Growth through Research and Development

By Heike Belitz, Simon Junker, Max Podstawski and Alexander Schiersch

DIW Berlin has examined the effects of investment in research and development on economic growth in Germany and other OECD countries. Their results show that an increase of one percentage point in research and development spending in the economy as a whole leads to a short-term average increase in GDP growth of approximately 0.05 to 0.15 percentage points. The coefficient for Germany is at the upper end of that range. The analysis shows, however, that it is difficult to separate the effect of aggregate R&D into contributions from private- and public sector R&D. R&D investment in both sectors has seen strong growth in Germany in recent years, particularly when compared internationally. For a country that owes its prosperity largely to its research-intensive manufacturing sector and to production-related, knowledge-intensive services, research and development remains key to future growth. It is therefore essential that Germany does not ease up on its efforts to increase R&D investment.

In developed economies, research and development (R&D) is considered to be a key determinant of international competitiveness, productivity gains, and economic growth. DIW Berlin has conducted a study examining the effect of R&D on economic growth in Germany and 18 other OECD countries in the last several decades.[1] Using time-series and panel-data modeling, it analyzed growth trends in R&D investment—both in private businesses and in public research institutes—as well as the effect of that growth on GDP.

R&D Investment in Germany, Compared to Other Countries

In 2012, Germany came very close to reaching its goal of increasing R&D investment to three percent of GDP (R&D intensity). This puts Germany's R&D intensity not only above the average for OECD countries, but also ahead of the US and far ahead of France and the UK. Of the larger research-intensive countries, only South Korea, Finland, Japan, and Sweden had higher R&D intensity levels in 2012 (see Table 1), and even that gap has been closing in the last few years.

Recent Above-Average Growth ...

From 1995 to 2012, total real spending on R&D in Germany (expressed in purchasing power parities at 2005 prices) grew by an average of 3.2 percent per year, somewhat lower than in the rest of the OECD region (see Table 2). Growth in Germany, on the other hand, accelerated and remained slightly over four percent from 2005 to 2012, taking second place behind South Korea in the growth ranking of the industrialized countries considered in this study. This rise in R&D investment

1 H. Belitz, S. Junker, M. Podstawski, and A. Schiersch, "Wirkung von Forschung und Entwicklung auf das Wirtschaftswachstum", *Politikberatung kompakt*, no. *102* (DIW Berlin, 2015). This is an assessment of the effect of research and development on economic growth, performed by DIW Berlin for the reconstruction loan corporation (*Kreditanstalt für Wiederaufbau, KfW*).

Table 1

R&D intensity for selected OECD countries

R&D investment relative to GDP

	1995	2012	Change 2012–1995	1995	2012	Anteil FuE-Investitionen[1] an OECD
	In percent		In percentage points	Rank		In percent
South Korea	2.3	4.4	2.1	5	1	5.9
Finland	2.3	3.6	1.3	7	2	0.7
Sweden	3.3	3.4	0.2	1	3	1.3
Japan	2.9	3.4	0.5	2	4	13.7
Denmark	1.8	3.0	1.2	11	5	0.6
Germany	2.2	3.0	0.8	8	5	9.2
Switzerland (1996)	2.6	3.0	0.4	3	7	1.2
Austria	1.6	2.8	1.3	13	8	1.0
USA	2.4	2.8	0.4	4	9	41.0
France	2.3	2.3	0.0	6	10	5.0
Belgium	1.7	2.2	0.6	12	11	0.9
Netherlands	2.0	2.2	0.2	9	12	1.4
UK	1.9	1.7	−0.2	10	13	3.5
Spain	0.8	1.3	0.5	15	14	1.8
Italy	1.0	1.3	0.3	14	15	2.4
OECD	2.0	2.4	0.4	–	–	100

1 In purchasing power parities.

Sources: OECD; calculations by DIW Berlin.

Germany ranked 5th for R&D intensity in 2012.

Table 2

Annual growth of R&D expenditures for selected countries

	1995–2012	1995–2005	2005–2012	1995–2012	1995–2005	2005–2012
	In percent			Rank		
South Korea	8.3	6.9	10.3	1	4	1
Germany	3.2	2.6	4.0	8	11	2
Belgium	3.5	3.2	4.0	6	8	3
Switzerland[1]	3.0	2.8	3.5	9	9	4
Austria	5.7	7.3	3.6	2	3	5
Denmark	4.2	5.2	2.9	5	5	6
USA	3.4	3.9	2.8	7	7	7
Netherlands	2.5	2.3	2.7	11	13	8
Spain	5.3	7.3	2.5	3	2	9
France	1.6	1.3	1.9	15	15	10
Italy	2.2	2.6	1.7	12	10	11
Finland	5.3	8.3	1.2	4	1	12
Sweden	2.8	4.0	1.1	10	6	13
UK	1.7	2.3	0.7	14	14	14
Japan	1.7	2.5	0.6	13	12	15
OECD	3.4	3.7	2.9	–	–	–

1 1996 and 2004.

Sources: OECD; calculations by DIW Berlin.

