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With a little help from my friends: patents, technological diffusion and firm productivity

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Introduction

Belgium is performing particularly well as far as innovation and R&D are concerned and is in fact one of Europe's top performers in this area. With that in mind, it is strange to note that Belgian productivity growth is so low. While low and even decelerating productivity growth has been a general trend in advanced economies over the last couple of decades, this phenomenon is particularly marked in Belgium where, in recent years, overall productivity growth has been only slightly positive. All of this is even more puzzling given the current period of rapid technological change, characterised by the generalised use of ICT, which should, in principle, boost productivity, as was the case during earlier waves of industrialisation.

Innovation is obviously beneficial for firms doing the innovating, as it enhances their productivity and thus their competitive position. For the economy as a whole, however, it is preferable when both innovative companies and other firms reap the benefits of R&D activities. This spillover of innovation on other firms is called technological diffusion. Technological diffusion is important not only because it raises the overall level of productivity in the economy but also because innovation is subsidised by substantial public resources and the return on public investment is higher when spillover effects occur and other firms can benefit from the developments. In this regard, government subsidies help to bring innovation efforts up to the optimal level for the economy and are economically justified, as investment in R&D without such support would be suboptimal. This article focuses on technological diffusion from innovative firms to others.

The first two sections contain a general description of the productivity puzzle. The first section focuses on R&D efforts and productivity growth while the second highlights certain factors liable to affect diffusion. The third section considers the question of whether diffusion effectively occurs and, if so, which are the most effective channels. In this context, a number of different diffusion channels are presented and empirically analysed, using Belgian firm-level data. Finally, conclusions are drawn and some policy recommendations made.

* The authors would like to thank Sarah Cheliout and Gert Bijnens for their invaluable help.

1. The productivity puzzle in Belgium

1.1 Substantial R&D efforts

Since 2021, Belgium has been considered an "innovation leader" in the EU, according to the European Innovation Scoreboard. This indicator, compiled by the European Commission, provides an overview of the innovation performance of the EU and other selected countries, by aggregating data relating to around 30 sub-indicators. These refer to aspects such as the importance of STEM (science, technology, engineering and mathematics) in the educational system, the availability of digital infrastructure, ICT skills, investment in R&D, the number of patent applications and the impact of innovation on employment, sales and exports.

Together with Sweden, Finland, Denmark and the Netherlands, Belgium is one of five EU countries performing particularly well as far as innovation is concerned.

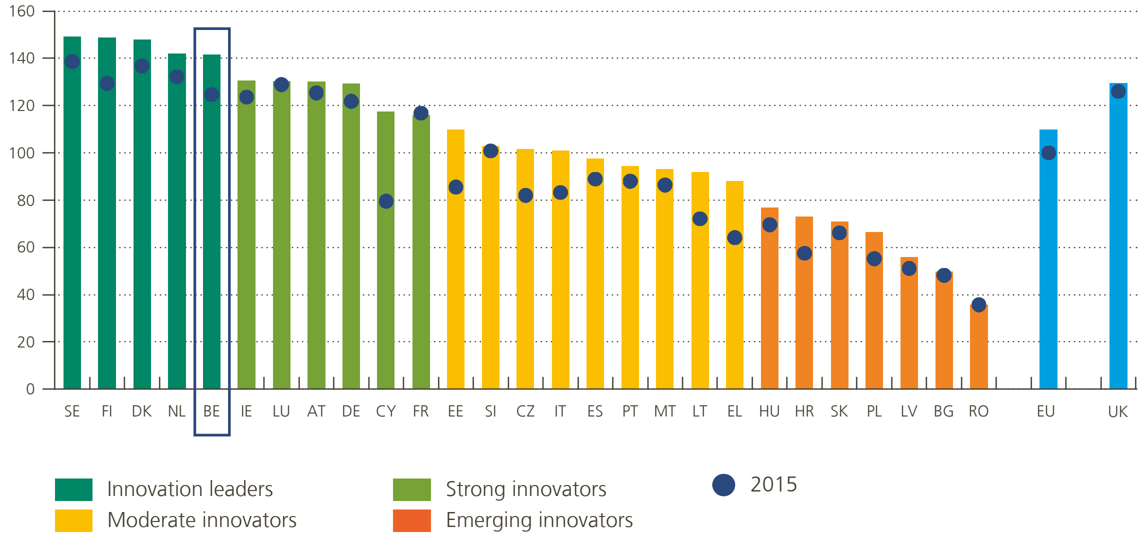
This strong performance is also apparent in the data on total R&D expenditure. In 2020,[1] Belgium spent 3.5 % of GDP on R&D, the highest figure in the EU (tied with Sweden). Belgium thus outperforms the European objective of 3 %, fixed in the early noughties as part of the Lisbon Strategy and still monitored in the framework of the European Semester.

