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On the R&D giants' shoulders: do FDI help to stand on them?

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Abstract We investigate the impact of outward Foreign Direct Investments (FDI) on the Multinational Corporations technological leadership, meant as the capacity of entering and remaining among the top Research & Development (R&D) world investors. The research hypotheses are formulated by distinguishing FDI in R&D from FDI in other economic activities. The findings support our hypotheses with respect to the top R&D circles of the European Industrial Research and Innovation Scoreboard. Increasing the number of FDI projects in R&D makes the entrance in these circles more probable. The same holds true for non-R&D FDI, but with a lower impact. The number of R&D–FDI also reduces the probability of exiting from the circles, while that of non-R&D ones does not. These results are robust when the value of FDI projects in R&D is considered, apart from their impact on the exit from the circles, which appears to vanish. Although with caveats, the policy support to R&D internationalization provides companies with a sustainable competitive advantage in the race for the most substantial R&D investments and for the entailed economic and financial benefits.

Keywords Foreign Direct Investments (FDI) · Multinational Corporations (MNCs) · Research & Development (R&D)

JEL Classification O32 · F23 · O33

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1 Introduction

In the current global scenario, populated by Multinational Corporations (MNCs) operating in an array of markets and technologies, innovation performances depend also and above all on the capacity of sourcing knowledge internationally and of exploiting it in production activities on a worldwide basis. Foreign Direct Investments (FDI), mainly but not only in Research & Development (R&D), are crucial in this last respect. They allow firms to expand their markets, enter into global value chains, interact with foreign business players and labs, get embeddeded in the scientific communities of the host country, and thus tap into its set of knowledge and competencies (Maskell et al. 2007).

Within this realm, the original focus of the paper resides in the effects that FDI have on the firm's capacity of outperforming its rivals in terms of R&D investments. As we will claim in the following, this is a crucial domain of competition for the technological leadership at the worldwide level, from which firms can gain important financial and economic gains. Furthermore, as we will also argue, the chances of success in this competitive process can be positively affected by the firms' decisions to invest abroad, although to an extent which depends on the activities FDI occur in. Accordingly, the paper identifies an additional sphere on which internationalization policies can intervene in order to foster the firms' competitiveness.

In spite of its relevance, the present research question has been overshadowed by the attention for the motivations that lead firms to invest abroad [see Franco et al. (2010) for a critical review]. In particular, the role of FDI driven by the search of new knowledge ["knowledge seeking" or "technology seeking" FDI Cantwell (1989)] has been singled out, especially through the internationalization of R&D activities.[1] Important results have also been obtained about the impact of these FDI on the firm's innovative and economic performance (e.g. Subramaniam and Venkatraman 2001; Penner and Shaver 2005).

The analysis of FDI for the firm's capacity of taking the technological leadership over its rivals on a worldwide scale has been instead limited[2] and affected by some crucial methodological choices. First of all, it has mainly focused on the "outcome" of the race for the technological leadership, as it might be revealed by the patent specialization of the competing firms in some crucial technology fields for innovating in their sectors (e.g. Cantwell and Andersen 1996). In so doing, the resources and the mechanisms through which firms get able to reach such specialization advantages have remained under-investigated. Secondly, in the few studies which have addressed the FDI-R&D relationship, *leaders* and *followers* have been distinguished on the basis of exogenously chosen statistical moments (e.g. mean and/or median) of their R&D intensity (e.g. Alcácer and Chung 2007). In this way, firms with a higher (e.g. than the mean) R&D intensity are easily distinguished

[1] Among the several works on the trends and drivers of R&D internationalization, see Patel and Pavitt (1991), Granstrand et al. (1993), Cantwell and Piscitello (2000), Gammeltoft (2006), Kinkel and Som (2012), Castelli and Castellani (2013).

[2] Relevant exceptions are represented by Naghavi and Ottaviano (2009) and Belderbos et al. (2008).

from those with a lower intensity among those which invest abroad, and scale effects are ruled out from the analysis (e.g. by relating R&D to sales or employment). However, in so doing the sight is unfortunately lost of two important issues: (1) the volume of the R&D expenditures firms can afford to invest in; (2) the 'endogenous' thresholds to overcome in order to stay among the leaders, depending on the R&D capacity of the relevant players.

Filling the previous gaps represents the main motivation of the present paper, in which we put forward some research hypotheses about the impact of FDI on the MNCs' technological leadership in terms of R&D expenditure. In the application of the paper, we then provide an empirical test of these hypotheses, by looking at the European Industrial and R&D Scoreboard. More precisely, subsequent releases of this Scoreboard are merged and the resulting panel is integrated with fDi Market data, in order to see the role of FDI in enabling the firms to enter, and eventually stay, in the circle of the top R&D Scoreboard companies. Drawing eclectically from the industrial organization literature, we model the competition for this circle through a sort of entry/exit model. The boundaries of this circle are first determined by looking at the distribution of the R&D investment capacity of companies at the worldwide level. FDI are then plugged into the model among the explicatives that can account for the propensity firms have to entry in and exit from such a circle.

As the Scoreboard companies are typically large conglomerates, operating in several international markets, which together account for more than 80 % of the total world R&D, their analysis represents a natural point of departure in searching for the circle of top R&D investors among them. As much natural will be, in our future research agenda, the extension of this analysis to those companies that are out of the scoreboard domain, and which could eventually use their FDIs to reach "the foot of the R&D giants".

The remainder of the paper is organised as follows. Section 2 illustrates the theoretical background and presents the main research hypothesis of the paper. Section 3 describes the model through which we test this hypothesis and the employed dataset. Section 4 discusses the estimation results. Section 5 concludes and draws some policy implications.

2 Theoretical background

2.1 R&D leaders and R&D top spenders

The fact that firms compete also and above all through their innovations has attracted a lot of attention in economic and management studies, especially along the Schumpeterian tradition. A number of drivers have been identified for firms to emerge as technological leaders in their markets and to build up a competitive advantage on this leadership (Teece 2006). The mastery of core capabilities—'dynamic' ones, in particular (Teece and Pisano 1994)—and the control of 'complementary assets' (Teece 1986)—in marketing, distribution, and manufacturing, for example—have appeared crucial to complement what remains however the key innovation input: that is, the firm's capacity to invest in R&D. In strategic management and in business studies the debate on the technological leadership of firms has in fact focused on the gains that R&D leaders have with respect to R&D followers. Drawing on and extending the conceptual framework of Caves and Porter (1977), these advantages have been identified in a mix of (1) knowledge-spillovers, (2) product differentiation, and (3) economies of scope. In parallel, the economic literature on innovation races spurred by the work of Reinganum (1985) has shown that a larger R&D spending is a source of higher monopoly rents and future performance, although with different outcomes between incumbents and new entrants of a sector. Finally, in the accounting literature on R&D evaluation, R&D leaders have been found to earn significant future excess returns on the R&D followers, even aside from their use for risk compensation (Lev et al. 2006).

