The factors that shape a country's ability to benefit from international R&D spillovers

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EXECUTIVE SUMMARY

This paper reviews the literature on international R&D spillovers with the aim of pinpointing what factors shape a country's ability to benefit from such spillovers. After defining what spillovers mean and how they occur, two strands of literature are surveyed. The first one measures international spillover as a weighted sum of foreign R&D stocks with weights proportional to transmission channels or proximity measures between senders and receivers and estimates the return of that variable econometrically. In general spillovers were found to be positive, both at the country and industry level, but asymmetric. The second stream of studies concentrates on the transmission channels – imports, exports, foreign direct investment, foreign patenting, patent citations and collaboration - and analyses in more detail how and why they produce spillovers, and under what circumstances they do not. The paper ends by summarizing from the evidence reported in the literature which factors are conducive to benefit from international R&D spillovers. Building up absorptive capacity by means of education and own R&D investment and the removal of barriers to technology adoption are key factors for absorbing the benefit from foreign R&D.

THEORETICAL AND CONCEPTUAL ISSUES

Research and development (R&D) conducted by one agent (firm/sector/region/country) can benefit another agent because of 'spillovers'. There are two kinds of R&D spillovers: knowledge spillovers and rent spillovers (Griliches, 1979).

Knowledge spillovers refer to the unintended transfer of knowledge between firms, sectors, and countries. The ideas stemming from R&D produced in one sector can be applicable in another sector. For example, scientific advances in the semi-conductor industry have led to new types of services in the media industry (e-journals), the hospitality industry (e-booking) and the transportation industry (Uber). This transfer of knowledge can take place because of the public good nature of knowledge. Indeed, knowledge is non-rival, meaning that it can be used by many agents at the same time, and it is non-excludable or only partially excludable, meaning that it is not easy to prevent knowledge from leaking to other agents, even in the presence of intellectual property protection.

Rent spillovers refer to unintended pecuniary spillovers between firms, sectors, or countries in the sense that one agent benefits in monetary terms from the R&D conducted by another agent. They can occur because of the impossibility of perfect price discrimination. The price paid for a new computer is generally far below the benefits that the consumer derives from it, and the producer cannot appropriate the full consumer surplus. R&D spillovers can also be due to complementary products (a new hardware calls for the development of new software) or to network externalities (the more researchers collaborate on a certain problem, the higher the chances of finding a solution).

In the growth literature developed in the late 1980s and early 1990s, R&D spillovers were brought to explain the phenomenon of long-run growth (Barro and Sala-i-Martin, 2004). The accumulated stock of knowledge would enter the production function and prevent a declining rate of return to capital causing growth to stop. More sophisticated models would model technological progress as endogenous depending on R&D efforts, which would either increase the number of goods – intermediate inputs or final consumption goods – or increase the quality of the goods. In the former case, new goods would increase technological complexity or specialization. For instance, digital technology has allowed the creation of apps that allow making hotel reservations online, but some people still prefer to go through a travel agency. In the latter case, better quality goods would displace existing goods. For instance, when the Nokia N-95 smartphone was launched in 2006 it quickly replaced previous mobile phones thanks to the many new features it incorporated, such as integrated GPS navigation, MP3 player, FM radio, video cameras, emails, internet connections, calendars, calculators and many more.

There can also be negative R&D spillovers, as when new knowledge gets more and more difficult to generate (erosion effect), when research gets duplicated without any knowledge sharing taking place (the winner-takes-all patent races), or when new products encroach on the market for existing products (market stealing) (see Jones and Williams, 1998; Bloom, Schankerman and Van Reenen, 2013). Most studies find that net R&D externalities are positive, yielding a social rate of return to R&D that exceeds the private rate of return. For a survey of empirical studies, see Appelt (2015) who reports that on average in empirical studies benefits from knowledge spillovers account for approximately three-fifths of the social return to R&D.

Spillovers can occur when firms trade goods and services with each other, when researchers or managers meet and discuss at conferences or trade fairs, when firms collaborate in research projects or when employees change jobs. Knowledge spillovers can be reflected by citations in patents or publications. The knowledge can spread more easily when the issuer and the receiver are close to each other. The proximity can be geographic, but it can also be in the space of competencies in the sense that researchers similar in what they know and what they do are probably more able to benefit from each other's knowledge.

International R&D spillovers can occur through the same channels as domestic R&D spillovers: trade in consumption goods, intermediate inputs, and capital goods, b) foreign direct investment (FDI), especially if it comes with manpower training to operate the new machines and to assimilate new production and management techniques, c) migration of scientists, engineers, educated people in general, or their attendance at workshops, seminars, trade fairs and the like, d) citations to publications in technical journals, scientific papers, and patents, e) international research collaborations or international mergers and acquisitions, and f) foreign technology payments, i.e. royalties on copyrights and trademarks, licensing fees, the purchase of patents, the payments for consulting services and the financing of R&D conducted abroad.