As in most countries, the lion's share of R&D expenditure in Belgium is by companies. However, significant governmental support is also provided; in total, the public sector provides funds representing about 0.6 % of GDP. In this respect, reference can be made to several measures to encourage research activities, such as a partial tax exemption for the salaries of qualifying researchers and tax incentives for intellectual property rights such as patents.

1 This is the most recent year for which data are available.

Chart 1

Belgium is a European innovation leader



Source: Eurostat.

Of course, substantial R&D efforts do not necessarily translate into significant innovation results. In that regard, the quantification of innovation output is not straightforward, as all innovations are not patented. For instance, legal protection is not often sought for know-how, making it difficult to measure. That being said, data are available for a specific result of innovation activity, namely patents, which protect the use of inventions. As the patent procedure is lengthy and costly, it is only worthwhile for valuable techniques or procedures. The number of patents and patent applications, in particular those granted by the European Patent Office (EPO),[1] is therefore a useful indicator of innovation output. As far as patents are concerned, Belgium does not top the European rankings but is nevertheless one of the better performing countries.[2]

1.2 Historically low productivity growth

Despite substantial R&D efforts, productivity growth in Belgium has been low for decades and continues to slow. This deceleration is of course a generalised phenomenon seen in all developed economies, but productivity growth is lower in Belgium than the average in the euro area or the US. In fact, even before the COVID-19 crisis, the country's productivity growth rates were barely positive.

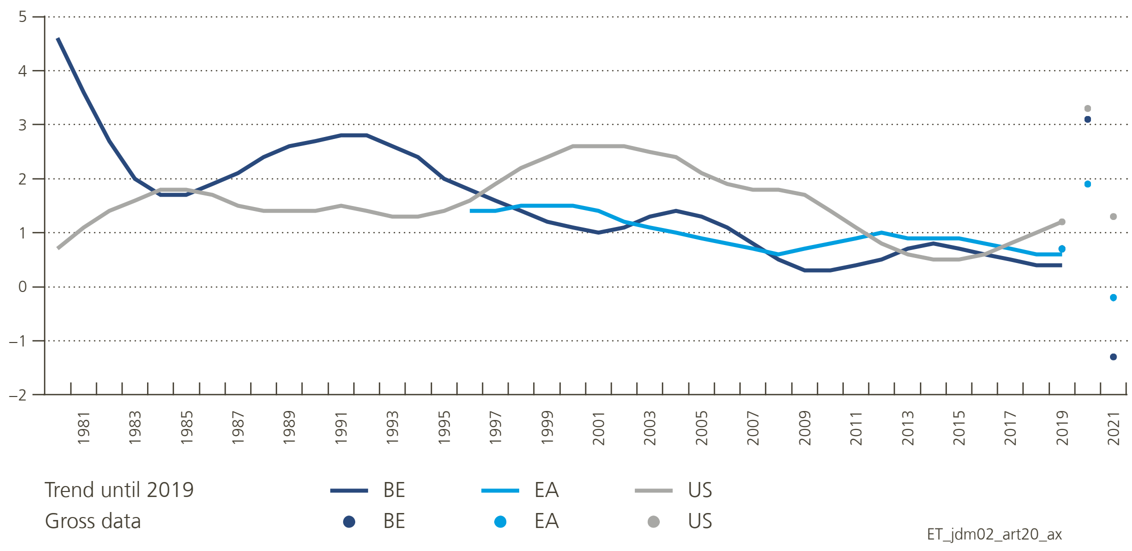
There was a short-lived uptick in 2020. Indeed, due to the COVID-19 crisis, hours worked decreased more than value added, resulting in an increase in apparent labour productivity. In 2021, labour productivity growth fell sharply again.