In all of these studies, R&D leadership is captured through some proxy of the firm's R&D intensity, like the ratio of R&D expenditure to sales, or to the market value of equity. As is well known, this is motivated by the intent of getting rid of size effects and focusing on the importance that R&D has with respect to the business scale of the firm. In this vein, large R&D spenders are those which invest the most of their resources in R&D, but not necessarily those which invest the largest amount of money in R&D, or in the largest R&D projects.

However, being among the largest R&D spenders of an economic sector in absolute terms could provide important advantages too. On the stock market, the amount of firm's R&D expenditures has an important signaling value for the investors: not only it signals a higher volatility of its future earnings, but also the reputation and capacity of dealing with important technological breakthroughs (Hall and Oriani 2006; Cincera et al. 2009). In real markets, instead, targeting the group of the largest R&D spenders can increase the probability of the firm to overcome sectoral thresholds in the relative expenditures, which make the R&D investment a "dilemma" (González and Pazó 2004). Under a certain absolute level, the output effect of investing could in fact be insufficient to recover its costs, given the presence of indivisibilities in R&D (*à la* Arrow), for instance, the fixed costs of research labs, the specialization required for an efficient team research work, and the pool of research projects for an adequate sharing of their risk. Top R&D investors will instead be able to run research projects of a larger average scale, with higher opportunities of international economies of scale, and a higher capacity of overcoming the up-front fixed costs and the indivisibilities from which path-breaking innovations are usually affected (Godoe 2000; Cohen 2010). The largest R&D investors can also be expected to have a wider and more diversified knowledge-base, through which they could be able to deal with a larger portfolio of innovation projects and have higher opportunities of risk pooling, although with a more demanding organisational governance (Gerybadze and Reger 1999; Mikkola 2001). Increasing the size of R&D investments above that of the majority of the rivals can also make R&D an effective barrier to entry, from which firms can benefit in a Schumpeterian fashion, when targeting a major (radical) process or product innovation (Mueller and Tilton 1969). Last, but not least, their capacity of scanning, accessing and combining external knowledge sources—that is, the second face of their "large R&D" (Cohen and Levinthal 1990)—could be arguably larger too, with higher chances of managing research cooperation in an open-innovation fashion (Enkel et al. 2009).

All in all, looking at top R&D spenders provides relevant information for the analysis of technological leadership. On the other hand, we cast some doubts on the methodological choices that the extant literature usually makes for distinguishing R&D leaders from the followers. In general, this is done by calibrating the distinction for the competitive forces operating within a certain industry and by referring to some kind of industry-adjusted R&D intensity. Firms whose R&D intensity is greater than (less than or equal to) the benchmark R&D intensity for the industry are classified as R&D leaders (followers). Different weighted and/or unweighted averages are used to define the benchmark (Lev et al. 2006; Alcácer and Chung 2007). This approach enables one to consider the sector-specific nature of R&D leaders/followers (i.e. R&D followers of some sector could be leaders in another, and vice versa). However, it neglects that the race for R&D (and innovation) spans also across the boundaries of the firm's main economic activity. On the one hand, firms generally invest in a much wider spectrum of technologies than those which pertain to their production realm (Brusoni et al. 2001). On the other hand, the largest R&D expenditures are carried out by conglomerates which operate in a number of economic sectors, making the industry calibration of their R&D leadership even less accurate. The relative position that a firm reveals with respect to its world R&D rivals, rather than to industry rivals as such, could be equally important to ascertain its eventual R&D leadership. Furthermore, rather than identifying such a position through a standard and exogenously given momentum (e.g. the median of the ranking), it could be interesting to see whether the competition for the largest R&D investments endogenously determines some thresholds of expenditure which firms shall overcome to become leaders. In so doing, the status of R&D leader is more directly related to the firm's capacity of outperforming its rivals in front of the 'R&D dilemma': that is, in accessing the 'club' of those R&D spenders which can bear the up-front costs for the most impacting R&D activities. As we will claim in the following, FDI can have a role in fostering such a capacity.

2.2 FDI and the competition for (higher) R&D expenditure

The relationship between FDI and R&D is a complex one. On the one hand, R&D activities can be claimed to provide firms with a number of advantages for becoming (more) multinational: both direct advantages, like those pointed out by the standard OLI (ownership, location, internationalization) paradigm (Dunning 1977); and indirect ones, such as the R&D productivity premium that firms can exploit for investing abroad, pointed out by the new literature on heterogeneity in trade and FDI (Helpman et al. 2004). On the other hand, FDI can have an impact on the firm's R&D in turn, as is shown by the role of MNCs in accounting for the volumes of R&D investments worldwide and for their internationalization (UNCTAD 2005; UNESCO 2010). This complexity makes the relationship at stake a dynamic interaction with potential reverse causality, which could be a source of endogeneity problems (Reeb et al. 2012).

Paying particular attention to this problem, in the paper we focus on the impact that FDI can have on the firm's level of R&D expenditure. Such an impact is apparently straightforward when we look at the international investments that the literature has called *knowledge* (or *technology*) *seeking* (Cantwell 1989; Patel and Vega 1999). These are a specific version of the "strategic-asset-seeking" FDI identified by the seminal taxonomy of Dunning (1993) and are mainly, though not exclusively, represented by *FDI in R&D* (Castelli and Castellani 2013). Through these FDI, MNCs can tap into the technological knowledge of the host country and catch-up with companies at the global frontier—when they actually lag behind (Pearce 1999; Niosi 1999)—but also sustain their eventual technological leadership by renewing their knowledge-base (Cantwell and Janne 1999; Chung and Alcácer 2002). "Home-base augmenting" MNCs, which tap into new knowledge abroad to develop technologies and products that serve, not only the host market, but also the home and the global ones, are gaining importance with respect to the traditional "home-base exploiting" ones (Cantwell and Mudambi 2005; Ambos et al. 2006). Accordingly, knowledge seeking can also occur between countries whose differences in technological levels and R&D intensity are small. For this reason, although the level of development of the host country remains important for the firms' location choice and the associated impact (Hall 2011), the analysis of the firm's FDI in R&D can be of relevance even disregarding their destination, as we actually do in the paper.