Recently only South Korea experienced larger growth in R&D expenditures as Germany.

in Germany was accompanied by stronger growth in the German economy as a whole, as compared to other EU member states.[2]

… and High R&D Intensity

Unlike other current expenditures for production, such as wages and other purchased materials and services, there is a certain time lag before the results of R&D expenditure are seen in production. In the national accounts system (*Volkswirtschaftliche Gesamtrechnungen, VGR*), they are therefore now handled as investments and capitalized as such.[3] Since official figures for R&D capital stock were not yet available for all countries at the time this study was conducted, estimates were made for R&D capital stocks according to methods used in the literature (see Box 1). The ratio of a country's R&D investment to its R&D capital stock (R&D investment intensity) is another key figure in international comparisons, as it shows how much countries are investing in the renewal and expansion of their R&D capital stock.

For several years now, R&D investment intensity has been decreasing in countries such as Finland, Sweden, and Japan, which have higher R&D intensity levels than Germany, and a similar trend has been observed in Denmark and the UK (see Figure 1). Toward the end of the observation period, Finland, Sweden, Japan, and the UK had R&D investment intensity levels of just above 15 percent, the depreciation rate assumed by this study. In France, this coefficient has stagnated since the early 2000s at a relatively low level. In Germany, however, there has been an upward trend since the comparatively low level of 2005, with a shortfall during the years of the global financial and economic crisis. Toward the end of the observation period, the figure for Germany was above that of the US, where investment intensity did not recover as quickly after the crisis. Thus both the level and growth of German R&D investment intensity show positive trends compared to other countries from 2008/2009 to 2012.

Interplay between Private and Public Sector R&D

In the mid to late 1990s, total R&D investment in Germany rose faster than GDP. It was the private sector, however, that was the sole driver of this rise. In the public sector — primarily universities, colleges, and public re-

2 Enquete Commission, *Wachstum, Wohlstand, Lebensqualität – Wege zu nachhaltigem Wirtschaften und gesellschaftlichem Fortschritt in der Sozialen Marktwirtschaft* (final report of the Enquete Commission regarding sustainable growth and social progress in a social market economy); *Deutscher Bundestag*, printed paper 17/13300, 17th parliamentary term, 43 (Berlin, 2013).

3 See European System of Accounts – ESA 2010.

Box 1

Calculating R&D Capital Stocks

R&D capital stocks are estimated using methods well established in the literature.[1] The R&D capital stock RC of country i at time t is calculated according to the perpetual inventory method as follows:

$$RC_{i,t} = (1-a)\ RC_{i,t-1} + r_{i,t}$$

where $RC_{i,t}$ is R&D capital stock, $r_{i,t}$ is R&D investment, and is the amortization rate of the R&D capital stock. An amortization rate of 15 percent is assumed for all countries. This is, however, a simplifying assumption that can only approximately reflect the various economic lifetimes of R&D results in different technology sectors.[2]

Since the OECD data on R&D investment only go back to the early 1980s for most countries and only as far back as 1991 for South Korea, estimates must be made for the initial values of R&D capital stock.[3] The initial value for R&D capital stock is calculated as follows:

$$RC_{i,0} = \frac{r_{i,0}}{(a_i + w_i)}$$

where $r_{i,0}$ is R&D investment when $t = 0$, is the amortization rate of R&D capital (assumed here to be 15 percent), and represents the estimated average growth rate of R&D investment in prior periods (estimated here as the average annual growth rate of the first ten available years).

1 Hall, B. H., Mairesse, J, Mohnen, P.(2010): Measuring the Returns to R&D. In: Handbook of the Economics of Innovation, Hall, B. H., Rosenberg, N. (ed), 1033–1082. Elsevier B.V., 2010.

2 Adler, W., Gühler, N., Oltmanns, E., Schmidt, N., Schmidt, P., Schulz, I. (2014): Forschung und Entwicklung in den Volkswirtschaftlichen Gesamtrechnungen. Wirtschaft und Statistik, Statistisches Bundesamt, S. 703–717.

3 Hall, Mairesse, and Mohnen (2010).

search institutes — R&D grew at approximately the same rate as GDP (see Figure 2). After 2007, R&D investment again grew faster than GDP, this time in both the private and public sectors. This is due in part to a change in government policy, which has since attached greater importance to publicly funded research.[4]

Private-sector R&D investment in 2012 amounted to approximately two percent of value added in Germany and the US, which was higher than the corresponding figure for France and the UK. However, the ratio of private-sector R&D investment to value added was even higher in South Korea, Japan, Finland, and Sweden, in some cases considerably higher (see Table 3). These are the same countries that show higher overall R&D intensity than Germany. Countries where less than two-thirds of R&D investment was made in the private sector, however, were less successful at raising R&D intensity (see Figure 3). These countries include Spain, Italy, and the Netherlands as well as the UK. This indicates that high R&D intensity in the economy as a whole is difficult to accomplish without considerable private-sector R&D investment.