Previous studies have broken down overall productivity by firm performance, separating those at the technological frontier from those lagging behind.[3] In an optimally functioning economy, "non-frontier firms" are encouraged

1 Patents granted by the EPO afford protection at an international level, which is only cost-effective for high-quality inventions.
2 For a detailed analysis of Belgian patents, see Cheliout (2020), "Belgium's innovative capacity seen through the lens of patent data", *Economic Review*, National Bank of Belgium, November.
3 See De Mulder and Godefroid (2018), "Productivity slowdown: findings and tentative explanations", *Economic Review*, National Bank of Belgium, December.

Chart 2

Productivity growth in Belgium is particularly low



Sources: OECD and NBB.

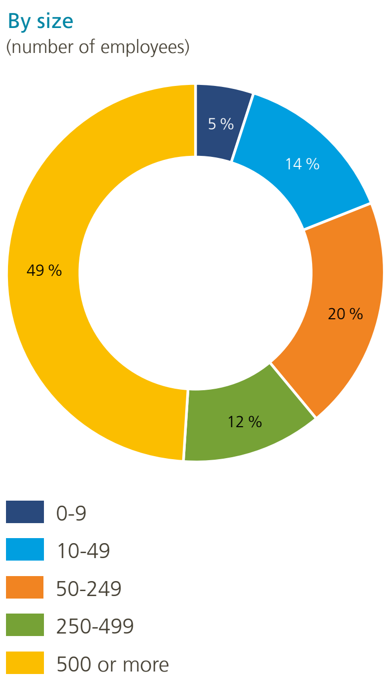
to innovate in order to catch up or even overtake the leaders. If they fail to do so, the technology gap widens over time, and they end up having to close down due to an inability to compete. Technological diffusion should therefore enable firms with a technological handicap to accumulate productivity gains and thereby close the gap with the frontrunners. However, while productivity growth remains substantial in "frontier firms" in Belgium, the productivity gap between those firms and non-frontier firms is gradually widening. The contribution by firms at the technological frontier is so vast that it accounts for almost all aggregate productivity growth. This contribution is not only attributable to internal productivity growth at these firms but also stems from a broader reallocation of resources to frontier firms, to the detriment of non-frontier firms. Technological diffusion therefore seems to be problematic in Belgium.

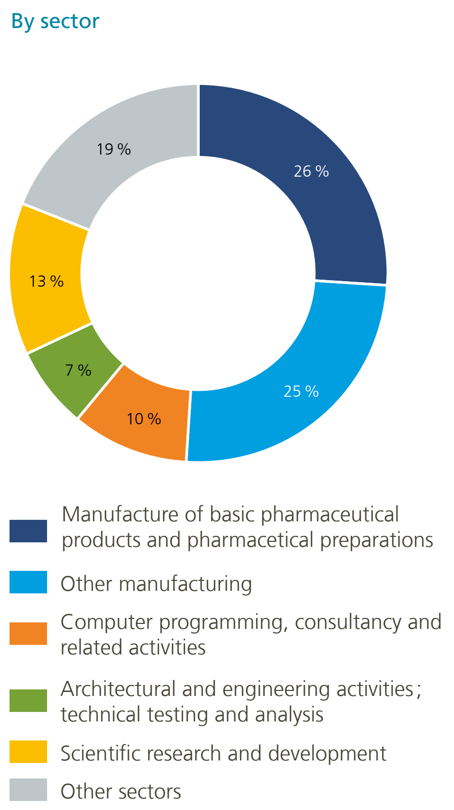
2. Possibility of a breakdown in technological diffusion

Two important observations can be made with regard to technological diffusion within the Belgian economy. First, innovation efforts appear to be highly concentrated. Broken down by size, almost half of all R&D expenditure is by firms with 500 or more employees, while small firms with fewer than 10 employees, representing 95 % of all companies, account for only 5 % of R&D expenditure. Furthermore, innovation expenses are concentrated in a limited number of sectors, such as the pharmaceutical sector. This concentration of innovation efforts by a

Chart 3

R&D efforts are concentrated in large firms and certain sectors[1]





Source: Eurostat.
1 Figures for 2019.

limited number of firms is not conducive to spillovers to the rest of the economy, which would be more likely to occur were innovation more widely distributed amongst firms and sectors.