The internationalization of R&D via FDI has received a lot of attention. Several studies have concentrated on the effects it has on the inventive capacity of the investing firms, for example in terms of patents production and/or citation (e.g. Penner and Shaver 2005; Criscuolo et al. 2005). Another stream of the literature have focused on the effects of R&D internationalization on the introduction of innovative products (Subramaniam and Venkatraman 2001; Naghavi and Ottaviano 2009).[3]

The impact that the internationalization of R&D has on R&D expenditure as such has instead been less investigated. FDI in R&D have been shown to make this expenditure more geographically footloose, if not even to change the patterns of innovation specialization of the investing firms (Hall 2011). More relevant for our research question is a different strand of literature, which has looked at the level of investments of MNCs compared to national firms. The empirical evidence reported in these works shows that multinational activities appear to increase the firm's propensity to invest in both tangible and intangible assets, and the scale of these investments too (Egger and Pfaffermayr 2009): a result that extends also to the expenditures firms incur for setting up new R&D plants and equipments and for obtaining new R&D knowledge. In both respects, the possibility that FDI crowds out the firm's domestic expenditures in R&D is in general excluded (Desai et al.

[3] In general, a positive innovation impact of the firm's R&D internationalization is not guaranteed and rather depends on a set of aspects. The complementarity between the technological base of the home and of the host country, the techno-economic characteristics (e.g. opportunity and appropriability conditions) of the industries in which they operate, the individual traits of the companies investing abroad, among which their capabilities of interacting and networking with the foreign providers, have appeared crucial (Chung and Alcácer 2002; Song et al. 2011; Ambos 2005; Piscitello and Santangelo 2011).

2009). For a simple cost-benefit motivation, the decision to locate R&D abroad rarely implies the shut-down of a lab at home, and is rather accompanied by an expansion of the firm's R&D capacity (Hall 2011). R&D investments carried out abroad can even have a "multiplier effect" with respect to the R&D invested at home (Makino et al. 2002). This is particularly so in the case of technological leaders that, unlike laggards, engage in foreign R&D to capture a larger share of profits on the foreign market (Belderbos et al. 2008). More concretely, setting a network of R&D centers and subsidiaries in different locations, and connecting them through proper network linkages and technologies, can be the key for a company to pursue large scale R&D investments, which could not be parceled out to fit the capacity of the home labs (De Meyer 1993; Chen and Chen 1998). The internationalization of R&D could also be beneficial for running large multi-technology projects based on a multi-disciplinary kind of knowledge. This knowledge is usually geographically dispersed and thus requires firms to tap into different country and/or region-specific innovation systems (Gerybadze and Reger 1999; Gassmann and Von Zedtwitz 1998).

On the basis of the previous arguments, FDI in R&D can be seen as a strategic leverage through which MNCs compete with their global rivals for the leadership in the realm of R&D investments, and for the gains this leadership entails (Sect. 2.1). More precisely, by investing more in R&D abroad, MNCs can have higher opportunities and capacities than their rivals to afford the largest R&D investments on a global scale, that is, of being a top world R&D spender. Furthermore, FDI in R&D could also be useful for the leaders to keep their leadership over time by resisting the efforts of the R&D laggards to move them away from the top positions; the competitive process is inherently dynamic. We thus put forward our first, twofold research hypothesis:

HP1 FDI in R&D are expected to positively affect the firm's capacity to: (1.a) join the circle of the top R&D spenders; (1.b) remain within it over time.

It should be noted that this hypothesis refers to a possible increase of FDI in R&D that MNCs can implement in two ways, either through a higher number of R&D projects or through R&D projects of larger size. Drawing eclectically on the literature on the margins of trade and FDI (e.g. Head and Ries 2008), we could refer to the first case as an 'extensive' strategy of R&D internationalization. Strictly speaking, a strategy of this kind would require that the higher number of projects come with a wider geographical dispersion of their host countries. Still, even without controlling for this important aspect, actually out of the paper's scope, and thus even with a certain geographical concentration, a 'thicker' portfolio of R&D projects (i.e. a generic collection of FDI projects), could support HP1 in an extensive fashion. That is, by providing MNCs with both economies of scope, by spreading common R&D costs across different horizontal R&D activities, and economies of scale, by specializing in different vertical R&D activities through international labor division. Once more eclectically, HP1 could be thought at the intensive margin, by referring to MNCs which invest abroad more largely in terms of total value of their own projects. In this latter case, the underlying mechanism would be represented by economies of scale in foreign R&D and by the capacity of overcoming eventual indivisibilities in exploiting R&D expenditure abroad

Carrying on with our research hypotheses, an impact on the global competition for the R&D leadership can also be expected from FDI in other activities than R&D, such as manufacturing activities as such, if not even service ones (e.g. marketing). In these cases the channels through which FDI can increase the scale of the firm's operations in R&D is less direct, but still important. First of all, FDI could matter in this respect when they are *resource seeking*, that is driven by the MNCs' search for particular types of resources that are not available at home, in absolute terms or at convenient relative prices (Dunning 1993). Even when we leave apart those technological and innovation management capabilities that fall more naturally in the knowledge seeking category (Franco et al. 2010), other international resources can in fact represent crucial complementary assets for the implementation of large R&D projects by MNCs. This is particularly evident with respect to skilled labor, which represents a crucial 'asset' that R&D intensive multinationals 'seek' for implementing their innovation projects into economic activities on a global scale (Zanfei 2000). Similarly, in order to move along the innovation value-chain, the firm's R&D could require natural resources available in the international markets (think about pharmaceutical and electronic MNCs in need of chemicals and semiconductors, respectively), and for whose acquisition transaction costs and incomplete contracts might make international trade inconvenient (e.g. in the form of outsourcing).

FDI in non-R&D activities can magnify the scale of the MNCs' R&D expenditure also when they are driven by a *market seeking* motivation Dunning (1993). This motive can also drive FDI in R&D and amplifies their role for the issue at stake. In general, a number of the international investments that MNCs carry out, especially in manufacturing, are driven by their search for host markets of greater dimensions and/or host markets of a special appeal in order to interact with key foreign suppliers and customers, prevent potential competitors from entering and supplying adjacent markets with goods and services ['export-platform' FDI (Ekholm et al. 2003)]. In the former case, these FDI can provide the MNCs with economies of scale that could lower the production costs of the outcomes of their R&D projects and overcome eventual indivisibilities in doing so. In the latter case, instead, the commercialization of the MNCs' R&D outcomes could be facilitated by economies of scope accruing by the exploitation of country-differences in consumer tastes and supply capabilities.

FDI can be expected to impact on the MNCs' capacity of undertaking R&D investments also when they fragment and delocalize their production activities following an *efficiency seeking* motivation. By exploiting cross-country differences in production costs, as illustrated in the original taxonomy of Dunning (1993)[4], as well other efficiency enabling factors, like more efficient institutions (Campos and Kinoshita 2003), privatization methods (Merlevede and Schoors 2005), and agglomeration economies (Tan and Meyer 2011), MNCs could be able to reduce

[4] As noted by Franco et al. (2010), from a conceptual point of view, the distinction between efficiency seeking, on the one hand, and market and resource seeking FDI, on the other hand, is quite blurred, as the latter points to mechanisms that are also present in the former.

possible slacks in production and organization and free additional resources. These later resources could be used to enlarge existing R&D projects, if not initiating new ones.