Table 3

R&D intensity in the private sector for selected countries

	1995	2012	1995	2012	Share of business	
					1995	2012
	In percent		Rank		In percent	
South Korea	1.7	3.4	4	1	74	78
Japan	1.9	2.6	2	2	65	77
Finland	1.4	2.4	7	3	63	69
Sweden	2.4	2.3	1	4	75	68
Switzerland (1996)	1.8	2.1	3	5	71	70
Germany	1.4	2.0	6	6	66	68
Denmark	1.0	2.0	11	7	57	66
Austria (1993)	0.8	1.9	13	8	56	69
USA	1.7	1.9	5	9	71	70
Belgium	1.2	1.5	10	10	71	68
France	1.4	1.5	8	11	61	65
Netherlands	1.0	1.2	12	12	52	57
UK	1.2	1.1	9	13	65	63
Italy	0.5	0.7	14	14	53	55
Spain	0.4	0.7	15	15	48	53
OECD	1.3	1.6	-	-	67	68

Sources: OECD; calculations by DIW Berlin.

Germany ranked 6th for private sector R&D intensity in 2012.

R&D Profile of the Private Sector: Manufacturing Industries Are Top R&D Investors

In Germany — as in Japan and South Korea — about 85 percent of private-sector R&D spending is concentrated in the manufacturing sector. The corresponding figure is less than 70 percent in the US, a little under 50 percent in France, and only 37 percent in the UK. Moreover, German private-sector R&D investment is concentrated relatively heavily in just a few industries. Based

4 This is indicated, among other things, by a continued increase in R&D spending at federal and *Länder* levels since 2006. As a share of the overall government budget, it rose from 2.7 percent per year to 3 percent in 2012. See www.datenportal. Bmbf.de/1.1.2, accessed 20.08.2015.

Figure 1

R&D investment intensity for selected countries

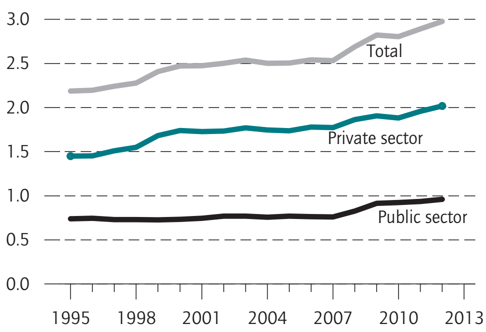
R&D investment relative to R&D capital stock, percentages

Sources: OECD; calculations by DIW Berlin.

In Finland, Sweden and Japan the R&D investment intensity decreased recently.

Figure 2

R&D intensity for Germany in the private and public sector
In percent



Sources: OECD; calculations by DIW Berlin.

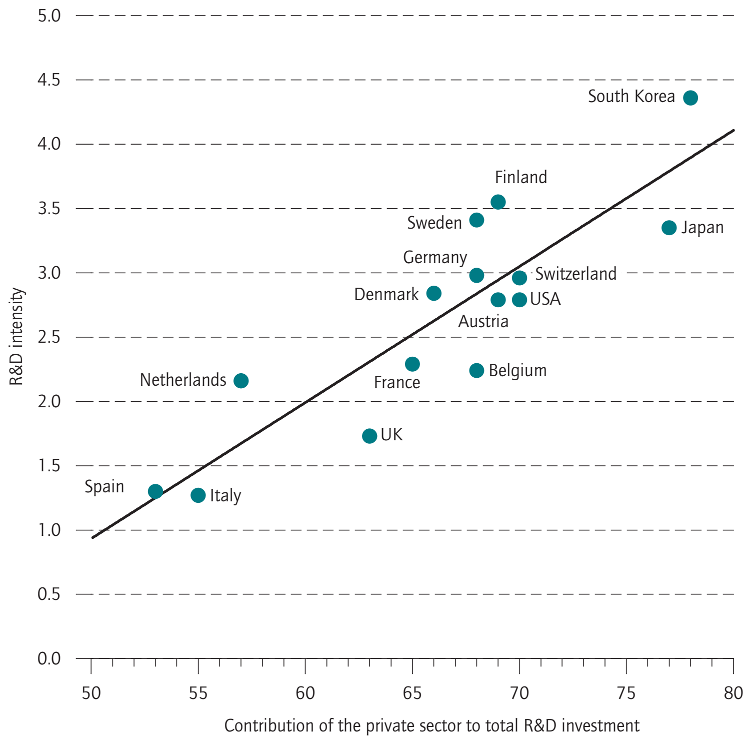
R&D growth was driven by private sector R&D until recently.

on calculations for the three most research-intensive industries, Germany ranks fourth among 13 OECD countries; based on the Herfindahl-Hirschman Index (HHI)[5], it ranks fifth (see Table 4). Higher concentrations are

5 The Herfindahl-Hirschman Index (HHI) is a statistical measure of concentration. In the present study, it is applied to 27 different industries and is calculated by squaring their respective shares in the total R&D spending of a national economy and then summing the squares. HHI scores can range from $\frac{1}{27}$ (equal distribution of shares) to 1 (maximum concentration).

Figure 3

Contribution to R&D investment by the private sector and R&D intensity in selected countries (2012)
In percent



Sources: OECD; calculations by DIW Berlin.

High levels of total R&D intensity depend strongly on private sector R&D.