While highly concentrated R&D is characteristic of the Belgian innovation landscape, the second observation is more general in nature. Productivity growth data since the end of the nineteenth century show that the first two waves of industrialisation (the first associated with the invention of steam power and the second with electricity, mass production and rapid scientific discovery) gave rise to substantial overall productivity gains. By contrast, this does not appear to be the case with the third wave (the digital revolution), connected to the widespread use of information and communication technologies (ICT). The first two waves were each followed by a period of high productivity growth, albeit with some delay as the innovations needed time to spread throughout the economy. In the wake of the third wave, however, productivity growth has remained very low, historically speaking, despite the fact that ICT has become a widespread and essential part of modern society. Several hypotheses have been put forward to explain this limited pass-through,[1] a precise explanation for which falls outside the scope of this article. However, this finding undoubtedly plays a role in Belgium, too.

3. Diffusion channels

3.1 Possible diffusion channels

Although innovation efforts in Belgium are high, the overall context does not appear very favourable to technological diffusion. In this section, we analyse how innovation can impact productivity. Different types of diffusion channels are presented and an empirical analysis is performed in order to know which channels play a role in practice. This paper focuses on four of them.

The first channel is sectoral, meaning innovation by a given firm can impact the productivity of other firms active in the same sector or, put differently, firm productivity may depend on innovation by other firms within the same sector. This channel is represented by the dark blue icon in Figure 4. The explanation is competition: if a firm's competitors innovate and become more productive, the firm becomes relatively less competitive unless it also becomes more productive (in other words, "learns from its competitors").

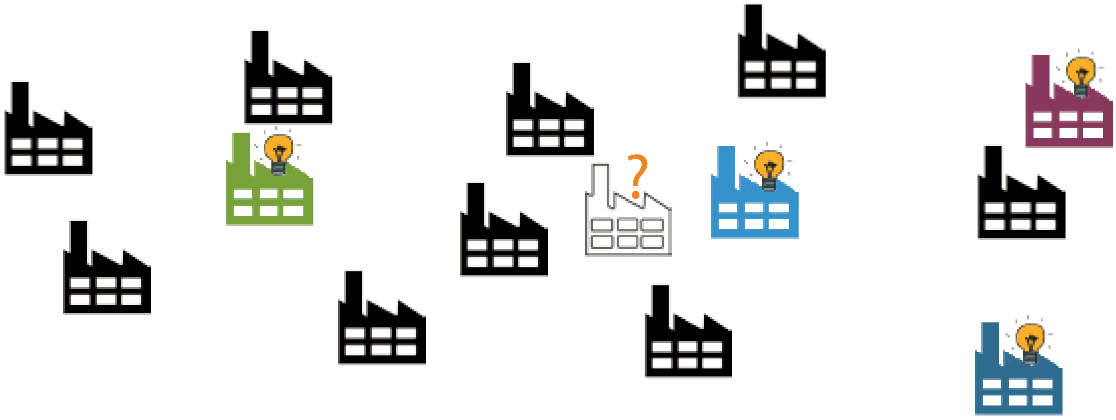
The second channel is geographic diffusion. In this case, firm productivity is influenced by innovation by firms in the same geographic area (represented by the light blue icon in Figure 4). In this case, diffusion can be explained by local networks in which entrepreneurs know each other, helping good practices to spread, regardless of the type of activity in which the firms are engaged (in other words, they "learn from their neighbours"). This channel was analysed because previous studies[2] have shown that the physical distance between firms impacts their trade relations and that relatively fewer transactions take place when the distance between firms increases. The question is of course whether this observation also holds true for innovation.

