that R&D does not induce growth cannot be rejected. I find evidence of positive long-run impact of the explanatory variables in both cases. The null hypothesis that growth is not induced by R&D is therefore rejected for this group of OECD countries.

The results are stronger when estimating a system of equations implied by a model of endogenous growth rather than estimating single equations, and when estimating aggregate relations rather than industry-level relations. The former finding points to the efficiency gains due to the theoretically implied system estimation, and the latter finding suggests the possibility of aggregate R&D spillovers on industry-level productivity. The conclusions are robust for a variety of specifications.

In the next section, I describe the data and in the third section I present the empirical analysis and results. The final section concludes.

2 Data

I perform the statistical analysis using aggregate data across thirteen OECD countries. These are Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the UK, and the U.S.. I check the robustness of the aggregate results by using data across seven two-digit manufacturing industries for seven OECD countries for which all data are available. These are Canada, Denmark, France, Germany, Japan, Sweden, and the U.S.. The two-digit manufacturing industries are: Food, Beverages, and Tobacco (31), Textile, Wearing apparel and Leather Industries (32), Paper and

Products, Printing and Publishing (34), Chemicals and Chemical Petroleum, Products made of Coal, Rubber, and Plastic (35), Non-metallic Mineral Products except Products of Petroleum and Coal (36), Basic Metal Industries (37), and finally, Fabricated Metal Products, Machinery, and Equipment (38). I do not consider industry 33, Wood and Wood Products, since the R&D data are not available for all of these countries in the case of this industry. The R&D data for the period 1973 to 1993 come from the 1998 OECD ANBERD database. GDP data were obtained from the 1994 OECD International Sectoral and STAN Databases for the period 1970 to 1991. Total Factor Productivity (TFP) data in levels for the period 1970 to 1991 were obtained from the 1994 OECD International Sectoral Database, and were used to construct TFP growth rates. A description of how the TFP data were constructed using constant shares of capital and labor inputs, is given in the explanatory section of the OECD International Sectoral Database.

For the purposes of this study, I use R&D expenditures weighted by gross domestic product (GDP). The latter ratio is often referred to in the literature on R&D as "R&D intensity. R&D intensities for a subgroup of the thirteen OECD countries (the G7) are presented in figure 1. It can be seen from this picture that R&D intensities vary across countries and time. I present the results of Park's (1990) G(1,2), G(1,3), and G(1,4) stationarity tests for these data in table 1. The aggregate economy R&D intensities across the thirteen OECD countries appear to be stationary. A panel test that uses the Bonferroni bound[3] implies that the null of stationarity cannot be rejected at the ten percent level of significance for the G(1,2), G(1,3), or G(1,4) tests. The G(1,4) test does not

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[3] Using a Bonferroni bound, one rejects the null hypothesis at the 5 percent level of significance for a panel of n countries or industries if one can reject the null hypothesis at the 5/n level of significance for any of the n countries or industries

reject the null of stationarity at the five percent level of significance for any one country. The G(1,3) test rejects the null of stationarity at the five percent level of significance for two of the thirteen countries, Finland and Germany. The G(1,2) test rejects the null of stationarity at a five percent significance level for Australia and Germany. There is no country for which the G(1,2), G(1,3), and G(1,4) tests all reject the null of stationarity, and there is only one country, Germany, for which two of these three tests reject the null of stationarity at a five percent level.