Table 4

Sector concentration of R&D expenditures for selected countries (2011)

	HH-Index		3 Sectors with the highest R&D expenditures		
		Rank	In percent	Rank	
Finland	0.270	1	62.8	3	Computer, electronic and optical products; Machinery; Electrical equipment
South Korea	0.266	2	67.0	1	Computer, electronic and optical products; Motor vehicles; Machinery;
Japan	0.169	3	64.0	2	Computer, electronic and optical products; Motor vehicles; Pharmaceuticals
UK	0.154	4	48.0	5	R&D; Motor vehicles; Other transport equipment
Germany	0.149	5	54.4	4	Motor vehicles; Computer, electronic and optical products; Machinery
USA	0.125	6	46.9	6	Computer, electronic and optical products; P Pharmaceuticals; Other transport equipment
Denmark	0.115	7	42.0	8	Pharmaceuticals; R&D; Machinery
Belgium	0.109	8	42.2	7	Pharmaceuticals; R&D; Computer, electronic and optical products
France	0.092	9	33.9	10	R&D; Computer, electronic and optical products; Other transport equipment
Austria	0.084	10	28.3	12	R&D; Electrical engineering; Machinery
Italy	0.081	11	36.1	9	Computer, electronic and optical product; Motor vehicles; R&D
Spain	0.067	12	28.2	13	Other transport equipment; Pharmaceuticals; Motor vehicles
Netherlands	0.066	13	28.5	11	Machinery; Computer, electronic and optical products; Chemicals

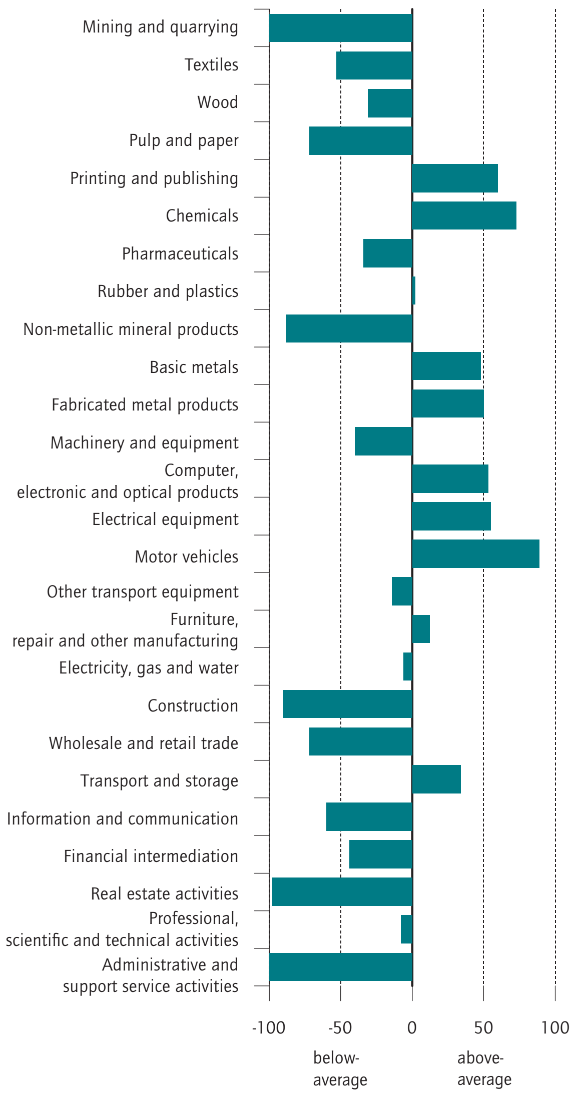
R&D: Research and Development.
Sources: OECD; calculations by DIW Berlin.

Private sector R&D is concentrated in a few industries.

Figure 4

Relative share of R&D investment[1] by economic activity for Germany (2011)

In percent



1 The relative share of R&D investment indicates whether the R&D investment in a specific German industry is smaller or larger than the average R&D investment in that industry across countries.

Sources: OECD; calculations by DIW Berlin.

Most R&D in Germany is undertaken in manufacturing.

found both in the larger economies of South Korea and Japan and in Finland. These countries with very heavy concentrations of R&D in specific industries have higher R&D intensity in the economy as a whole than Germany. But even in the UK, where private-sector R&D intensity is considerably lower, the concentration of private-sector R&D spending is similar to Germany's. In many countries, the R&D service sector is one of the most research-intensive industries (Austria, France, the UK, Belgium, Denmark, and Italy). R&D intensity in the economy as a whole in these countries is lower than in Germany, however, where R&D is concentrated in the manufacturing industries.

International comparisons of the concentration of private R&D investment in different industries involves calculating a "relative share of R&D investment in industry *j* of country *i* (RAF_{ij})."[6] The indicator for relative share of R&D investment for Germany shows whether a higher share (positive value) or a lower share (negative value) of R&D expenditure is invested in an industry, as compared to the average for research-intensive countries.

R&D activities in Germany are heavily concentrated in the research-intensive manufacturing industries of chemical, electrical, mechanical, and automotive engineering (see Figure 4). Other key R&D industries in Germany include the production of metal and metal products as well as print and media. However, compared to other countries, relatively little research is done in Germany in the research-intensive industries of pharmaceuticals, computers, electronics, and "other" vehicle manufacturing. Other countries also have higher concentrations of R&D in most of the service industries, and in infrastructure, mining, and construction. One exception is the service industry of transportation and storage.