The difference between spillovers and formal technology transfer is that spillovers occur without counter payments; they are, in some sense, uncontrollable. Spillovers can go in either direction. For instance, in the case of trade, international spillovers can be transmitted by new technologies incorporated in imports. But it could also be that exporters gain from the knowledge base of their buyers, especially when buyers suggest ways to improve the product or the process of manufacture. For previous reviews of international R&D spillovers, see Branstetter (1998), Mohnen (2001), Cincera and van Pottelsberghe (2001), Keller (2004 and 2010), Foster (2012), Appelt (2015), Belderbos and Mohnen (2020).

INTERNATIONAL R&D SPILLOVERS WITH MEASURES OF FOREIGN R&D

Measuring foreign R&D

International R&D spillovers can be embodied in international flows of goods and services or foreign direct investment (FDI). New technologies are incorporated in imported new machines or intermediate inputs. Knowledge is exchanged at scientific meetings or in joint research projects. Therefore, international R&D spillovers have often been measured as proportional to imports, exports, foreign direct investments, patents classified by industry of origin and sector of use or flows of migration. The same channels can, however, also be used as proximity measures between the sender and the potential receiver of R&D spillovers of the disembodied type: the more i trades with j (buying or selling), invests in j's economy, collaborates with j, the more i is likely to diffuse its knowledge to j. Proximity can be measured independently of any economic transaction between the sender and the receiver of spillovers, be it by citations (the more i cites j's patents or publications, the more i is supposed to benefit from j's R&D) or by uncentered correlations of position vectors in some technology spaces (the more i patents in the same technology classes as j, hires the same type of scientists as j or does the same type of R&D as j, the more i and j are close to each other and benefit from their mutual research). It can also be the case that more knowledge can potentially spill over when two patents or research teams are farther apart in the knowledge space.

Measures of proximity independent of any economic transactions are expected to capture essentially knowledge spillovers. Rent spillovers, in contrast, are likely to occur whenever monetary transactions take place. In practice, rent and knowledge spillovers are hard to dissociate and are likely to occur simultaneously. International trade involves rent spillovers but is also a means of communication and of knowledge transmission. Dissociating the two dimensions of spillovers is not easy.

Spillovers can also be indirect. Firm i can benefit from the R&D conducted by firm j, but firm k can also benefit from the R&D of firm j by transacting with firm i. Given the existence of these ripple spillover effects, we expect trade in intermediate inputs along the value chain to emit higher spillovers than trade in final products, which benefit only the final consumer.

Spillovers are generally estimated by linking outcome measures such as total factor productivity (TFP) with a measure of foreign R&D. A weighted sum of R&D stocks from various potential emitters of R&D spillovers is then usually constructed and inserted with other determinants in a TFP level or growth regression. The question is what weights should be used. The weights can be proportional to the flow or the proximity measures indicated above. The R&D stock of firm i would have a higher weight than the stock of firm j in the spillover index of firm k if i is closer to k than j or if i has more transactions with k than j has. R&D stocks are preferred to R&D flows because R&D can emit spillovers over many years. The R&D stocks are themselves weighted sums of past R&D flows with weights decreasing in proportion to an assumed depreciation or obsolescence rate of R&D, often guesstimated to be around 15 to 25%. Alternatively, patent stocks can be used if one considers patents to be more representative than R&D in measuring knowledge. Some studies have also constructed different spillover indexes, like those associated with trade and those associated with FDI, or those with weights proportional to proximities in the patent space and those with weights proportional to proximity in the product space. The former is supposed to capture positive knowledge spillovers, the latter market stealing negative spillovers (Bloom et al., 2013). Some attempts have been made to include a vector of R&D stocks with separate marginal effects instead of a synthetic index of outside R&D (Bernstein and Nadiri, 1988).

A few econometric problems, which have not always been tackled correctly in the literature, are worth mentioning. First, when introducing several spillovers variables in the same regression multicollinearity can make their separate identification cumbersome. Second, TFP and the stock-related spillover variables can be co-integrated, i.e., have a common stochastic trend, calling for proper estimation methods to compute standard errors of the estimated coefficients. Third, TFP can also be due to other determinants than spillovers, for instance education, regulations, or skills, calling for additional controls in the regression equations. Fourth, there is heterogeneity across sectors and technology classes, and data do not always exist in fine detail (e.g., industries or patent classes at the 4-digit level), so that the weights used in the construction of spillover variables may contain measurement errors.