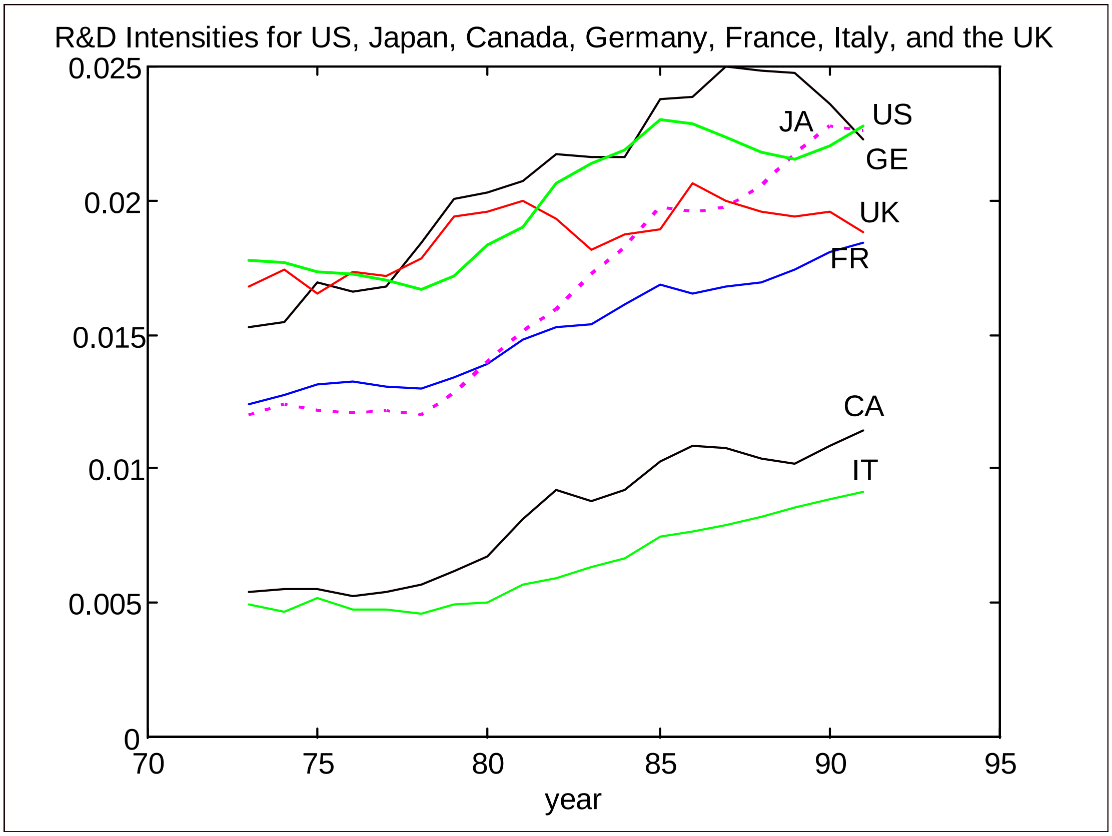

Figure 1

R&D/GDP (1973-91)			
Country	G(1,2)	G(1,3)	G(1,4)
Australia	0.039*	0.086	0.162
Canada	0.607	0.078	0.141
Denmark	0.124	0.058	0.113
Finland	0.359	0.034*	0.074
France	0.598	0.245	0.419
Germany	0.020*	0.039*	0.087
Italy	0.086	0.088	0.175
Japan	0.276	0.093	0.177
Netherlands	0.194	0.198	0.105
Norway	0.635	0.487	0.105
Sweden	0.062	0.059	0.122
UK	0.079	0.211	0.308
U.S.	0.963	0.092	0.188

Table 1: P-values for the Null of stationarity using Park's (1990) G test.

Notes:
* Reject the stationarity null at the five percent significance level.

Country	ISIC	31	32	34	35	36	37	38
Canada G(1,2)		.073	.725	.117	.145	.388	.349	.172
G(1,3)		.197	.371	.144	.188	.133	.457	.221
G(1,4)		.201	.289	.276	.263	.147	.618	.185
Denmark G(1,2)		.904	.663	.415	.042*	.009*	.242	.134
G(1,3)		.348	.075	.181	.090	.016*	.057	.013*
G(1,4)		.138	.103	.301	.156	.019*	.109	.029*
France G(1,2)		.258	.013*	.154	.064	.021*	.077	.711
G(1,3)		.439	.046*	.064	.159	.070	.023*	.085
G(1,4)		.275	.056	.030*	.254	.104	.057	.122
Germany G(1,2)		.034*	.146	.050*	.009*	.033*	.089	.064
G(1,3)		.105	.326	.137	.036*	.093	.234	.146
G(1,4)		.177	.165	.197	.067	.167	.205	.168
Japan G(1,2)		.578	.468	.145	.559	.032*	.240	.058
G(1,3)		.018*	.346	.032*	.296	.064	.298	.052*
G(1,4)		.042*	.183	.076	.480	.112	.435	.115
Sweden G(1,2)		.019*	.136	.271	.532	.482	.627	.263
G(1,3)		.056	.113	.531	.479	.371	.049*	.532
G(1,4)		.124	.224	.712	.688	.399	.081	.150
U.S. G(1,2)		.066	.771	.258	.738	.088	.045*	.213
G(1,3)		.068	.129	.071	.666	.135	.130	.082
G(1,4)		.140	.252	.151	.437	.216	.207	.159