Thinking of their manifold R&D impact, non-R&D FDI come to represent an additional means through which MNCs can gain positions over their rivals for the leadership of global innovative investments. A higher degree of internationalization could actually provide firms with a wider and possibly better set of resources and market conditions than the rivals for the economic sustainability of larger volumes of R&D expenditures than theirs. Once more, a higher level of non-R&D internationalization could also provide MNCs with efficient barriers against the R&D laggards' attempt of forging ahead.

This last set of arguments leads us to our second research hypothesis, which is also twofold.

> **HP2** FDI in non-R&D activities are expected to positively affect the firm's capacity to: (1.a) join the circle of the top R&D spenders; (1.b) remain within it over time.

A third hypothesis naturally emerges when we compare the different FDI motivations and channels of impact that support HP1 and HP2. First of all, as we said, while the effect of FDI projects in R&D on the technological competition we are addressing is direct, that of non-R&D FDI is indirect. The latter effect works through the acquisition of resources, which MNCs use complementary with the innovation (R&D) investments that enable them to scale up R&D positions, and which the former possibly reinforce. Secondly, FDI in R&D could be simultaneously used by MNCs for both knowledge and market (if not even, resource) seeking and thus have a larger impact on their R&D capacity than non-R&D ones, whose acquisition role of knowledge at the international level is limited. On this basis, we expect that:

> **HP3** FDI in R&D activities are expected to have a larger effect than non-R&D ones on the firm's capacity to: (1.a) join the circle of the top R&D spenders; (1.b) remain within it over time.

3 Empirical application

3.1 R&D and FDI company data

Two data sources are used for the empirical application. On the one hand, R&D investments have been drawn form the EU Industrial R&D Investment (IRI) Scoreboard (http://iri.jrc.ec.europa.eu/). This is a scoreboard analysis of top R&D investors across the World, representing more than 80 % of the world business R&D expenditure, that the Institute of Prospective Technological Studies (IPTS, Joint Research Centre, European Commission) carries out annually since 2004. In particular, company level data have been drawn for the R&D investments and for other accounting variables of the top 1,500 R&D investors over the period 2004–2011.

Scoreboard information has been matched with data from a second source, that is fDi Markets, by fDi Intelligence (The Financial Times Ltd). The database tracks cross-border greenfield investments, covering all sectors and countries worldwide since 2003. In particular, information on investment activity (e.g. R&D, manufacturing, sale and marketing) and capital expenditure (*Capex*) of FDI projects has been drawn from the database.[5]

In performing the merge between the two datasets, the FDI projects carried out by the subsidiaries of a certain MNC have been assigned to the relative parent company. In so doing, 1,150 scoreboard companies have been identified in fDi Markets and thus retained for the empirical application. As Table 1 shows, in-between 2003 and 2012, these top R&D spenders have invested in 33,572 FDI projects. The largest number of them has been initiated in manufacturing (37.6 %), followed by sales and marketing (14.6 %), and then R&D (11.7 %), pointing to a pattern of internationalization of economic activities that is quite well known (e.g. Karabag et al. 2011).

Although lower than in manufacturing and marketing/sales, the share of projects in R&D is not negligible. It should also be noticed that, for the sake of our empirical application, among these we have also considered the projects that fDi Markets classifies as "Design, Development & Testing" projects as distinguished from "Research & Development". This is an empirical choice made by other studies using the current database. It is motivated by the fact that knowledge sourcing opportunities may arise at different stages of the research and development/deployment chain of the innovative companies. A finer analysis of the R&D projects mapped by fDi Markets has revealed among them the presence of foreign R&D labs that carry out local *development* activities, and even *adaptation* activities of products and technologies to local customers, in addition to pure *research* labs (D'Agostino and Santangelo 2012). Still, the inclusion of FDI in design, development and testing helps us in including further learning processes that occur on the basis of research, trials-and-errors and feed-backs at lower stages of the innovation chain. One should just think of the case of software companies, for which the research and the testing of the product is nearly indistinguishable.

[5] It should be noted that for a number of projects the Capex is estimated. The algorithm to fill Capex missing information works as it follows: it first looks at projects in the same country/sector/activity with actual Capex data and then removes the smallest and largest 5 % of projects in order to create an estimation dataset. If there are less than 5 projects in this dataset, then the algorithm switch to regional data (i.e. North America in the case of projects in Canada); if there are still less than 5 projects, then the algorithm switch to global data (this would only be the case for rare combinations of sector/activity). Where the Capex is known, the algorithm uses the estimation dataset to look at the average ratio of Capex and to fill the gaps. These estimates are generally pretty accurate as the ratios in a given combination of country/sector/activity are pretty standard. If the Capex is unknown, the algorithm uses the average values of the dataset.

Table 1 Distribution of FDI projects per economic activities

FDI activity	# of projects	%
Manufacturing	12,612	37.6
Sales, marketing support	4,909	14.6
Research & Development	3,918	11.7
Retail	2,795	8.3
Logistics, distribution transportation	1,808	5.4
Business services	1,655	4.9
Headquarters	1,290	3.8
ICT internet infrastructure	794	2.4
Maintenance servicing	671	2.0
Electricity	631	1.9
Customer contact centre	564	1.7
Education training	542	1.6
Extraction	509	1.5
Technical support centre	340	1.0
Shared services centre	297	0.9
Construction	162	0.5
Recycling	75	0.2
Total	33,572	

3.2 The circles of top R&D investors

Looking for a threshold to identify the circle of top R&D investors at the worldwide level is not an easy task. The IRI Scoreboard already identifies a threshold with this aim, but it simply sets it up exogenously with a fixed number of ranked companies, with respect to which it carries out the analysis over time. Apart from being exogenous, the same threshold has appeared to separate from the non-Scoreboard ones a number of companies whose innovative behavior and economic performance are far from homogeneous. Kancs and Siliverstovs (2012), for example, have recently shown that the relationship between R&D expenditures and productivity growth of the Scoreboard companies is actually non-linear. Namely, the impact of R&D on productivity growth becomes significantly positive only after a certain critical mass of R&D is reached.

This kind of evidence seems to suggest that the ladder of companies that the Scoreboard identifies is not that smooth in terms of levels of investments. On the contrary, even when its 1,500th step has been climbed, further steps might emerge along the ladder, whose height (size) can create discontinuities in benefiting from R&D expenditure.

The distribution of the R&D expenditure of the Scoreboard companies against their ranking position in the latest available year (2011) (Fig. 1) confirms this expectation (the distribution for the other years is almost identical). The level of R&D expenditure increases at an increasing pace approaching the top of the ranking. The relationship between the companies ranking position and their R&D

expenditure appears exponential, with the latter that starts to break off around the 500th rank position and takes then off around the 250th. In other words, in correspondence of these two positions the R&D rate of change along the ranking increases steeply, suggesting these to be the most important posts (not to say discontinuities) for leaders to let the followers at a safer distance.