The third and fourth diffusion channels studied are based on economic ties via trade relations in the value chain. These channels are called backward and forward diffusion, as they refer to the economic actors one step before (suppliers) or one step further (customers) in the value chain (represented, respectively, by the green and purple icons in Figure 4). Backward diffusion implies that the productivity of a firm may depend on innovation by its suppliers ("learn from your suppliers"). In other words, when suppliers introduce new technologies and become more productive, this can affect the productivity of their clients. Forward diffusion refers to the influence of client innovation on firm performance ("learn from your customers"). Innovative clients may expect productivity improvements from their suppliers. If a supplier fails to deliver, the client may decide to go elsewhere, thereby putting pressure on it.

1 For an overview, see Cordemans (2018), "Is weak productivity growth a fatality?", *Economic Review*, National Bank of Belgium, December.
2 Dhyne and Duprez (2022), "Sourcing of services and total factor productivity", NBB Working Paper 425.

Chart 4

Diffusion may take place via different channels[1]



Source: NBB.

1 The white icon represents the firm whose productivity is being tested (the reference firm). All other icons represent other firms in the economy, which may or may not interact with the reference firm. The dark blue icon represents a firm operating in the same economic sector as the reference firm. The light blue icon represents a firm located in geographic proximity to the reference firm (geographic diffusion). Finally, the green icon represents a supplier and the purple icon a customer of the reference firm (backward and forward diffusion, respectively).

3.2 Diffusion in Belgium

In order to empirically analyse the impact of innovation on productivity via the selected diffusion channels, firm-level data were used for the period 2002-2017, for all Belgian companies.

Patents applied for or granted by the European Patent Office (EPO) can indicate the innovative activities of firms. As mentioned above, however, patents are not a perfect indicator of innovation efforts. Nonetheless, a patent provides a strong indication of an economically valuable innovation, especially when it is granted by the EPO, as seeking patent protection on an international scale is time-consuming and costly.[1]

When it comes to measuring productivity, two concepts are used, namely apparent labour productivity (ALP) and total factor productivity (TFP). The first is easy to calculate and refers to the value added per hour worked, taking only the labour input into consideration, not the contribution of capital stock. By contrast, TFP reflects the way in which all factors of production used by a firm contribute to wealth creation but presents the disadvantage of not being directly observable and, therefore, necessarily estimated.[2] Both concepts were tested, and the results were very comparable. Therefore, it was deemed preferable to present the results of the most intuitive concept, namely labour productivity.

Finally, Belgian B2B VAT transaction data were used in order to establish trade relations (suppliers and customers) between firms.

1 R&D expenditure could be another possible indicator of innovation in this context but presents the disadvantage of indicating R&D input rather than innovation output. In addition, for this analysis, firm-level data were needed, and no reliable data are available on R&D expenditure for individual firms.

2 Empirically speaking, TFP is measured as the residual of a production function.

The empirical analysis was performed by estimating the following basic equation [1]:

$$Prod_{it} = c + \alpha \, Pat_{it-1} + \beta_1 \, Pat_{st-1} + \beta_2 \, Pat_{gt-1} + \beta_3 \, Pat_{bt-1} + \beta_4 \, Pat_{ft-1} + FE_{it} + \varepsilon_{it} \qquad [1]$$

in which:

$Prod_{it}$ = productivity of firm i in year t;

Pat_{it-1} = the number of patents applied for and/or obtained by firm i in year $t-1$;

Pat_{st-1} = the number of patents in the sector[1] of firm i (excluding patents applied for or obtained by firm i itself) in year $t-1$;

Pat_{gt-1} = the number of patents in the geographic area of firm i (excluding patents applied for or obtained by firm i itself) in year $t-1$;

Pat_{bt-1} = the number of patents applied for and/or obtained by all suppliers of firm i in year $t-1$;

Pat_{ft-1} = the number of patents applied for and/or obtained by all customers of firm i in year $t-1$;

FE_{it} = fixed effects (firm, year, etc);

c and ε_{it} refer to a constant and the error term, respectively.