Table 2: P-values for the Null of stationarity for R&D/GDP for the period 1973-93 using Park's (1990) G test.

Notes:

* Reject the stationarity null at the five percent significance level.

The two-digit ISIC codes are: 31: Food, Beverages, and Tobacco, 32: Textile, Wearing apparel and Leather Industries, 34: Paper and Products, Printing and Publishing, 35: Chemicals and Chemical Petroleum, Products made of Coal, Rubber, and Plastic, 36: Non-metallic Mineral Products except Products of Petroleum and Coal, 37: Basic Metal Industries, 38: Fabricated Metal Products, Machinery, and Equipment.

In table 2, I present stationarity tests for seven two-digit manufacturing industries across seven OECD countries for which data are available. A panel test that uses the Bonferroni bound implies that the null of stationarity cannot be rejected at a five percent significance level for the G(1,2), G(1,3), or G(1,4) tests. However, for some industries in certain countries there is evidence against the stationarity null. For example, in industry 36 of Denmark the G(1,2), G(1,3), and G(1,4) tests all reject the null of stationarity at a five percent significance level. In industries 32, 36, and 37 of France and industry 35 for Germany the G(1,2), G(1,3), and G(1,4) tests reject the null of stationarity at the ten percent level.

GDP growth and TFP growth series for a subgroup of the thirteen countries in the sample are shown in figures 2 and 3 respectively. It can be seen that these series exhibit greater variability over the cycle compared to that for the R&D intensities shown in figure 1. Moreover, the apparent existence of a common business cycle across these countries implied from figures 2 and 3 means that it makes sense to use time-specific dummies in the econometric analysis of the next section since that analysis aims at capturing the long-run relation between economic growth, productivity growth, and R&D intensity.

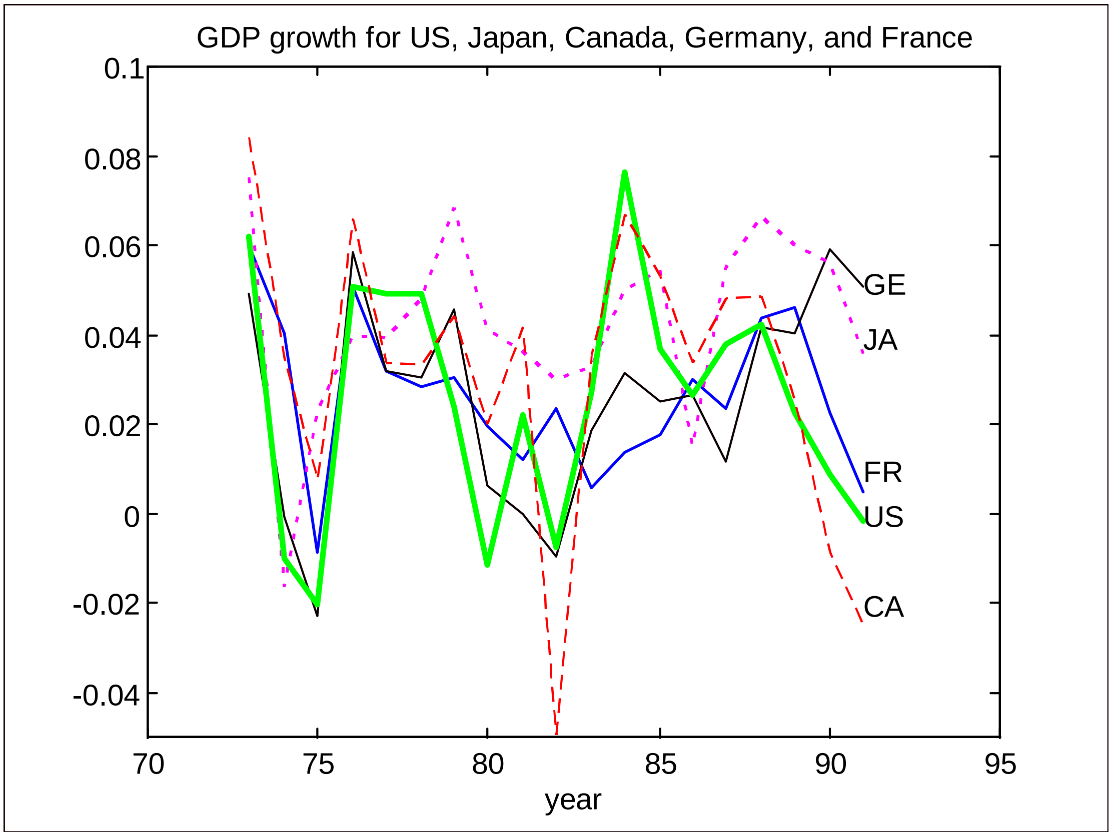
GDP growth for US, Japan, Canada, Germany, and France
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
70
75
80
85
90
95
year
GE
JA
FR
US
CA