It should be noticed that, while the 250th cut-off is actually close to the average of the R&D distribution (reached by the 265th position), generally used in the literature for discriminating R&D leaders from the followers, the 500th one appears more selective than the median position (the 750th), also used for the same scope. In order to test whether the thresholds derived from the data are more informative than the standard ones, we have regressed the R&D growth rates along the sample ranking against a dummy for each of 'our' candidate positions and for the average and the median ones. Table 2 compares the relative R^2 and F statistics, revealing that, in both cases, our thresholds explain a larger part of the variance of the R&D growth rates and provide a better fit to the data under analysis. Accordingly, the 250th and the 500th positions have been chosen as boundaries of the (two) circle(s) of top R&D investors we are looking for.

Let us observe that the identified thresholds actually discriminate our Scoreboard companies in a way which is consistent with our theoretical premises. First of all, Table 3 shows that the identified groups actually concentrate the bulk of the R&D expenditure, both at the beginning and at the end of the period. In 2011, the top 250 companies carried out about 72 % of the total R&D expenditure, with a median value of 854 millions. When we consider the top 500, the share over the total R&D expenditures raises up to about 82 %, with a concomitant decline in the median value (366). Companies below the 500 ranking position display on average a much lower level of R&D expenditure. Similar patterns can be observed in 2004 (our first year sample period), when R&D expenditures were even more concentrated.

More relevant is the fact that in 2011, for which we were able to obtain reliable figures only[6], the market capitalization per employee (*MktCap/Emp*) of the (median) Scoreboard companies increases by moving up along the ladder (top 250: 0.33; top 500: 0.25; other companies: 0.23). This confirms the prize of R&D market value already found by Cincera et al. (2009) and the argument according to which, when a company is a top spender, investors are inclined to discount a positive relation between higher R&D capital and subsequent stock returns (Lev and Sougiannis 1996).

Quite interestingly, in both 2004 and 2011, the (median) R&D investors of the top circles in the ladder show better performances than (that of the) followers in terms of two variables usually taken into account for the impact of innovation on: the firm's competitive advantage over the rivals (e.g. Nakao 1993)—that is, operating profit per employee (*OpProf/Emp*)—and the (labor) productivity of its economic activities (e.g. Ortega et al. 2011)—that is, net sales per employee (*Sales/Emp*). These advantages are consistent with those we have hypothesized in Sect. 2.1.

[6] For 2004 we do not have enough available data on market capitalization to calculate representative figures.

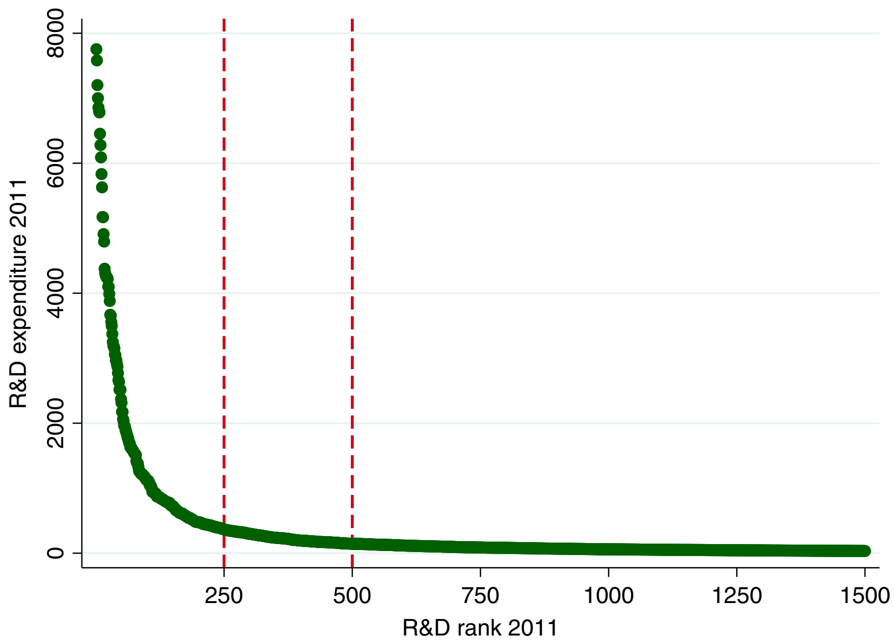

Fig. 1 Ranking and R&D expenditures

Table 2 Testing the thresholds on R&D growth-rates along the ranking

	250th	Average (265th)	500th	Median (750th)
Threshold	0.0104***	0.0099***	0.0065***	0.0047***
	(0.000)	(0.000)	(0.000)	(0.000)
R-squared	0.270	>0.260	0.171	>0.101
F-test	553.7	>525.5	309.1	>167.7

Standard errors in parentheses— *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

3.3 Entry-exit and top R&D circles: model and econometric strategy

In order to model the entry and exit with respect to the top R&D circles, we draw eclectically on previous studies in industrial organization, which address a similar competitive dynamics with respect to markets with different structures and degrees of firm heterogeneity (e.g. Lieberman 1989; Berry and Reiss 2007). For each company $i = 1, \ldots, N$, at time $t = 1, \ldots, T$, we accordingly define entry and exit as the outcome of a Markov process, where $y_{it} = 1$ indicates that the company has a level of R&D spending sufficiently high to be in the ladders' circle, and $y_{it} = 0$ otherwise. The conditional distribution of company's i R&D expenditure, assumed independent across firms, is then given by:

Table 3 R&D distribution and descriptive statistics by ranking groups (Million Euros)

	R&D expenditure (total)	Sample % R&D	Mean R&D	Median R&D	Median MktCap/Emp	Median OpProf/Emp	Median NSales/Emp
2011							
Top 250	384,927	71.7	1,540	854	0.333	0.035	0.318
Top 500	442,433	82.4	885	366	0.253	0.023	0.259
Others (501–1,500)	94,648	17.6	40	29	0.227	0.015	0.222
Whole sample	537,081		189	38	0.241	0.017	0.235
2004							
Top 250	264,590	81.5	1,058	469	–	0.027	0.281
Top 500	295,672	91.1	676	243	–	0.020	0.236
Others (501–1,500)	28,843	8.9	23	17	–	0.014	0.187
Whole sample	324,514		184	28	–	0.016	0.202

$$\pi_{i,v|u} = P(y_{it} = v | y_{it-1} = u) \quad (1)$$

where $\pi_{i,v|u}$ is the probability of a transition from the state $u = 0, 1$ at time $t - 1$ to the state $v = 0, 1$ at time t.[7]