Estimation of foreign R&D spillovers

The first studies often failed to find significant international R&D spillover effects (Gittleman and Wolff (1995), Sakurai et al. (1997), Evenson (1997) on country data; Fecher (1989), Basant and Fikkert (1996) and Vuori (1997) on firm level data for Belgium, India, and Finland, respectively). This could partly be explained by the shortness of the time series, the use of equal weights, the simultaneous use of various synthetic indices of foreign R&D and the absence of heterogeneity in the estimated elasticities of foreign R&D. Hanel (1994) obtained more precise estimates of foreign R&D spillovers when allowing for gestation lags. Park (1995) reported a peak effect of R&D spillovers on productivity growth after three years and a declining effect afterwards.

An influential paper by Coe and Helpman (1995) obtained a significant and positive elasticity of TFP with respect to foreign R&D, where foreign R&D was measured by the import-share weighted sum of domestic R&D in 21 OECD countries plus Israel. Their results showed that the elasticity increased with the openness of the countries to imports, and that the elasticity with respect to foreign R&D was higher than with respect to domestic R&D in the smaller countries and the opposite for the G7 countries. Similar effects were reported in Coe, Helpman and Hoffmaister (1997) when adding to the initial 22 countries, 77 countries from the South.

There was some disagreement in the literature over the way trade-related weights were calculated in Coe and Helpman (1995). Keller (1997) compared equal weights, input-output related weights, patent classification weights (more on this below) and random weights when aggregating different sources of foreign R&D. He found that for TFP level regressions random weights did not perform worse than input-output weights and better than the other two weighting schemes. Coe and Hoffmaister (1999) noted that Keller's bilateral import shares were similar to equal weights, or simple averages of trading partners' knowledge stocks, suggesting that Keller's weights were not in fact random. Using alternative random weights, they found that the estimated foreign knowledge spillovers were extremely small. They concluded that using bilateral import weights or simple averages performed better than random weights suggesting that a country's productivity is related to its trading partners' knowledge stock but conceded that the actual intensity of the trading relationship may not be that important due to the public good nature of knowledge.

Kao et al. (1999) questioned the calculation of standard errors in the presence of cointegrated variables. They argued that, since the estimated coefficients in Coe and Helpman are small, it is not clear whether they are significant. They used non-stationary panel techniques and found that while the coefficient on the foreign R&D spillover variable remained positive, it was no longer significant.

Alternative transmission channels and corresponding weights have been explored: inward and outward FDI and exports. The empirical evidence linking FDI to technology diffusion is mixed. In general, there is little evidence of substantial FDI spillovers for developed or developing countries. Lichtenberg and van Pottelsberghe (1998) and Xu and Wang (2000) extend the approach of Coe and Helpman (1995), adding both inward and outward FDI flows as weights on foreign knowledge stocks for a sample of up to 21 OECD countries over the period 1971-1990 and find little evidence of spillovers through inward FDI, but some evidence of spillovers through outward FDI. Globerman, Kokko and Sjöholm (2000) using data on patent applications by Swedish multinational corporations (MNCs) and non-MNCs also find evidence that outward FDI is the more important source of technology transfer. An alternative approach has been to consider patent citations as an indicator of the extent of spillovers instead of productivity. Using data on Japanese FDI into the United States, Branstetter (2001) finds evidence that FDI encourages technology spillovers through subsidiaries bringing technology from their countries of origin and through MNCs facilitating learning of foreign technologies. Funk (2001) and Falvey et al. (2004) have found that weighting foreign R&D by exports also yields significant coefficients. Verspagen (1997) used patents classified by industry of origin and sector of use as technology flows to weight foreign R&D stocks and also concluded that foreign R&D spillovers are significant. Delera and Foster-McGregor (2023) find that TFP is more elastic to imported R&D through global value chains (GVC) than to any other kind of R&D. The effect on TFP of GVC related R&D is higher for country/sectors further away from the technology frontier and negatively related to geographical distance.

It is difficult to conclude that one transmission channel works better than the others in the construction of the foreign R&D index. In any case, knowledge spillovers get transmitted through multiple channels and often these channels are correlated with each other. It has been found that adding more channels to the analysis improves the quality of estimated spillovers (Verspagen, 1997), while Keller (2002) shows that spillovers decrease with geographical distance, a variable that has been linked to various flows through the gravity model.

International spillover effects were found to be asymmetric, flowing more from R&D-intensive to less R&D-intensive countries than the other way round (see Coe, Helpman and Hoffmaister (1997), Del Barrio-Castro, López-Bazo and Serrano-Domingo (2002); Khan and Luintel (2004), Frantzen (2002) and Griffith, Harrison and Van Reenen (2006)). Results thus suggest that countries well away from the technological frontier that have limited own-R&D activities themselves can benefit from R&D activities undertaken elsewhere.