In this way, the productivity level of the firm was examined by looking at its own innovation (with coefficient α) and at innovation via the four selected diffusion channels (with coefficients β_1 to β_4).

All variables were expressed in logarithmic terms, implying that coefficients α and β_1 to β_4 can be interpreted as elasticities. They therefore indicate the estimated percentage change in productivity when one of the patent variables increases by 1 %.

All patent figures were depreciated, as the value of patents decreases over time and in any case becomes zero when the period of protection ends. Two calculation methods were tested, with different depreciation periods. In the first, granted patents were depreciated linearly over 15 years and non-granted patent applications over seven years. In the second, the depreciation period for granted and non-granted patents was set at 20 years and 10 years, respectively. In addition to the straightforward counting of (depreciated) patents, a quality-adjustment was tested. After all, not all patents are equally valuable, as they can protect minor inventions of little use or widely applied, major inventions. In order to capture this, a quality-adjusted number of patents was calculated, following methodology developed by the OECD.[2] In total, four different methods were tested, i.e. a depreciation period of 15 or seven years, quality-adjusted or not, and a depreciation period of 20 or 10 years, again quality-adjusted or not. All four yielded very comparable results, indicating that the results obtained are quite robust. The results for quality-adjusted patent stock, depreciated over 15 or seven years, are presented below.

Finally, all patent data were lagged by one year as inventions cannot be expected to affect the productivity of other firms at once. Of course, a firm's own innovation will have a more immediate impact on its performance,[3] but for the sake of consistency, a one-year time lag was applied here as well.

1 In this respect, a very detailed sectoral definition is used, a five-digit NACE code.

2 According to the OECD methodology, the quality of patents is evaluated using data regarding, for instance, whether the patent was granted or not, the domain and the number of citations. For more information, see Squicciarini, Dernis and Criscuolo (2013), "Measuring patent quality: Indicators of technological and economic value depreciation rate", OECD, Science, Technology and Industry Working Papers 2013/03.

3 The firm's own productivity can of course be affected even before the patent process is commenced or finalised.

Table 1

Firms benefit most from own innovation but also from innovation by others[1]

Variables / specifications	(1)	(2)	(3)	(4)	(5)	(6)
Own patents (α)	0.0811**	0.0826**	0.0812**	0.0764**	0.0799**	0.0771**
Competitors' patents (β_1)		0.0112***				0.0111***
Neighbours' patents (β_2)			0.0011			0.0009
Suppliers' patents (β_3)				0.0137***		0.0126***
Customers' patents (β_4)					0.0112***	0.0108***

Sources: EPO, NBB and own calculations.
1 Quality-adjusted patent stock, depreciated over a period of 15 or seven years (for granted and non-granted applications, respectively).
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Taken individually, all patent variables appear to have a statistically significant impact on productivity, with the exception of patents in the firm's own (geographic) district (see specifications 1 to 5 in Table 1). This result also holds up when equation [1] is estimated as a whole, taking all variables together, as reported in specification 6.

The greatest impact is attributable to the firm's own patents. This is no surprise, as it would be odd if a firm benefitted more from innovation by other companies than from its own efforts, which are specifically intended and designed to respond to its own needs. If the β coefficients were larger than α, firms would have no incentive to innovate, as it would be more beneficial to take advantage of innovation by others (in other words, to ride on their coattails). As other firms would make the same assessment, such a situation would be detrimental to the innovative capacity of the economy as a whole.

In addition to the clear and preponderant impact of own innovation efforts, the results also provide clear evidence for the existence of diffusion through the sectoral and economic channels. Therefore, innovation by competitors, suppliers and customers appears to generate productivity gains.