Cutting-Edge Technology in German Auto Industry

Almost a third of private-sector R&D spending in Germany goes to auto manufacturing. This is often viewed critically, as auto manufacturing is categorized as a high-tech industry, in which R&D intensity, measured as a share of production value (which includes purchased material and services), is lower than in cutting-edge technologies.[7] R&D intensity in auto manufacturing, measured as a share of production value, was 5.2 percent in

6 The relative share of a country's R&D investment in an industry is calculated using a formula similar to that for the relative share of world trade, an indicator used in foreign trade analysis. This measure is used to compare the share of private R&D spending in Germany for industry *j* with the share for that industry in other countries (in this case, the 13 leading R&D countries in the OECD):

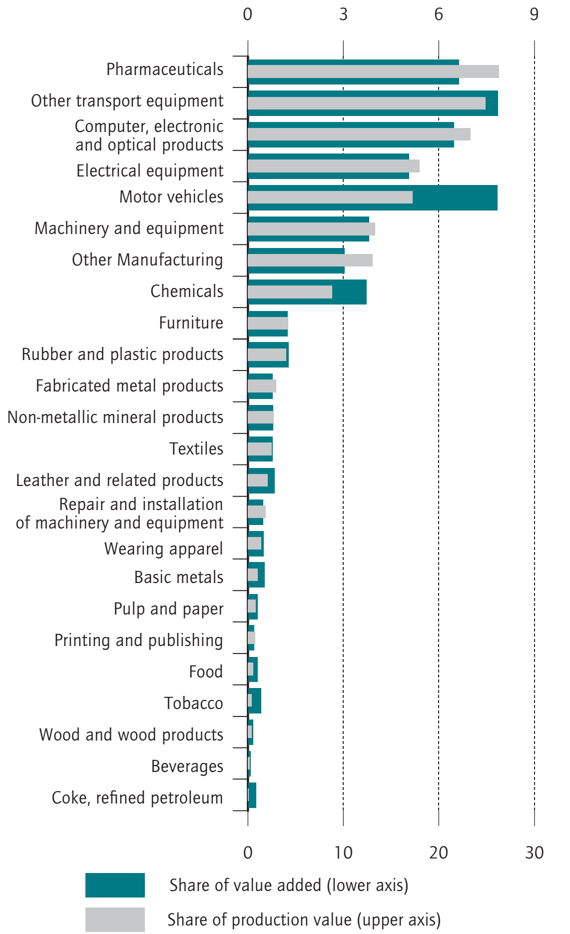
$$RAF_{ij} = \text{tanhyp } 100 \ln \left[\frac{(a_{ij} / \sum_j a_{ij})}{(\sum_i a_{ij} / \sum_{ij} a_{ij})} \right]$$

7 The term "high-tech" applies to industries and product categories where the ratio of internal R&D expenditure to production value is between 2.5 percent and 7 percent. "Cutting edge" technology applies to industries and product categories with a ratio of R&D intensity to production value of seven percent or more (Gehrke, Frietsch, et al., 2013).

Figure 5

R&D Intensity in Germany measured as a share of value added and production value by economic activity (2012)

In percent



Source: Federal Statistical Office; calculations by DIW Berlin.

The German automobile industry may be called leading edge technology.

2012, according to statistics regarding cost structure in the manufacturing industries. When R&D spending is calculated as a share of value added, however, R&D intensity in auto manufacturing (26 percent) is virtually identical to that in the cutting-edge pharmaceuticals industry (22 percent), in other vehicle manufacturing (26 percent), or in the production of computers, electronics, and optics (22 percent) (see Figure 5). German auto manufacturing is an industry with high value added and particularly high R&D intensity, both domestically and internationally, which qualifies it as a cutting edge industry within Germany.

Breakdown of Industrial R&D Intensity by Country

The difference between the private-sector R&D intensities of two countries—measured as a ratio of R&D expenditure to value added—can be attributed to different patterns of investment behavior in the relevant industries or to different economic structures (as industry shares in total value added vary from country to country). The impact of these two components is measured using a variant of the shift-share analysis. This approach breaks down the observed difference in R&D intensities between Germany and another country into two components, one structural and one behavioral. The structural component captures the proportion of that difference that is attributable to differences in the relative sizes of specific industries in the two countries. The behavioral component measures the proportion of the total difference that is attributable to divergent R&D behavior (R&D intensity) within an industry (see Box 2).

Comparisons between Germany and other OECD countries for 2011 or 2010 were made by calculating private-sector R&D intensity based on value added (see Table 5). For example, R&D intensity in Germany in 2010 was 1.5 percentage points lower than in South Korea. A gap of 1.8 percentage points is attributable to differences in economic structures. This structural effect works against Germany. The behavioral effect, on the other hand, works in Germany's favor, contributing 0.3 percentage points.