Figure 2

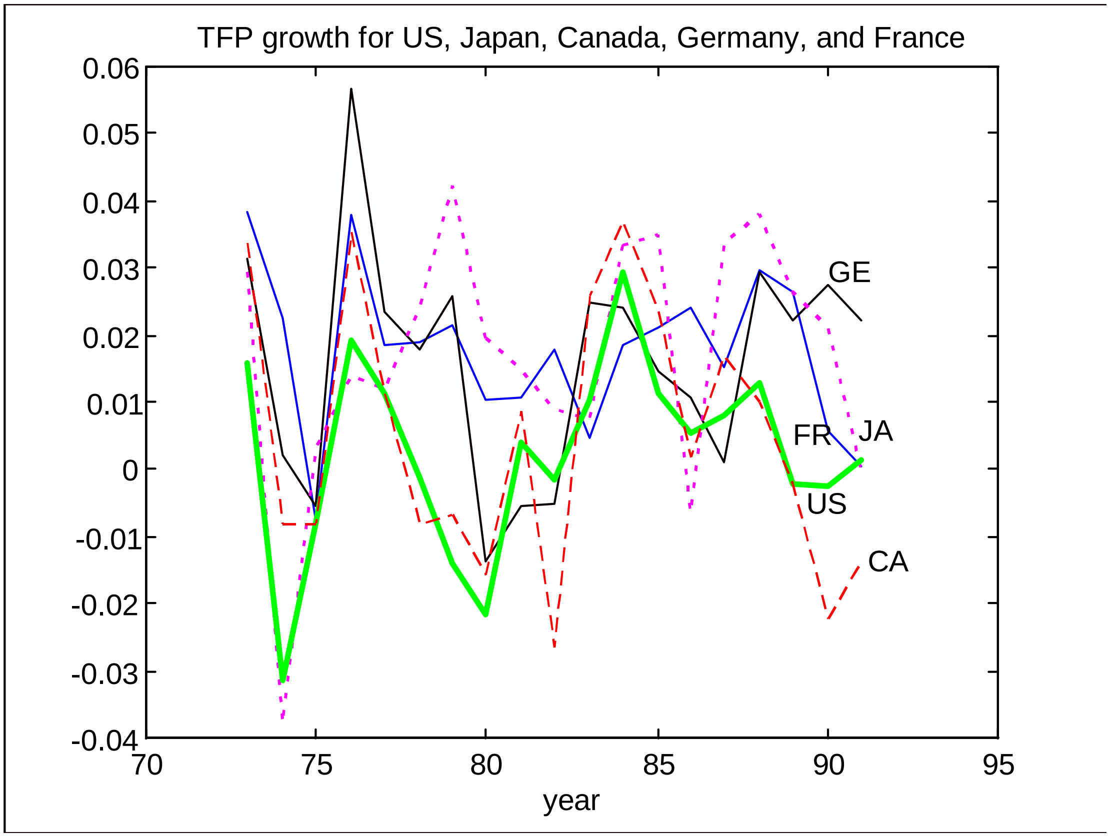
TFP growth for US, Japan, Canada, Germany, and France
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
70
75
80
85
90
95
year
GE
FR
JA
US
CA