The country-level approach of Coe and Helpman (1995) ignores the possibility that spillovers can be intra-national in scope, with a further concern being that the high level of aggregation may bias results. Keller (2000), for example, argues that focusing on trade flows between industries instead of countries is more likely to capture embodied new technology. As such, studies have adapted the Coe and Helpman type framework to industry-level data, allowing for spillovers from own and other sectors, both domestically and internationally. Evidence from a broad range of industry level studies (e.g., Keller, 2000; Schiff and Wang, 2006, 2007) suggests that R&D spillovers through trade are present when using industry-level data, with some evidence suggesting that effects differ by industry. Bournakis et al. (2015), for example, find that high-tech industries display greater spillovers than low-tech industries.

While many industry-level studies focus on manufacturing, with the argument being that traditionally R&D activities have been heavily concentrated in manufacturing sub-sectors, some work has further considered the services sector. This focus is justified by the increasing R&D intensity of many services sectors and the increasing tradability of services. Poeschl et al (2016), for example, consider the impact of both domestic and imported R&D in high-tech services on manufacturing performance, finding that the magnitude of the effect of services R&D is around one third of that from domestic own-sector R&D.

ESTIMATING INTERNATIONAL R&D SPILLOVERS VIA TRANSMISSION CHANNELS

Instead of focusing on foreign R&D, weighted somehow by the assumed transmission channel of essentially knowledge spillovers, subsequent studies have concentrated on the channels themselves without linking them explicitly to foreign R&D. Spillovers then capture both knowledge and rent spillovers, where knowledge is not just restricted to R&D but also to experience, learning by doing and education. The data used are continuous variables like patent citations, FDI, exports, imports and migration of scientists, or dichotomous revealed sources of knowledge spillovers such as those declared in the Community Innovation Surveys. One difficulty here is the endogeneity bias as for instance when TFP itself is a determinant of FDI: multinationals prefer investing in more advanced countries with higher TFP. In that case, instrumental variables or quasi-experiments can be used to establish causality.

International trade

The increasing availability of firm-level data over the past couple of decades has allowed for an examination of the performance of firms and whether global interactions – through trade and foreign ownership – impact upon the performance of firms. In the case of exporting (and importing) two alternative – though not necessarily mutually exclusive – explanations as to why exporters may be more productive than non-exporters have been proposed, namely self-selection and learning-by-exporting. While self-selection occurs because there are additional costs associated with selling goods abroad, including transport, distribution, marketing costs, etc., learning-by-exporting is strongly related to the notion of spillovers occurring due to exporting. Exporting can be an important channel of information flows, for example, with overseas buyers sharing knowledge of the latest design specifications and production techniques, and providing a competitive environment, in which efficiency advantages can be obtained.

From a theoretical perspective, Melitz (2003) developed a monopolistically competitive model of trade with firm heterogeneity, in which only the most productive firms export, while less productive firms may not survive or only serve the domestic market. The model assumes that there are both fixed and variable costs of exporting, with the presence of such costs implying that only those firms with a high productivity find it profitable to export in equilibrium. As such, the model supports the notion of self-selection rather than learning-by-exporting. Empirically, most studies conclude in favour of self-selection and against the learning-by-exporting hypothesis (see for example Bernard and Jensen, 1999; Isgut, 2001; Delgado et al, 2002), with only a few studies reaching the opposite conclusion (Bigsten et al, 2004; Aw et al, 2000).

In general, evidence in favour of learning effects tend to be stronger in developing countries. The lack of evidence in favour of learning-by-exporting in the developed world is attributed to the fact that the most advanced technologies are already available in the home market. In contrast, in emerging and developing economies exporters often trade with relatively more skilled countries where they can benefit from customer's technical assistance, new managerial practices, market information, information systems and supply chain networks for example. The survey of Wagner (2007) concludes that "details aside the big picture that emerges after ten years of microeconometric research in the relationship between exporting and productivity is that exporters are more productive than non-exporters, and that the more productive firms self-select into export markets, while exporting does not necessarily improve productivity" (Wagner, 2007: 67). A similar literature has emerged looking at imports rather than exports, with the results again tending to support the self-selection hypothesis, with initially more productive firms entering importing (for a survey, see Wagner, 2012).

Foreign direct investment

The early literature on FDI and growth employed aggregate data. Borensztein et al. (1998) for example found that FDI had a positive impact on growth in countries with a sufficiently educated workforce. Blömstrom et al. (1994) obtained results suggesting that FDI has a stronger effect on growth in richer countries. Alfaro et al. (2003) and Balusubramanyam et al. (1996) also found evidence in favour of a contingent relationship between FDI and growth, with the former concentrating on the development of financial markets and the latter on the level of trade openness.