Let us define $\mathbf{x}_i \equiv (1, x_{i1}, \ldots, x_{ip})'$ as the vector of p covariates for the ith company, which affect the transition from state u to state v, and let $\boldsymbol{\beta}_{uv} \equiv (\beta_{0uv}, \beta_{1uv}, \ldots, \beta_{puv})'$ be the vector of parameters for the same transition. The transition probabilities in terms of conditional probabilities as functions of covariates $\mathbf{x}$ are:

$$\pi_{i,v|u}(\mathbf{x}) = P(y_{it} = v | y_{it-1} = u, \mathbf{x}) = \frac{\exp(\beta'_{uv}\mathbf{x}_{it})}{\sum_{uv} \exp(\beta'_{uv}\mathbf{x}_{it})}. \quad (2)$$

By imposing that $\boldsymbol{\beta}_{00} = 0$ and $\boldsymbol{\beta}_{11} = 0$, the transition probability from being below the threshold and staying below (and being and staying above) the threshold in the next period can be written as:

$$\pi_{i,v=u}(\mathbf{x}) = \frac{1}{1 + \sum_{u \neq v} \exp(\beta'_{uv}\mathbf{x}_{it})} \quad (3)$$

and the probabilities of crossing the threshold as:

$$\pi_{i,v \neq u}(\mathbf{x}) = \frac{\exp(\beta'_{uv}\mathbf{x}_{it})}{1 + \sum_{u \neq v} \exp(\beta'_{uv}\mathbf{x}_{it})}. \quad (4)$$

Once conditioned on the covariates, the transition probabilities are assumed to be independent across companies and time, and we can retrieve both the transition matrix and the impact of the FDI determinants via maximum likelihood estimation.

[7] Note that $\sum_{v=0,1} \pi_{i,v|u} = 1, \; u = 0, 1$.

More precisely, we estimate a system of two logistic regressions, one for the entry and the other for the exit process, via Seemingly Unrelated Estimation (SUE). This approach allows us to retrieve both robust standard errors and estimates of the between-model covariances of the parameters, and thus to test for differences (in the absolute values of the parameters) in the two equations. For those covariates that provide a significant contribution in explaining both the entry and exit dynamics, we will test whether they exert symmetric effects on the two processes.

In order to test our three research hypothesis (Sect. 2.2), we plug in vector **x** the involvement of the company in outward FDI projects. As a first step to attenuate the problem of endogeneity that could affect the use of FDI as a regressor for entry/exit in the R&D circles, we take stock of the dynamic nature of our data and introduce a time-lag between the latter and the former. In this way, we factually prevent a reverse causality from belonging to the circles to investing abroad. In order not to lose an excessive number of observations, we assume that one year of time could be enough for an FDI project to have an effect on the R&D expenditure of the investing firm, and thus refer to FDI at time $t-1$ for entry and exit at time t. The green-field nature of the FDI projects collected in the fDi Market database, whose implementation presumably urges a more prompt and substantial injection of fresh R&D resources than a M&A project, makes this 'early' impact hypothesis not so prohibitive to support. Of course, other sources of endogeneity could still remain, that only randomised controlled experiments could satisfactorily solve (Reeb et al. 2012). As we will say in the following, in the absence of a suitable counter-factual group, we will however resort to the more standard, tough imperfect, technique of controlling for other variables and sources of unobserved heterogeneity in the relationship at stake.

The previous methodology is applied in two classes of models. In Model 1, we assume that the probability that a company i enters in (Model 1.1), and exits from (Model 1.2), the circle at time t, $\pi_{i,t(1|0)}$ ($\pi_{i,t(0|1)}$) is affected by the number of its FDI projects in R&D at time $t-1$ ($FDIrd_{t-1}$), and we thus refer to the extensive kind of R&D internationalization we have discussed in Sect. 2.2. Following a similar extensive logic for the firm's internationalization at large, in Model 2, entry in (Model 2.1) and exit from (Model 2.2) the identified circles at time t are explained by adding to $FDIrd_{t-1}$ the number of FDI projects carried out in non-R&D activities at time $t-1$ ($FDInonrd_{t-1}$). As a robustness check of the previous one, Model 3 refers to what in Sect. 2.2 we have called R&D internationalization at the intensive margin. The determinants of entry (Model 3.1) and exit (Model 3.2) are thus investigated by replacing $FDIrd_{t-1}$ with the total capital expenditure in R&D projects by company i at time $t-1$ ($FDIrdexp_{t-1}$), using $FDInonrd_{t-1}$ as control for the internationalization degree of the focal firm.

In all the models we have to consider that, in addition to FDI projects, the process of entry/exit with respect to the circle of top R&D investors could be affected also by other variables, which should enter the **x** vector too. First of all, companies might climb up and down the R&D ladder depending on their availability of financial resources to invest in R&D, providing an interesting opportunity for testing a relationship on which the evidence is still not unambiguous (Hundley et al. 1996). In this vein, the operating profit of the firms (*OpProf*) is considered among the regressors of all the previous three models.

Further explanatory variables emerge by drawing eclectically on industrial organization also for the determinants it has found for firm entry and exit with respect to "standard" markets. First of all, the capacity of being and staying among the R&D leaders could depend on the firm's size, with the possibility of extending to this realm the evidence of a "liability of smallness" (Aldrich and Auster 1986; Honjo 2000). Accordingly, the natural logarithm of the company's employees ($Log(Emp)$) is inserted among the controls. In the same vein, the age of the firm (*Age*) could affect its potential of scaling up the thresholds of the R&D worldwide ranking, as well as the risk of falling below them over time: the equivalent of a "liability of newness" becomes thus interesting to test (Stinchcombe 2000; Geroski 1995).

A series of dummies complete the list of controls, in order to take into account industry, country and time specificities. As we said, in order to overcome potential endogeneity problems, all the variables apart from $Log(Emp)$ and *Age*, and of course the dummies, enter into the model with a year lag.

4 Results

In general, the estimation results provide us with support to our research hypotheses. However, important and interesting specifications emerge across the two considered circles of top R&D spenders and across the estimated models.

4.1 Top 500 R&D spenders

Starting with the extensive kind of internationalization that the number of projects enable us to consider (that is, $FDIrd_{t-1}$), and looking at the lower in rank of the two circles (Table 4), our first research hypothesis about the role of FDI in R&D (Sect. 2.2) gets confirmed in both of its two parts. A larger number of international R&D projects significantly increases the firm's probability of entering into the group of the top 500 R&D spenders (Model 1.1), thus supporting *HP1a*. Furthermore, it significantly reduces the risk of exiting from the same group in the aftermath of the same projects (Model 1.2), consistently with *HP1b*.[8]

This is a first interesting result. It adds new evidence on the advantages that companies can have when, through R&D FDI, they can seek knowledge and other resources internationally for their innovative projects, and/or look for international markets where to exploit the relative results. Through these international activities firms can afford to pursue the largest R&D investments at the worldwide level, and to compete for the markets and technologies which require such a large R&D involvement, for example, because of the presence of up-front fixed costs and indivisibilities. On the other hand, drawing more extensively than the other R&D

[8] As reported at the bottom of the estimation tables, tests on the coefficients prevent us from retaining as significant apparent differences between those for entry and exit.

giants on international markets for their R&D activities, firms are also able to renew their knowledge base and to better resist the competition for the technological leadership at stake.