Figure 3

3 Empirical analysis and Results

I consider a model of R&D-induced growth based on the model in chapter twelve of Aghion and Howitt (1998). This simple model abstracts from international technology spillovers and considers that for developed OECD countries own-country R&D determines productivity growth which in turn determines output growth for each country. This assumption is made in order to investigate the relevance of a basic R&D model of endogenous growth and is not meant to imply that international technology spillovers are unimportant for the OECD countries in this sample. Keller (1999) finds that about sixty percent of the total productivity effect originates from domestic R&D and the rest is due to international technology spillovers.

The main components of the model assumed to apply for every country are given by

$$G_t = g_t + \alpha \frac{\dot{k}_t}{k_t} \tag{1}$$

$$g_t = \beta \phi\left(\frac{R_t}{A_t^{\max}}\right), \phi' > 0, \phi'' \leq 0 \tag{2}$$

Equation (1) implies a positive long-run relationship between output growth given by G_t, and technological change given by g_t. The term $\frac{\dot{k}_t}{k_t}$ captures the extent to which the economy's capital stock is away from its steady-state value.

Equation (2) implies a positive relationship between g_t and the adjusted level of R&D at time t given by n_t. In equation (2) $\beta = \sigma\lambda$, σ is the innovation size, $\lambda > 0$ is the flow probability of an innovation, and ϕ gives the relation between R&D inputs and innovation output.

Research intensity is given by $n_t = \frac{R_t}{A_t^{\max}}$ with R_t the total amount of final output invested in R&D at date t. $A_t^{\max}$ is the leading-edge productivity parameter at date t and division by this indicates that the cost of further advances increases proportionately to technological advances as a result of increasing complexity. Research expenditures should increase at the same rate as the technology frontier shifts outwards just to keep the flow of innovations constant.

In steady state, the rate at which the technology frontier improves is in turn the same as the rate of output growth. To see this, note that the arrival rates of innovations in different sectors of a country draw from the same pool of knowledge whose state is represented by that country's leading-edge technology parameter A_t^{max}.[4] The ratio of the leading edge to average technology is $A_t^{max}=(1+\sigma)A_t^{avr}$ implying $\frac{\dot{A}_t^{avr}}{A_t^{avr}} = \frac{\dot{A}_t^{max}}{A_t^{max}}$ with σ, the size of innovations, constant. The steady-state rate of technological progress is then given by $g_t = \frac{\dot{A}_t^{avr}}{A_t^{avr}}$. As can be seen from equation (1), in a steady-state with $\frac{\dot{k}_t}{k_t} = 0$ technology and output grow at the same rate. This implies that in steady state $\frac{R_t}{A_t^{max}}$ and $\frac{R_t}{Y_t}$ will exhibit similar time-series behavior. This allows us to proxy the former ratio with the latter ratio which is much more straightforward to construct.

The empirical specification I consider below allows for lagged relationships between the variables of interest, taking into account that the essence of these growth models relates to medium to long-run rather than contemporaneous or short-run relationships.[5] I perform iterated SUR estimation[6] on the empirical model

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[4] Again, we abstract from inter-country technology spillovers in considering the validity of this basic model which relates domestic R&D intensities to domestic gains in productivity and output growth.

[5] The empirical specification for the relation of productivity growth with R&D intensity makes the simplifying assumption that $\phi(\frac{R_t}{A_t^{max}}) = n_t^{\gamma}$, $\gamma = 1$. This assumption makes it possible to consider a linear relation between technological change and the lags of R&D intensity.