At the firm-level, a literature has developed examining whether there are spillovers from the presence of foreign-owned firms (i.e., foreign affiliates) within a country. Foreign affiliates may differ from domestic firms in varied ways. Affiliates are likely to possess proprietary technology and knowledge that provides them with a firm-specific advantage that allows them to compete with other MNCs and local firms. Such knowledge may include specialised knowledge about production, superior management and marketing capabilities, export contacts, and relationships with buyers and suppliers. Spillovers can arise for varied reasons, including through labour training and turnover, the provision of high-quality intermediate inputs to domestic firms, imitation through reverse engineering, and an increased ability to export following the development of distribution networks and transport infrastructure. While FDI can be an important channel for technology diffusion when firm-specific technology is transferred across borders, FDI has the important advantage for MNCs over licensing and joint ventures that it keeps the technology internal to the firm. This characteristic may limit the diffusion of technology within the host country.

The empirical literature tends to address the presence of spillovers from FDI by considering whether the presence of foreign affiliates within a sector – as measured by the foreign share of employment and equity in a sector – impacts upon the performance of domestic firms in that sector. Görg and Greenaway (2004) review the evidence from 40 studies of FDI spillovers, finding mixed results with positive, insignificant, and negative effects of foreign presence being found. Evidence from cross-section studies appear more likely to result in positive spillover effects. In most cases, however, no significant effect of FDI presence on firm productivity is found, though some studies using panel data and published after the work of Görg and Greenaway (2004) suggest evidence of positive spillovers (Haskel et al., 2007; Keller and Yeaple, 2009).

One interesting aspect of the existing literature on FDI spillovers is the large number of papers reporting evidence of negative effects of foreign presence on domestic spillovers (e.g., Aitken and Harrison, 1999; Castellani and Zanfei, 2002; Djankov and Hoekman, 2000; Konings, 2001; Zukowska-Gagelmann, 2000, Damijan et al., 2001). One explanation put forward for the negative impact is that increased competition in product and factor markets can have a negative impact on a domestic firm's productivity (Aitken and Harrison, 1999; Konings, 2001).

While various reasons may explain the lack of significant spillovers – or the presence of negative spillovers – one possibility is that spillovers do not occur horizontally (i.e., intra-industry), but through vertical linkages which are missed in conventional studies. Görg and Greenaway (2004) discuss the possibility that MNCs may voluntarily or involuntarily help to increase the efficiency of domestic suppliers (upstream) or customers (downstream) through vertical input-output linkages. MNCs for example, may provide technical assistance to enable suppliers to raise the quality of the intermediate products they produce or provide high quality standards for local inputs thus providing an incentive for local suppliers to upgrade their technology. Javorcik (2004) suggested the use of sectoral input-output linkages to capture the importance of foreign affiliates in upstream and downstream sectors, and presenting evidence for Lithuania finds that spillovers are present, but only through backward linkages. Similar results are also found by other studies (Blalock and Gertler, 2003, 2008; Schoors and van der Tol, 2002; Jabbour and Mucchielli, 2007). Wu et al. (2023) estimate that FDI, be it horizontal or vertical, increases eco-innovation in Chinese firms. The FDI spillover effect is higher in high-tech, pollution-intensive and competitive industries and in regions with more stringent environmental regulations.

The mixed results on FDI spillovers may have further explanations, with two being related to firm capabilities (and absorptive capacity) and agglomeration (or regional spillover) effects. The absorptive capacity of domestic firms is likely to be an important determinant of the extent of spillovers, with firms with greater absorptive capacity better able to evaluate new technologies that MNCs bring, better able to assimilate the new technology, and better able to exploit the new technology. FDI spillovers may further decrease with geographical distance between foreign affiliates and domestic firms, with many of the potential sources of FDI spillovers – labour turnover, competition, and demonstration effects – limited in space. Conversely, physical proximity (and density) may speed the flow of ideas, especially when a significant part of intangible knowledge is often tacit, and social networks tend to be strong.

Patent citations

Patent citations are supposed to reflect knowledge flows. If patent i cites patent j it is because patent j contained some knowledge that led to the knowledge contained in patent i. Like any other measure it has its drawbacks: it is not sure that a citation really indicates an indebtedness of knowledge reception, especially if patent citations are added on by patent officers. Moreover, it only applies to patented knowledge, whereas for many technologies patents are not the most appropriate source of knowledge appropriation. However, it has the advantage to work with technology classes (patent classifications), which more precisely measure knowledge transmissions than industry classifications. It also indicates the locations of inventions and the possible international research collaborations that led to a patent for instance by multinationals. The textual description of patents can moreover be used to conduct a text analysis in order, for instance, to discover technological novelties reflected by new occurrences of combinations of words or technology classes. For further discussions of patents in relation to the measurement of spillovers, see Belderbos and Mohnen (2020).