On the whole, the structural effect and the behavioral effect play more or less equally important roles in explaining the differences between Germany and other countries with regard to private-sector R&D intensity. While Germany often suffers from the behavioral effect, it usually benefits from the structural effect. Both effects are strongly driven by a few particularly research-intensive industries, as can be seen in the examples shown in Table 6. For example, the computer and electronics industry plays a key role in explaining why R&D intensity in Germany is approximately 1.5 percentage points lower than in both South Korea and Finland. The industry invests heavily in research and carries considerably more weight in these countries than in Germany. This structural effect puts Germany behind South Korea by 1.8 percentage points and behind Finland by 0.5 percentage points, thus contributing greatly to the differences in private-sector R&D intensity. This industry also has a particularly high intensity in Finland, however (behavioral effect: 1.3 percentage points). Compared to the UK, Germany benefits from the auto manufacturing industry in particular—in terms of both its greater weight and its higher R&D intensity.

Box 2

Shift-Share Analysis[1]

The difference in private R&D intensity between two countries ($FI^{DEU} - FI^{Other\ country}$) is decomposed into two components, a structural component (Δ_{ST}) and a behavioral component (Δ_{VH}):

$$FI^{DEU} - FI^{Other\ country} = \Delta_{ST} + \Delta_{VH}$$

The structural component (Δ_{ST}) captures the share of that difference that is attributable to differences in the relative sizes of industry sectors in the two countries. It is derived from the difference in sectoral weightings – measured here based on the relevant sector's share of value added and the R&D intensity of that sector in the other country. The weighted R&D intensities are aggregated across all available sectors:

$$\Delta_{ST} = \sum_i FI_i^{Other\ country} (\mathrm{SHARE}_i^{DE} - \mathrm{SHARE}_i^{Other\ country})$$

where i = sector, 2-digit sector code

The behavioral component (Δ_{VH}) measures the share of the total difference that is attributable to divergent R&D behavior (R&D intensity) within a sector. It is derived from the sectoral difference in R&D intensity between two countries, which is weighted with the relevant German sector's share of value added. The weighted sectoral differences are aggregated across all available sectors:

$$\Delta_{VH} = \sum_i \mathrm{SHARE}_i^{DE} (\mathrm{FI}_i^{DE} - \mathrm{FI}_i^{Other\ country})$$

where i = sector, 2-digit sector code..

1 The decomposition technique used here is based on Ronald Oaxaca and Alan Blinder's work on wage differentials. R. Oaxaca, "Male–female wage differentials in urban labor markets," *International Economic Review* 14 (3) (1973): 693–709. A. Blinder, "Wage Discrimination: Reduced Form and Structural Estimates," *Journal of Human Resources* VII (4) (1973): 436-455. The technique was used to explain, among other things, the differences in R&D intensity between countries and corporate groups (Belitz and Zambre (2011)).

Table 5

Decomposition of the private sector R&D intensity, difference between Germany and other OECD-countries

		Number of sectors	R&D Intensity (Country)	R&D Intensity (Germany)	Spread Germany – other county	Structural effect	Behavioral effect
			In percent		In percentage points		
South Korea	2010	27	4.14	2.64	−1.51	−1.77	0.27
Finland	2011	26	4.37	2.95	−1.42	−0.06	−1.37
Denmark	2010	27	3.36	2.64	−0.72	−0.03	−0.70
USA	2010	26	2.73	2.64	−0.09	0.53	−0.63
Austria	2011	27	2.90	2.96	0.05	1.35	−1.29
Belgium	2011	27	2.32	2.96	0.64	0.99	−0.35
UK	2011	27	1.89	2.96	1.07	0.88	0.19
Netherlands	2011	27	1.65	2.96	1.31	2.29	−0.98
Italy	2010	27	1.04	2.64	1.59	0.62	0.97

Sources: OECD; calculations by DIW Berlin.

Structural and behavioural differences explain deviations in private sector R&D among countries.

R&D and Economic Growth

In this study of selected research-intensive OECD countries, an initial look at the association between average annual growth of R&D investment—both as a whole and in the private sector—and average annual growth of GDP suggests a positive correlation (see Figure 6). If we assume a linear correlation, an increase in annual growth of total R&D investment of one percentage point in the period from 1995 to 2012 is associated with an increase in annual growth of GDP of slightly over 0.3 percentage points. The coefficient for R&D spending in the private sector is somewhat smaller.

The degree to which this correlation can be confirmed by econometric analyses was tested using both panel data and time series models. Panel models can be used to measure the short-term effect of R&D on economic growth across several countries. Time series models are well suited for examining dynamic effects within a single country. They can also be used to analyze long-term correlations between R&D spending and economic growth. The analysis uses figures for gross investment.[8] The data for Germany and the 18 other industrialized countries were taken from OECD research and development data for 1981 to 2012. The time series analyses for Germany also used annual R&D data from the German government's reports on research and innovation (*Bundesforschungsberichte*) and economic data from the *Stifterverband für die Deutsche Wissenschaft*, a charitable foundation that supports education, science, and research. This made it possible to extend the period covered by the time series back to 1964.

Both the time series analysis (see Box 3) and the analysis of panel data (see Box 4) suggest that R&D investment promotes economic growth in a country as measured by GDP. The panel data analyses show that for the OECD countries examined in the study an increase of

Table 6

Sectors with the highest contribution to the private sector R&D intensity, difference between Germany and other selected countries
Percentage points

	Spread Germany – other country	Structural effect	Behavioral effect
South Korea 2010	−1.51	−1.77	0.26
Computer and electronics	−1.78	−1.75	−0.03
Finland 2011	−1.42	−0.05	−1.37
Computer and electronics	−1.85	−0.54	−1.31
Information and communication	−0.22	−0.09	−0.13
Motor vehicles	0.95	0.22	0.73
UK 2011	1.10	0.88	0.19
Motor vehicles	0.81	0.51	0.29
Machinery and equipment	0.22	0.22	0.00

Sources: OECD; calculations by DIW Berlin.