[6] The estimates are obtained using the LSQ command in TSP which allows simultaneous iteration on the parameters and the residual covariance matrix.

$$G_{it} = \alpha + \alpha_i + \alpha_t + \sum_{r=1}^{l} \xi_r g_{it-r} + e_{it} \tag{3}$$

$$g_{it} = \psi + \psi_i + \psi_t + \sum_{r=1}^{l} \beta_r n_{it-r} + v_{it} \tag{4}$$

where the subscript i stands for country i, g_{it} is TFP growth, G_{it} is GDP growth, n_{it} is R&D intensity, v_{it} and e_{it} are unobservable stationary errors, ψ_i and α_i are dummy variables specific to each country, and ψ_t and α_t are dummy variables specific to each time period. The parameter β captures the impact of R&D intensity on productivity growth, and the parameter ξ captures the impact of productivity growth on output growth. For each equation I set the parameters for the first country and time period equal to zero and include a constant, ψ or α. The Newey-West (1987) heteroskedasticity and autocorrelation consistent covariance matrix with three lags is used to obtain the standard errors. Time-specific dummies are included in order to avoid biasing the results due to the presence of a common business cycle. Country-specific dummies are included in equations (3) and (4) so as to capture variation across countries not attributable to R&D intensity or productivity growth.

For specifications (I) to (III), I set the number of lags, l, equal to one. For specification (I) I use annual data for the period 1974 to 1990 across the thirteen OECD countries shown in table 1, for a total of 221 observations. The parameter estimates are shown in row (I) of table 3 and are positive and statistically significant.

As a robustness check, I average the data for periods of three years each. I do this to limit the problem of spurious procyclicality that might be present in the proxy of productivity growth. I estimate the above system for five three-year periods between 1976 to 1990 for a total of 65 observations (specification

II) and using total manufacturing data for the same period (specification III). The parameter estimates and t-statistics for these two regressions are presented respectively in rows (II) and (III) of table 3. The system estimation implied by a model of R&D-induced growth gives positive and statistically significant parameter estimates for specifications (II) and (III).

Next, I consider extending specification (I) to include three lags (l=3) of the explanatory variables (specification IV) and to include six lags (l=6) of the explanatory variables (specification V). The justification for looking at additional lags of the explanatory variables comes from the observation that growth relates to medium to long-run rather than contemporaneous or short-run relationships. The sum of the parameter estimates and t-statistics for lags one to three and one to six for each of these two samples are presented respectively in rows (IV) and (V) of table 3. Once more, the system estimation implied by a model of R&D-induced growth gives positive and statistically significant parameter estimates consistent with a long-run impact of R&D on productivity and output growth. Interestingly, the estimation of the individual equations for specification (V) fails to uncover the accumulated long-run impact of R&D on productivity and output growth.

To check the robustness of these results, I consider an alternative proxy of technological change from Imbs (1999) which purges the Solow Residual from spurious[7] procyclicality by allowing for factor hoarding. I use an economywide sample from eight countries[8] for the period 1976 to 1989 taking three lags of the explanatory variables for a total of 112 observations. I report the results of this estimation in row (VI) and results using unadjusted Solow residuals from Imbs

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[7] "Spurious" in the sence that such cyclicalities are unrelated to techical change which is what the TFP growth proxy is meant to measure when used in growth applications.

[8] These are Australia, Canada, France, Germany, Italy, Japan, the UK, and the US.

(1999) in row (VII). Using the adjusted proxy again gives positive estimates for β and ξ. However, the parameter estimate for ξ, although positive, is not statistically significant at conventional levels of confidence. It is statistically significant only at a fifteen percent level of significance. Using the unadjusted Solow Residual for the same group of countries and the same time period gives bigger estimates than Imbs adjusted proxy of technological progress for both parameters of interest. In contrast, the Basu, Fernald, and Kimball (1998) methodology of adjusting the Solow residual to account for demand-induced cyclicalities, provides proxies of technological progress for U.S. manufacturing industries which are more strongly related to future output growth than unadjusted Solow residuals. The degree to which this is due to the different samples used (OECD aggregate data versus U.S. manufacturing industries) or due to the methodology of Basu, Fernald, and Kimball (1998) being superior to that of Imbs (1999) can only be investigated by applying the former methodology to OECD data. Unfortunately, the methodology of Basu, Fernald, and Kimball is more demanding on data than Imbs' methodology making it hard to apply for a broad OECD sample.