Jaffe (1986) observed that citations are not bound to occur within patent classes but could also occur across patent classes. Jaffe, Trajtenberg and Henderson (1993) found that patent citations are more localized than expected given their characteristics and given the concentration of research around the location of the cited patent. Jaffe and Trajtenberg (1999) examined the citation frequencies, i.e., the probability that a randomly drawn patent in the citing group cites a randomly drawn patent in the cited group for patent originating in the G-5 countries (the U.S., France, Germany, Japan, and the United Kingdom) between 1963 and 1983. The citation frequencies increase in the first few years and then tend to fade away over a long period. From their econometric analysis the authors conclude that patents are 100 times more likely to be cited by patents in the same patent class. Domestic citations are more likely than international citations. There are a lot of bi-directional knowledge flows but also some particular pairwise frequencies of patent citations.

Guillard et al. (2021) examine the spillovers of research using direct and indirect patent citations. The more a patent is cited and the citing patents are cited, the higher the implicit value of a patent. In this way they identify individual patents that are hidden giants, that is worth much than the simple sum of their direct citations. These patents make up over 50% of the value of all global (worldwide) research spillovers. The share of spillovers that are realized within country borders varies by technology field. It goes from 27% for 3D printing to 58% for IT methods of management. The technological fields in which countries achieve the highest global returns differ across countries.

Arvanitis et al. (2023) conclude from looking at the nationalities of co-patenting in Switzerland that TFP of Swiss firms is driven by foreign, essentially European sourced, knowledge capital and not by domestic knowledge capital. Swiss firms source knowledge abroad for market seeking purposes, but for knowledge sourced in Europe also for pure knowledge seeking.

Foreign patenting

Foreign patenting is a way of appropriating the diffusion of knowledge. Eaton and Kortum (1996, 1997, 1999) construct a general equilibrium model that determines the productivity growth rates, relative productivity levels, R&D, and patenting in various countries. From the steady state of their model, they estimate the structural parameters of their model that replicate as closely as possible the observed levels of the endogenous variables in 1988 in five countries (France, Germany, Japan, the United Kingdom, and the United States). Among the structural parameters are the quality of ideas, the diffusion rates of new ideas and the rates of imitation. Countries patent their ideas in order to decrease the probability of imitation. From these calibrated parameters and the exogenous variables, productivity growth in each country can be attributed to the research done in the other countries. Their results show that ideas from Germany and Japan diffuse most rapidly. France and Germany are the quickest to receive ideas. Diffusion is faster within than between countries. On average 60% of foreign ideas get adopted. The European countries derive most of their growth from foreign R&D whereas the United States and Japan rely slightly more on their own research. The U.S., Japan and Germany are in that order the leading sources of growth in every country, the U.S. and Japan accounting together for over 65% of productivity growth in each country. Except for the U.S., which gets 80% of its returns in domestic market, foreign markets provide more than half of the returns in the other four countries.

Collaborations

Collaboration in research, which shows up in co-patenting and co-publications, is another channel of knowledge transmission. Cantner et al. (2023) find that scientific similarities and homophily characteristics favour co-authoring. They also notice that co-authoring between researchers has been increasing overall, but in relative terms co-authoring between high- and low-income countries has stagnated. Müller et al. (2023) have examined international co-authorships of South African scientists between 2002 and 2015. Their paper shows that local ties between scientists in South Africa strengthens international collaboration and the formation of international social capital. Foreign ties benefit the individual scientist but also develop the social capital of local collaborating scientists. Akçomak et al. (2023) conclude from their examination of networks of research projects within the Framework Program of the EU that trust and past relations are important and that the evolution of the network is explained by regional, dyadic, and network characteristics.

CONTINGENT SPILLOVERS

Backwardness and absorption capacity

Simply having access to foreign R&D through imports, exports, FDI or some other international flow may not be sufficient for technology diffusion to occur. Instead, other conditions may need to be in place, either at the country level or within firms and industries. Such arguments are linked to the debates around the work of Gerschenkron and Abramovitz, among others. The idea that countries may obtain access to the knowledge and technology of other countries is part of an old debate, with Gerschenkron (1962) discussing the so-called 'advantage of backwardness', whereby countries positioned inside the world technological frontier may benefit by learning from technological leaders. Gerschenkron observed that 'Industrialisation always seemed the more promising the greater the backlog of technological innovations which the backward country could take over from the more advanced country' (1962, p. 8). Such arguments imply that the further a country is away from the technological frontier, the greater the potential for the spillover of knowledge and technology.