Box 3

Time Series Analysis

Time series analysis provides evidence of a robust, significant positive effect of R&D investment on economic growth. Its theoretical basis is a production function that associates overall economic activity with the input factors R&D, work, and capital. It does not control for the effect of human capital, as its measurements hardly vary at all over time. R&D spending is calculated using figures for real gross investment in R&D over the period from 1964 to 2012; these figures were adjusted for changes in price levels in the economy as a whole.

As only relatively short time series are available, we estimated univariate models that make fewer demands on the data and therefore may produce more precise estimates than multivariate models. The results indicate a positive correlation between R&D and economic growth. However, in such a setup the effect of R&D investment on economic growth is viewed in isolation from possible feedback effects. Estimations of the aggregate production function with lagged R&D investment show an effect of approximately 0.15 percentage points of GDP growth following a one-time increase in R&D investment of one percentage point. Variations in R&D spending, at about six percent, account for a considerable share of the variation in GDP growth rates.

Autoregressive distributed lag models, i.e. time series models that permit more flexible dynamics by taking intoconsideration economic growth as well as the growth in production factors of prior periods, also indicate a significantly positive correlation between R&D investment and economic growth. This finding is robust over a variety of specifications. This correlation is even slightly stronger than in the specification of the production function. Models with time-variant coefficients also show that the effect of total R&D investment on economic growth diminished slightly over time. Using multivariate analysis, it is possible to explicitly consider the interaction between R&D spending and economic growth. Changes in R&D investment, to give just one example of such interactions, have a delayed effect on economic growth, which in turn impacts future R&D spending.

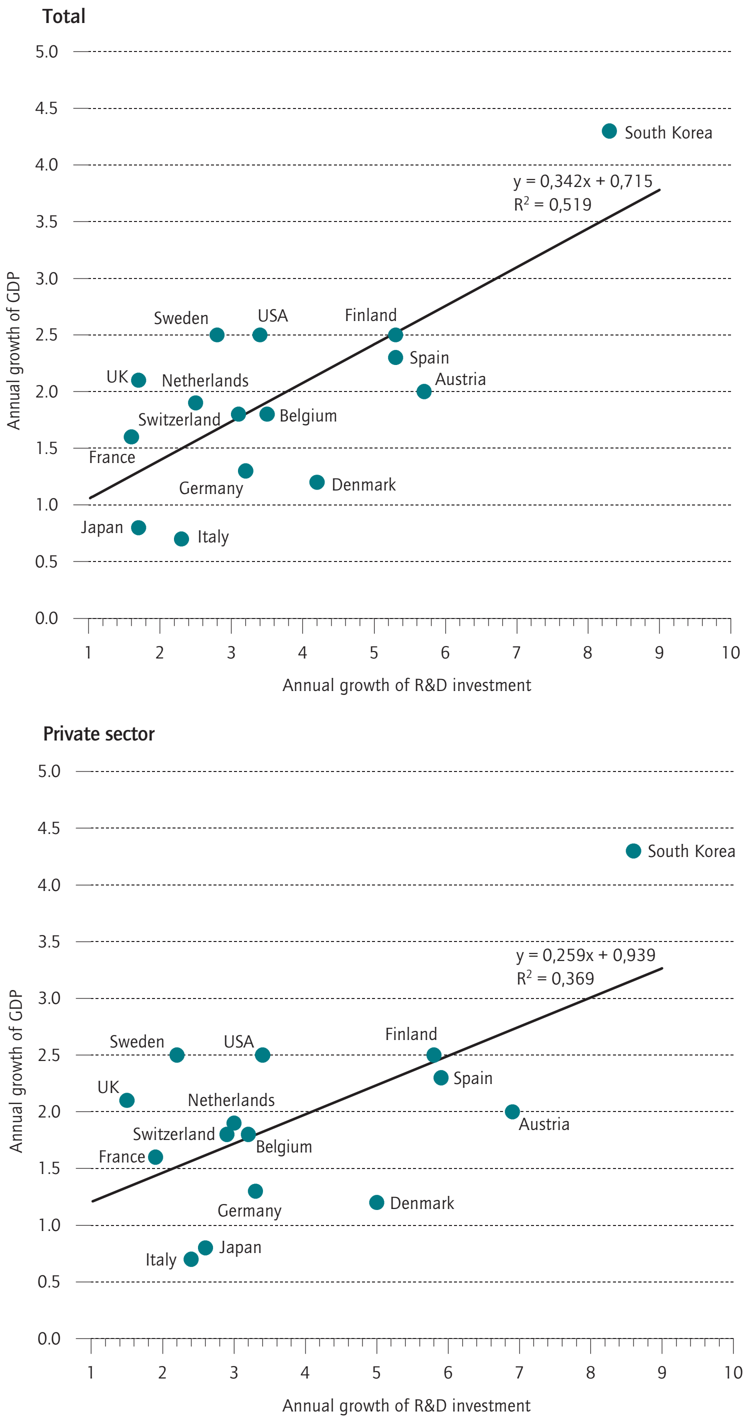
Granger causality tests show that total investments in R&D drive economic growth, but provide virtually no evidence of converse effects; it is therefore presumably the growth-promoting effect of R&D that is paramount.