Overall, the parameter estimates presented in table 3 are consistent with R&D-induced growth in the OECD. The results are usually stronger when estimating a system of equations as implied by a model of endogenous growth rather than estimating single equations implied by partial equilibrium analysis as in much of the previous work on R&D and productivity. Finally, both conclusions are robust across the seven specifications I consider.

	single equation		system estimation	
	β	ξ	β	ξ
(I)	1.147 (1.49)*	0.339 (3.74)***	0.885 (1.68)**	0.200 (3.72)***
(II)	1.840(2.32)**	-0.096(-0.66)	1.067(1.75)**	0.239(2.13)**
(III)	1.389(3.15)***	-0.55(-0.48)	0.626(3.36)***	0.139(2.09)**
(IV)	1.816 (2.04)**	0.372 (3.32)***	1.151 (1.92)**	0.504 (5.71)***
(V)	0.512 (0.39)	-0.066 (-0.24)	1.685 (2.33)***	0.743 (5.65)***
(VI)	1.077 (1.02)	0.193 (1.32)*	1.489 (1.86)**	0.151 (1.26)
(VII)	1.655 (1.52)*	0.242 (1.44)*	2.261 (3.68)***	0.341 (2.67)***

Table 3: Results from estimation of equations (3) and (4) with aggregate data

Notes:

t-tests of the hypothesis that the parameter equals zero given in brackets.

* p-value of hypothesis test $<$0.10, ** p-value of hypothesis test $<$0.05, *** p-value of hypothesis test $<$0.01

β: Parameter for the impact of R&D intensity on the TFP growth.

ξ: Parameter for the impact of TFP growth on Output Growth.

For (IV), (VI), and (VII) I report the sum of the estimated parameters of lags one to three, and for (V) the sum of lags one to six respectively.

The Newey-West covariance matrix with one lag for specifications (II), and (III), and three lags for specifications (I), (IV), (V), (VI), and (VII), is used for obtaining heteroskedasticity-consistent and autocorrelation-robust standard errors.

(I) Aggregate economy, taking one annual lag of the explanatory variable, a total of 221 observations from thirteen countries for the period 1974 to 1990.

(II) Aggregate economy, taking one three-year period lag of the explanatory variable, a total of 65 observations from thirteen countries and five three-year periods between 1976 and 1990.

(III) Manufacturing sector, taking one three-year period lag of the explanatory variable, a total of 65 observations from thirteen countries and five three-year periods between 1976 and 1990.

(IV) Aggregate economy, taking three annual lags of the explanatory variable, a total of 195 observations from thirteen countries for the period 1976 to 1990. Reporting the sum of parameter estimates for three lags.

(V) Aggregate economy, taking six annual lags of the explanatory variable, a total of 156 observations from thirteen countries for the period 1979 to 1990. Reporting the sum of parameter estimates for six lags.

(VI) Aggregate economy using adjusted proxies of technological change from Imbs (1999), taking three annual lags of the explanatory variable, a total of 112 observations from eight countries for the period 1977 to 1989. Reporting the sum of parameter estimates for three lags.

(VII) Aggregate economy using Solow Residuals from Imbs (1999), taking three annual lags of the explanatory variable, a total of 112 observations from eight countries for the period 1977 to 1989. Reporting the sum of parameter estimates for three lags.

Considering panel data across the industries of each country can potentially improve the power of the tests. Moreover, the comparison between the aggregate data results and the industry-level results from the R&D-intensive manufacturing sector can be instructive about the economy-wide relevance of studies of the manufacturing sector like Mansfield (1988).

I now assume that equations (3) and (4) apply to each industry. Here, I consider only the own-industry effect on productivity and output growth, abstracting from the important question of interindustry R&D spillovers. This enables a striking comparison with the aggregate data results which provide much stronger evidence for R&D-induced growth suggesting the possibility of R&D spillovers at the aggregate level.

I use data across seven manufacturing industries for the seven OECD countries shown in table 2 for which the data are available over the period 1973 to 1991. I include industry-specific dummies to capture variation across industries not attributable to R&D intensity or to productivity growth.