Others, however, argue that while the potential for spillovers may be larger for countries further away from the technological frontier, benefits from the access to such technology and knowledge need not occur without certain preconditions being in place. Such arguments are captured by the work of Abramowitz (1986), who accepts that being backward carries the potential for rapid advance which should lead to convergence over long periods of time, but who also argues that backwardness in itself is unlikely to lead to greater knowledge diffusion and catch-up unless certain preconditions exist that allow countries to absorb the inflow of foreign ideas and knowledge. These preconditions have been termed 'social capability' by Abramovitz, with the related term 'absorptive capacity' also often used. Abramovitz's concept of social capability is a broad one, involving many factors that could be considered important for a country's absorptive capacity, making measurement difficult. Such ideas are also linked to the recent work on economic complexity (see Hausmann and Hidalgo, 2009; Balland et al., 2022), which highlights among other ideas the need to develop through production the capabilities that allow countries to move into new products, sectors and technologies.

Building upon these arguments, however, Cincera and van Pottelsberghe de la Potterie (2001) argue that 'in order to gauge the importance of international spillover effects, it may also be worth it to examine the factors improving the absorptive capabilities of foreign R&D such as education, training, mobility of the human capital or R&D collaborations.' In the context of the international spillover of technology, Keller (1996) has formalized such ideas in a theoretical model in which trade liberalization provides access to new goods and technologies. In the model, the ability to implement these new technologies depends upon the accumulation of human capital, with the result that if human capital accumulation is not sustained following liberalization neither will be the faster technological transformation made available through trade liberalization, with the result that growth falls to pre-liberalization rates. The model thus highlights the country-specific nature of growth and the important role that domestic capabilities can play in influencing the effect of foreign technology. Goñi and Maloney (2014), using a panel of 75 countries over 40 years, find an inverted-U relationship between the returns to R&D and the distance to the frontier, i.e., they rise with the distance to the frontier, and then start to fall, turning potentially negative for some of the poor countries. The authors interpret these findings as consistent with the importance of other factors which are complementary to R&D, such as education, the quality of scientific infrastructure and the overall performance of the national innovation system, and the quality of the business sector.

Country Size

Arguing that the stock of researchers is lower in smaller countries and that the stock of foreign R&D is higher for small than for large countries, Guellec and van Pottelsberghe (2001) show that smaller countries do indeed benefit more from foreign R&D than larger countries. However, when the knowledge spillover comes from outward FDI, Lichtenberg and van Pottelsberghe (2001) find the opposite result: larger countries have more outward FDI and benefit more from outward FDI spillovers than smaller countries. It does not seem that size in itself is a factor that allows to capture more R&D spillovers.

Human capital

Using human capital as an indicator of absorptive capacity, Falvey et al. (2007) adopt a threshold regression model to examine whether human capital and the technology gap impact upon trade-related R&D spillovers. They find that higher levels of human capital are associated with larger knowledge spillovers, while spillovers have the strongest impact on productivity in countries with an intermediate technology gap. The results suggest that human capital can play a role in the international diffusion of technology, but that its role in encouraging domestic innovation is limited to the most advanced countries. More recent evidence highlighting the importance of human capital in facilitating international R&D spillovers includes Bournakis et al. (2015), who find that countries improving their level of human capital can enhance the gains from spillovers through both trade and FDI. Fracasso and Marzetti (2014) introduce human capital as an indicator of absorptive capacity as well as relative backwardness in their empirical model, confirming previous evidence that higher levels of human capital can enhance the effect of international R&D spillovers. They further find that relative backwardness is found to have a negative impact on international R&D spillovers, suggesting that countries further away from the technological frontier are not able to capture the gains from foreign R&D.

R&D

Also measuring absorptive capacity using human capital as well as the domestic R&D stock and adopting the Coe and Helpman framework, Crespo-Cuaresma et al. (2004) find that the benefits of foreign R&D spillovers are stronger in OECD countries that conduct significant R&D and that have relatively high levels of absorptive capacity as measured by education variables. The use of domestic R&D as an additional dimension of absorptive capacity links to the arguments of Cohen and Levinthal (1989), who argue that to acquire outside technology a firm may itself need to invest in R&D. These authors argue that own R&D expenditures are critical for enabling the firm to understand and evaluate new technological trends and innovations. Such arguments have found empirical support, with Griffith et al. (2004) using industry-level data from twelve OECD countries and finding that conditional on a certain productivity gap to the leader country, subsequent productivity growth in an industry is higher, the higher are its R&D expenditures. At the firm-level, the early study of Dougherty (1997) finds evidence to suggest that technology diffusion is positively related to the presence of domestic enterprise-level R&D programmes using data on Chinese enterprises. More recent work on Chinese firms by Liao et al (2012) provides further support for the importance of absorptive capacity in facilitating R&D spillovers. Vega-Jurado et al. (2008) argue that there is a difference between the scientific/technological absorption capacity and the industrial absorption capacity, in other words between the ability to absorb basic research and applied research. This distinction is also brought up by Robin and Schubert (2013) when they compare the innovation systems in France and in Germany. Because the French education system aims at training highly specialized civil servants while the German education puts more emphasis on hands-on experience, French firms are more than German firms able to collaborate with basic research institutions but less so to collaborate with applied research conducted in industry.