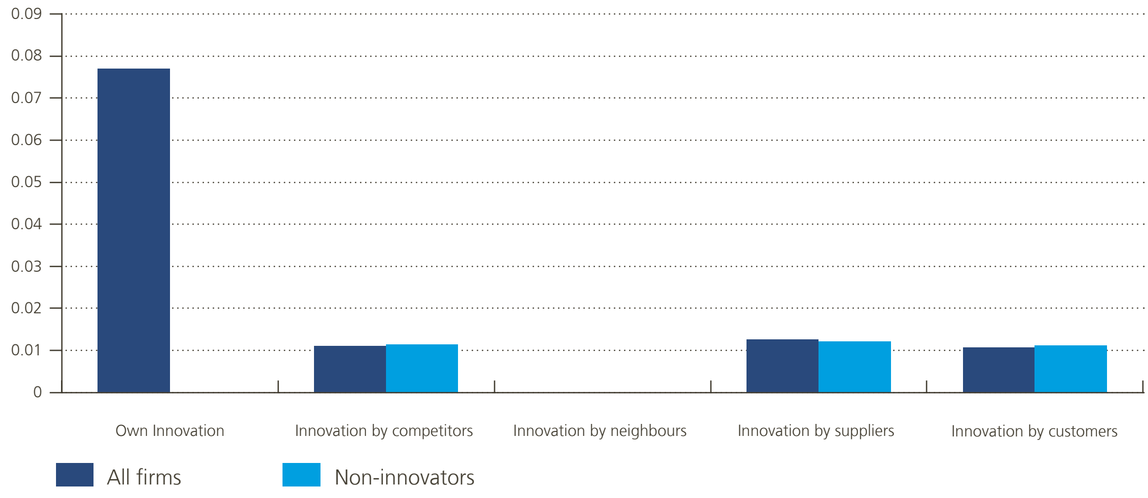
By contrast, no empirical evidence was found for the geographic spillover channel. This result is also unsurprising. For day-to-day transactions, such as buying lunch or other small necessities, it is logical to do business with businesses in the immediate vicinity. However, when looking for innovative projects, an entrepreneur will seek out companies known to be innovative, regardless of where they are located. So even if coefficient β_2 had been significantly different from zero in specification 3, this significance would most likely have disappeared when combining all channels in specification 6, as possible local innovations are more likely to have an impact via the sectoral or economic channels.

Interestingly, the same diffusion results are obtained if the sample is limited to non-innovative firms. While of course for such firms there is no impact of own innovation, as they do not have patents themselves, the β coefficients are very comparable to those obtained for the sample as a whole. This indicates that a pure diffusion effect is effectively taking place, as the productivity of non-innovative firms is positively influenced by innovation by competitors, suppliers and/or customers.

While estimation of the basic equation [1] shows the impact of innovation on productivity after one year, another specification was tested in which lags of up to five years were used, in order to verify the speed of the different diffusion channels. This analysis highlighted, as expected, the difference between the impact of own innovation and innovation by others. While the impact of own innovation is immediate, it takes more time (up to five years) before productivity is fully influenced by innovation on the part of competitors, suppliers or customers.

Chart 5

The diffusion effect also holds for non-innovative firms



Sources: EPO, NBB and own calculations.
1 Quality-adjusted patent stock, depreciated over a period of 15 or seven years (for granted and non-granted applications, respectively). One-year lag.

3.3 Possibility of random diffusion

In the previous section, four different diffusion channels were presented and empirically tested. However, the significant results obtained for three of these channels do not necessarily mean that all possible diffusion channels have been documented. It is indeed possible that other diffusion mechanisms play a role (for instance, foreign innovation could positively affect domestic firms through international trade or FDI linkages, common board membership between innovative and non-innovative firms could have a positive impact on the latter, etc.).

Below we make an initial attempt to look for other channels, by checking the practical validity of an extreme diffusion channel, asking whether spillovers take place from firms with which there is in principle no link at all. In that case, diffusion would occur randomly, as innovation by any given firm (illustrated by the black icons in Figure 4) could impact the productivity of other firms in the economy.

In order to check the validity of this hypothesis, basic equation [1] was extended to become:

$$Prod_{it} = c + \alpha\, Pat_{it-1} + \beta_1\, Pat_{st-1} + \beta_2\, Pat_{gt-1} + \beta_3\, Pat_{bt-1} + \beta_4\, Pat_{ft-1} + \beta_5\, Pat_{ot-1} + FE_{it} + \varepsilon_{it} \quad [2]$$

in which the following variable was added:

Pat_{ot-1} = the number of patents applied for and/or obtained by 10 randomly chosen innovative firms in year $t-1$.