The parameter estimates and t-statistics from estimating equations 3 and 4 using these data are presented in table 4. Again, the system estimation implied by a model of R&D-induced growth gives positive estimates for the parameters of interest. However, the estimates of parameter β, the impact of R&D on productivity, for specifications (II) and (III) are not statistically significant at conventional levels of significance. The higher standard errors for specifications (II) and (III) responsible for this outcome are likely due to the smaller sample used there, as a result of considering a three year lag, compared to that in specification (I).

The smaller parameter estimates obtained using the industry data compared to those for the economywide data suggests that industry-level studies might be underestimating the impact of R&D on growth when ignoring aggregate spillovers. The results are consistent with the idea that individual industries can draw from an aggregate pool of knowledge and do not depend only on the private knowledge generated by their own R&D expenditures.

	single equation		system estimation	
	β	ξ	β	ξ
(I)	0.291 (2.55)***	0.017 (0.42)	0.066 (2.99)***	0.113 (1.59)*
(II)	0.288 (2.10)**	-0.091 (-1.12)	0.074 (0.98)	0.137 (2.63)***
(III)	0.214 (1.64)*	0.159 (2.08)**	0.069 (0.96)	0.130 (3.33)***

Table 4: Estimation of equations (3) and (4) with industry-level data.

Notes:

t-tests of the hypothesis that the parameter equals zero given in brackets.

* p-value of hypothesis test $<$0.10, ** p-value of hypothesis test $<$0.05, *** p-value of hypothesis test $<$0.01

β: Parameter for the impact of R&D intensity on TFP growth.

ξ: Parameter for the impact of TFP growth on Output Growth.

The Newey-West covariance matrix with one lag for specification (III), and three lags for specifications (I) and (II) is used for obtaining heteroskedasticity-consistent and autocorrelation-robust standard errors.

(I) 882 observations from 7 industries, 7 countries, and 18 years for 1974 to 1991. Taking one annual lag of the explanatory variable.

(II) 784 observations from 7 industries, 7 countries, and 16 years for 1976 to 1991. Taking 3 annual lags of the explanatory variable. Reporting the sum of parameter estimates for the three lags.

(III) 245 observations from 7 industries, 7 countries, and 5 three-year periods between 1976 and 1990. Taking a three-year lag of the explanatory variable.

4 Conclusions

I estimate a system implied by a model of R&D-induced growth that relates R&D intensity, productivity, and economic growth. Aggregate data across thirteen OECD countries and two-digit manufacturing industry data for seven OECD countries for the period 1973 to 1991 are employed in this analysis. The regression of productivity growth on lags of R&D intensity and the regression of output growth on lags of productivity growth should give nonzero sums of the slope coefficients for models of R&D-induced growth. A zero sum of slope coefficients for either of the two equations would imply that the null hypothesis that R&D does not induce growth cannot be rejected.

The current analysis differs from previous work on R&D in two respects. First, by considering a system of equations implied by a theoretical model we achieve efficiency gains relative to the single equation estimation suggested by partial equilibrium analysis. Second, by allowing for lags between R&D, productivity, and the growth rate of output, the current approach goes a long way towards remedying the problem of reverse causality driving the results of much of the previous literature with its focus on contemporaneous relationships.

The system estimation provides evidence of positive long-run impact of R&D activity on the growth rate of output. The null hypothesis that growth is not induced by R&D is therefore rejected for this group of OECD countries. Results are stronger when estimating a system of equations implied by a model of endogenous growth rather than estimating single equations as done in much of the microeconomic R&D literature. This is due to the efficiency gains associated with system estimation. Moreover, the results are stronger when estimating aggregate relations rather than industry-level relations, suggesting the possibility of spillovers from aggregate R&D. The conclusions are robust for a variety of specifications.

The above findings suggest that models of R&D-induced growth are consistent with the experience of countries close to the technology frontier. Such models could then serve as empirical templates to assess the potential of different policies in inducing growth for these countries. Moreover, to the extent that technologies developed in the R&D-intensive countries flow across national borders, models of R&D-induced growth will have important implications about the policies that governments and other institutions should be undertaking in order to promote growth in less developed countries that do not perform intensive R&D. Empirical work on the impact of R&D on world economic growth and the channels through which this takes place, is bound to be a fruitful area for future research.

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