Looking at the first circle of top R&D spenders, our second research hypothesis gets confirmed only partially. On the one hand, the access to the top 500 R&D investors is also helped by a larger number of FDI projects in activities other than R&D, $FDInonrd_{t-1}$ (Model 2.1). Although with a lower level of significance, *HP2a* appears to be supported. Moreover, the size of the coefficient for R&D FDI does not change with respect to Model 1.1. This is a second interesting result of our application, which points to a possible role of 'complementary' international activities to R&D ones for firms to reach the leadership for the largest R&D investments: investing abroad in search of resources and/or markets might provide firms with an R&D advantage, even when this occurs in other activities than R&D. The degree of internationalization that firms acquire by setting up new subsidiaries abroad, irrespectively from their dedication to innovation-related activities, apparently increases their set of knowledge and market opportunities, to the point of spurring a shift to a larger scale of R&D investments in order to exploit them.

On the other hand, a greater internationalization of activities other than R&D does not help the R&D giants in resisting the competition for the leadership; on the contrary, the number of FDI projects in R&D ($FDIrd_{t-1}$) does (Model 2.2): *HP2b* is not confirmed. While a wider access to international markets for the sake of R&D helps the leaders to stay in the top-500 circle, a larger number of international activities per se does not guarantee safer positions in it. Once they got into the circle, companies need to resort to more research-related international strategies for resisting the competition of the new large-R&D comers.

This last result provides indirect support to our *HP3b*, with respect to which the lower exit impact of non-R&D FDI is actually a not significant one vs. the significant impact of R&D FDI. *HP3a* is instead directly supported, given the lower impact of *FDInonrd* with respect to *FDIrd* (Model 2.1). As expected, a larger portfolio of international R&D projects helps more, rather than a larger portfolio of other international economic activities, in climbing the R&D ladder. As we argued in Sect. 2.2, the former provides more direct and extensive advantages in terms of R&D expenditure than the latter.

In this last respect, let us also observe that, as Fig. 2 shows (solid lines), the estimated probabilities of *entering* in the circle of the top 500 sharply increase with the number of R&D projects (upper part of the figure), and approach a certainty kind of outcome (that is a unitary probability) already for the companies with the lowest numbers of projects, revealing a kind of logistic distribution. Conversely, the estimated probabilities of joining the same group increase much more smoothly, with the increase in the number of non-R&D FDI (lower part of the figure). As we said, unlike an R&D based one, a general internationalization strategy, whose knowledge outcome can be only indirectly functional to R&D investments, appears less powerful in guaranteeing the status of top spenders.

Table 4 Number of FDI projects and top 500 R&D spenders

	Model 1.1 Entry	Model 1.2 Exit	Model 2.1 Entry	Model 2.2 Exit
$FDIrd_{t-1}$	0.5185***	−0.5990***	0.5271***	−0.5415***
	(0.184)	(0.218)	(0.169)	(0.207)
$FDInonrd_{t-1}$			0.0501*	0.0199
			(0.028)	(0.027)
$Log(Emp)$	0.6673***	−0.7844***	0.6303***	−0.7131***
	(0.120)	(0.163)	(0.116)	(0.137)
$OpProf$	0.0001***	−0.0001	0.0001**	−0.0001
	(0.000)	(0.000)	(0.000)	(0.000)
Age	0.0000	−0.0016	0.0005	−0.0015
	(0.002)	(0.003)	(0.002)	(0.003)
Sector dummies	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included
Country dummies	Included	Included	Included	Included
Constant	−9.1097***	−8.7567***	−8.7680***	4.0037**
	(1.750)	(1.895)	(1.223)	(1.601)
Observations	3,899	3,899	3,899	3,899
Pseudo R-squared*	0.182	0.198	0.184	0.199
Coefficient tests				
FDI projects in R&D: $\|entry\| = \|exit\|$	0.08 (0.7779)		0.01 (0.9571)	
FDI capex in R&D: $\|entry\| = \|exit\|$				
Employees: $\|entry\| = \|exit\|$	0.33 (0.5642)		0.21 (0.6448)	

Robust standard errors in parentheses— *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$—Pseudo R-squared from the original logit regressions