Impulse responses based on the estimated vector autoregressive models show that a stimulus to R&D investment leads to a robust, significant increase in the growth rate of GDP. This confirmes the results of univariate estimates: in response to an increase in R&D spending of slightly more than three percentage points (standard deviation), it is chiefly in the first subsequent year that a significant positive response is seen in GDP, which grows by slightly more than half a percentage point. This indicates that the effect of R&D investment on GDP becomes evident relatively quickly.

Figure 6

Annual Growth of GDP relative to annual R&D investment growth (1995–2012)

In Percent



Sources: OECD; calculations by DIW Berlin.

High R&D Investments are associated with stonger economic growth.

one percentage point in the growth of R&D expenditure in the economy as a whole results in a short-term average increase in GDP growth of 0.05 percentage points. The time series models for Germany exhibit an even stronger effect that is almost three times as high in the preferred specification. Using a production function that takes into account R&D, the effects for Germany in 2012 can be illustrated using the following calculation: given coefficients of 0.15, a rise in R&D expenditure of one billion euros would result in an increase in GDP the following year that—depending on the amortization rate that is assumed for R&D investments—would range from 470 million euros (amortization rate of five percent on R&D capital stock) to somewhat over one billion euros (amortization rate of 15 percent). The results of the time series analyses, however, indicate that the strength of this relationship in Germany reduced over time. The long-term, cumulative effect of a one-percent increase in R&D spending in the economy as a whole is 0.12 percentage points. It should be noted, however, that the effect for Germany was estimated on the basis of a relatively small data sample and is subject to considerable uncertainty.

Econometric analyses show that R&D investment in industrialized countries is a key driver of growth. Harvesting the full benefits of this growth is doubtless only possible if new ideas continue to be developed and fed into the innovation process.

Conclusion

In 2012, Germany came very close to reaching its goal of investing three percent of GDP in research and development. This puts Germany above the average for OECD countries, still ahead of the US, and far ahead of France and the UK. Of the larger research-intensive countries, only South Korea, Finland, Japan, and Sweden had higher R&D intensities in 2012. From 2007 onward, R&D in Germany saw particularly strong growth domestically and by international standards, with spending rising faster than GDP both in the private sector and in public research institutes. This was due in part to a change in policy, which has since attached greater importance to publicly funded research.

The results of econometric analysis consistently support the conclusion that R&D investment is an important driver of growth. The panel data analyses show that for the OECD countries examined in the study an increase of one percentage point in R&D expenditure in the economy as a whole results in a short-term average increase in GDP growth of 0.05 percentage points. The time series models for Germany exhibit an even stronger effect that is almost three times as high in the preferred spec-

Box 4

Panel Analysis

Different methods of panel analysis were used to examine whether R&D spending has an effect on economic growth across multiple countries. The dataset comprises 19 OECD countries and includes observations over a period extending from 1981 to 2011. The theoretical basis of the analyses is a production function in which economic growth is determined by work, capital, and R&D spending.[1] Estimates are based on the fixed effect estimator and the GMM approach, among other methods. The latter in particular has a number of advantages over less complex regression models for panel data analysis. Primary among them is that it avoids distortions in estimates resulting from the (potential) endogeneity of explanatory variables.

1 The analyses are based on the theoretical concept of a production function with knowledge capital, as proposed by Griliches. See Z. Griliches, "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *The Bell Journal of Economics* (1979): 92–116. To test the robustness of the results, additional control variables were incorporated into the estimates at a later stage in the process. These included a variable for change in the unemployment rate and a proxy variable for human capital .

The analyses consistently show a clear and significant relationship between rates of change in R&D spending in the economy as a whole and annual economic growth. These findings are independent of econometric estimation techniques and are thus very robust. In the estimates based on the GMM approach, presupposing the endogeneity of R&D spending and taking into account country and time effects, the effect amounts to 0.05 percentage points. A one-time increase of one percentage point in R&D spending in the economy as a whole thus leads to a one-time increase in GDP growth of 0.05 percentage points.

Further analyses confirm this positive relationship: while estimates with non-linear terms do not show any disproportionate effects of particularly high R&D investments, these estimates do provide evidence of a positive correlation between R&D spending in the economy as a whole and economic growth.

On the whole, the results of the panel analyses for the 19 OECD countries are consistent with those of the time series analysis for Germany (see Box 3).

ification. However, it is hard to differentiate/disentangle the aggregate effect into contributions from private- and public sector R&D. This is probably due at least in part to close interaction between the two sectors in the national innovation systems of the industrialized countries examined here, even if the exact form of this interaction may vary from country to country and over time.

Germany is on the right track, but it must not ease up on its efforts to increase R&D investment. For a country that owes its prosperity in large part to its research-intensive manufacturing sector and to production-related, knowledge-intensive services, investment in R&D — both public and private — remains key to future growth.

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