As the 10 firms were randomly selected from all companies with patents, no interaction was assumed to take place between these firms and firm i. In order to exclude coincidence, this exercise was performed 1,000 times. The resulting coefficient β_5 is the average of the β_5 coefficients of the 1,000 estimations.

It was first noted that when estimating the extended equation [2], the α and β_1 to β_4 coefficients were comparable to the results obtained when estimating equation [1]. The conclusions regarding the impact of

Table 2

Firms do not benefit from innovation by unrelated firms[1]

Variables / specifications	(6)	(7)
Own patents (α)	0.0771**	0.0826**
Competitors' patents (β_1)	0.0111***	0.0119***
Neighbours' patents (β_2)	0.0009	0.0009
Suppliers' patents (β_3)	0.0126***	0.0126***
Customers' patents (β_4)	0.0108***	0.0108***
Random firms' patents (β_5)	–	0.0000

Sources: EPO, NBB and own calculations.
1 Quality-adjusted patent stock, depreciated over a period of 15 or seven years (for granted and non-granted applications, respectively).
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

own innovation and the three identified diffusion channels are therefore confirmed. Secondly, the coefficient β_5 appeared to be equal to zero.[1] This result implies that there is no random diffusion of innovation: innovation at a given place in the economy does not "spontaneously" lead to higher productivity elsewhere. Overall, it can be concluded that only own innovation and innovation by "linked" companies give rise to higher productivity.

Conclusion

For two years now, Belgium has been considered an "innovation leader" based on the European Innovation Scoreboard. The substantial efforts made in this area are clear when looking at R&D expenditure, expressed as a percentage of GDP. Together with Sweden, Belgium tops the ranking. A significant share of funding is provided by the public sector, with R&D efforts concentrated in large companies and a limited number of sectors (including pharmaceuticals).

Despite these efforts, the Belgian economy performs particularly weak in terms of productivity growth, which is surprising given the massive ICT developments we are currently witnessing. The economy is therefore characterised by a productivity puzzle, as very strong innovation efforts go hand in hand with increasingly weak productivity growth.

This article looks at one aspect of this puzzle, namely technological diffusion. To determine the impact of innovation on productivity, we examined the extent to which in-house innovation gives rise to productivity gains and four possible diffusion channels. As expected, firms benefit mainly from their own innovation efforts, but we also found evidence of productivity gains for three of the four diffusion channels, namely sectoral diffusion (linked to innovation by competitors in the same sector) and economic spillovers (innovation by suppliers or customers). On the other hand, no evidence was found for geographic diffusion (linked to innovation by neighbouring firms). Thus, the more tenuous the link between the innovator and other firms, the weaker technological diffusion will be. In short, productivity appears to be boosted only by firms' own innovation efforts and those of firms with which they interact.

1 The coefficient is equal to zero up to six digits after the decimal point and is not statistically different from zero.

Some policy recommendations can be made based on the results of this analysis. These provide support for specific innovation-enhancing measures, benefitting both innovative firms and other (linked) firms. Government subsidies to stimulate R&D are therefore useful. However, it is important to have a comprehensive industrial policy that enables technological diffusion. In this context, it is important to firmly anchor innovative companies in the Belgian economic fabric, e.g. through links with manufacturing companies, which requires that particular attention be paid to foreign investment and start-ups.

Conventional signs

%	per cent
e.g.	*exempli gratia* (for example)
etc.	*et cetera*
i.e.	*id est* (that is)

List of abbreviations

Countries or regions

BE	Belgium
EA	Euro area
EU	European Union
US	United States

Abbreviations

ALP	Apparent labour productivity
B2B	Business-to-business
COVID-19	Coronavirus
EPO	European Patent Office
FDI	Direct Foreign Investment
GDP	Gross domestic product
ICT	Information and communication technologies
NBB	National Bank of Belgium
OECD	Organisation for Economic Cooperation and Development
R&D	Research and development
STEM	Science, Technology, Engineering and Mathematics
TFP	Total factor productivity
VAT	Value-added tax

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