Institutions

A further aspect of social capability highlighted by Abramowitz are institutional barriers to the adoption of new technology. In a series of papers, Parente and Prescott (1994, 1999 and 2003) argue that absorptive capacity is to a large extent determined by institutional aspects that give rise to absorption barriers, which in turn lead to the inefficient use of inferior technologies. Underlying this work is the idea that barriers are put in place to protect the interests of groups vested in current production processes. Intuitively, since firms are not threatened by the prospect that their competitors might introduce more productive technologies, they may prefer to stick to their current technology, although better ones are available. Parente and Prescott (1994) argue that even if countries have access to the same technology not all countries will employ the best available technologies, since the adoption of such technologies involves a cost. Moreover, such costs may be determined by country-specific institutional constraints including the regulatory environment and competition policy. In related work, Parente and Prescott (1999) highlight monopoly rights as a further institutional feature that may act as a barrier to the adoption of foreign technologies. They argue that industry insiders with monopoly rights to the current technology may resist the adoption of better production techniques, with the extent of the monopoly power determining the extent of resources that potential entrants with superior technology must spend in order to enter the industry. As such, they conclude that more competitive economies are likely to benefit from spillovers to a larger extent.

From an empirical perspective, Coe et al (2009) focus on the impact of institutions in impacting upon the extent of international R&D spillovers. Specifically, they focus on four types of institutions linked to economic performance, namely: the ease of doing business; the quality of tertiary education; the strength of intellectual property rights; and the origins of the legal system (i.e., French, German, Scandinavian or English law). Coe et al. argue that each of these may impact upon the degree to which both domestic and foreign R&D impact upon productivity, with a given R&D effort – either domestically produced or imported – being potentially more productive in environments where tertiary education produces more productive workers and where strong IPRs and the ease of doing business protect and encourage entrepreneurial R&D, with different legal systems further impacting upon the type and productivity of R&D. Using data for 24 (developed) countries over the period 1971-2004, the authors find that the ease of doing business, tertiary education quality and stronger IPR protection are associated with a more pronounced benefit from both domestic and foreign R&D, with countries with a French and Scandinavian legal system benefitting less from foreign and in particular domestic R&D. The study of Bournakis et al (2015) also considers the role of IPRs, finding that countries with more stringent IPRs can benefit to a greater extent from international R&D spillovers.

In addition to barriers protecting industry insiders, labour market institutions could also be a relevant barrier to technology adoption. Labour unions may oppose the introduction of labour-saving technologies, for example, limiting the extent of technology diffusion and adoption. Crespo-Cuaresma et al. (2004) consider whether indicators of product and labour market regulations impact upon the extent of foreign knowledge spillovers. Their results indicate that measures of product market regulation, employment protection and the coordination of wage bargaining all impact upon the extent of foreign knowledge spillovers. In all cases higher barriers are associated with lower foreign knowledge spillovers.

CONCLUSION

R&D conducted in one country also has repercussions in other countries. The knowledge produced spreads across national borders and creates positive or negative rents. Spillovers get transmitted through various channels stretching from trade in goods and services, technology transfer and foreign direct investment to migration of scientists, R&D collaboration, publications or tacit transmission of knowledge.

Empirical studies on the extent of international R&D spillovers can broadly be classified in two streams. Either a pool of foreign R&D stock is constructed as a weighted average of national R&D stocks and inserted besides traditional inputs in a production function, or particular channels of spillover transmission are related to measures of economic performance. The former studies are generally based on sector level data, the latter go deeper into the heterogeneity of spillovers by relying on micro data. While the former studies tend to conclude to the existence of positive international R&D spillovers, the latter studies find more mixed results and make the spillovers contingent on certain characteristics.

Backward countries have a greater possibility to catch up with the more developed countries, but benefiting from spillovers requires not so much a larger size as the presence of an absorption capacity. The latter entails the creation of human capital, the pursuit of own R&D, the protection of intellectual property rights, and the removal of regulations in the product and factor markets that protect certain actors and inhibit technology adoption.

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