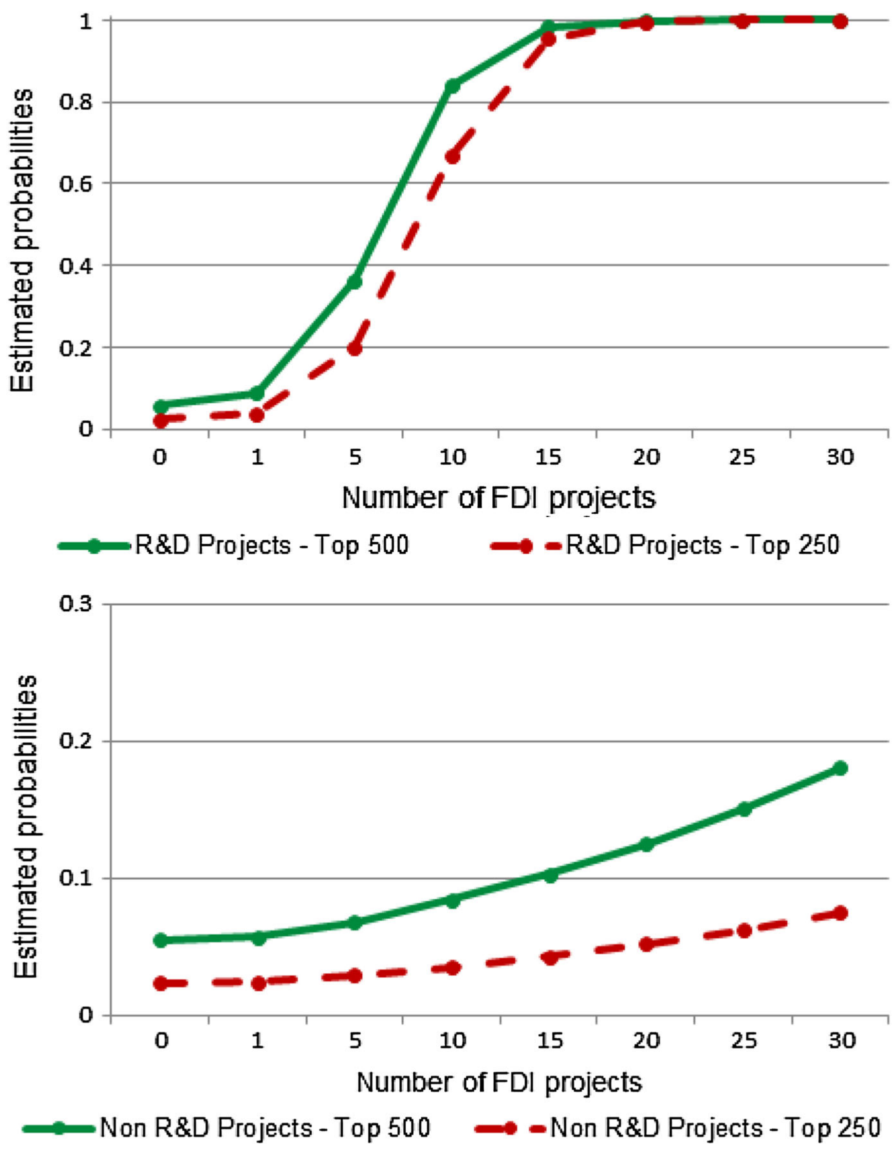

Fig. 2 Estimated probabilities of entering in the top 500 & 250 *circles*

4.2 Top 250 R&D spenders

The previous results are nearly completely confirmed when we look at the R&D spenders' dynamics with respect to the upper threshold, that is the 250th position (Table 5), and considering the number of projects (that is, $FDIrd_{t-1}$). Increasing the number of FDI in R&D still appears a significant strategy for gaining (Model 1.1) and maintaining (Model 1.2) the access to the very top of the worldwide ranking in

Table 5 Number of FDI projects and top 250 R&D spenders

	Model 1.1 Entry	Model 1.2 Exit	Model 2.1 Entry	Model 2.2 Exit
$FDIrd_{t-1}$	0.6334*** (0.178)	−0.3882** (0.158)	0.5644*** (0.168)	−0.3591** (0.153)
$FDInonrd_{t-1}$			0.0463* (0.026)	−0.0030 (0.048)
$Log(Emp)$	1.0037*** (0.178)	−0.5507*** (0.213)	0.9037*** (0.140)	−0.5493*** (0.190)
$OpProf$	0.0001 (0.000)	−0.0001* (0.000)	0.0001 (0.000)	−0.0001** (0.000)
Age	0.0057* (0.003)	0.0036 (0.004)	0.0030 (0.002)	0.0023 (0.004)
Sector dummies	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included
Country dummies	Included	Included	Included	Included
Constant	−12.2994*** (2.129)	−7.8428*** (2.797)	−12.5526*** (1.512)	3.3187 (2.231)
Observations	3,899	3,899	3,899	3,899
Pseudo R-squared	0.268	0.194	0.269	0.194
Coefficient tests				
FDI projects in R&D: $\|entry\| = \|exit\|$	1.06 (0.3033)		0.81 (0.3670)	
Employees: $\|entry\| = \|exit\|$	2.67 (0.1025)		2.25 (0.1333)	

Robust standard errors in parentheses—*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$—Pseudo R-squared from the original logit regressions terms of R&D expenditure, providing support for both *HP1a* and *HP1b*. As Fig. 2 (upper part) shows, and as expected, reaching this upper circle through R&D internationalization is more difficult than reaching the lower circle, at least for the companies with a smaller portfolio of R&D projects: the first part of the dotted sigmoid is shifted downward with respect to the solid one. Still, setting FDI in R&D projects at work helps with that. Along with evidence on the 500th position, this result provides a general support to our first research hypothesis: the internationalization of R&D activities via FDI can have a significant impact on the competition for the largest R&D expenditures.

The entry/exit dynamics with respect to the higher 250 spenders also support our second research hypothesis, about the role of FDI in activities other than R&D. Once more, the support is partial and limited to the access to this higher group (Model 2.1), which is significantly fostered by *FDInonrd*, consistently with *HP2a*. This time, however, the explaining power of *FDIrd* does not keep its original size (as from Model 1.1) but slightly diminishes, pointing to a lower complementarity between the two kinds of FDI when the target is the highest circle along the R&D ladder.

Also in this case, the comparison between the upper and lower part of Fig. 2 (red lines) suggests that widening the portfolio of non-R&D international projects increases the entry-probabilities in the group much more smoothly than widening that of R&D projects. Furthermore, the same internationalization strategy is much less powerful than that of targeting the top 500. The dotted line stands quite below the solid line in the lower part of the figure. Quite interestingly, the divide between the two curves is larger than in the upper part of the same figure, suggesting that the 'escalating power' of non-R&D FDI gets more substantially exhausted than that of R&D FDI.

Our second research hypothesis is instead not confirmed when we look at the exit dynamics from the group of the top 250, that is at *HP2b* (Model 2.2). Similarly to the top 500, a generic increase of the internationalization degree of the sample companies is not enough (significant) for protecting them against the competition of new large R&D comers, which apparently requires more research-based international activities.

Finally, also with respect to the top 250, the comparative effect of *FDIrd* and *FDInonrd* on entry and exit confirms both *HP3a*—directly, with an impact of 0.5644 and 0.0463, respectively—and *HP3b*—indirectly, with a −0.3591 and a non-significant impact, respectively.

4.3 Robustness checks and controls

As a sort of robustness check of our previous results, Table 6 reports the estimates of another class of entry-exit models (Models 3.1 and 3.2) where, instead of the number of R&D projects ($FDIrd_{t-1}$), the internationalization of R&D activities is examined by looking at the total capital expenditure in R&D projects by company ($FDIrdexp_{t-1}$), using $FDInonrd_{t-1}$ as control. In so doing, as we argued in Sect. 2.2, we aimed at addressing what we eclectically called the effect of an intensive internationalization of R&D.

Table 6 Size of R&D FDI projects and top 250/500 R&D spenders

	Top 500		Top 250	
	Model 3.1 Entry	Model 3.2 Exit	Model 3.1 Entry	Model 3.2 Exit
$FDIrdexp_{t-1}$	0.0115*** (0.004)	−0.0214** (0.010)	0.0129*** (0.004)	−0.0057 (0.006)
$FDInonrd_{t-1}$	0.0512* (0.029)	0.0197 (0.029)	0.0508* (0.028)	−0.0117 (0.048)
$Log(Emp)$	0.6480*** (0.117)	−0.7173*** (0.139)	0.9281*** (0.142)	−0.5816*** (0.197)
$OpProf$	0.0001** (0.000)	−0.0001 (0.000)	0.0001 (0.000)	−0.0001** (0.000)
Age	0.0005 (0.002)	−0.0015 (0.003)	0.0030 (0.002)	0.0025 (0.004)
Sector dummies	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included
Country dummies	Included	Included	Included	Included
Constant	−8.9274*** (1.239)	4.0019** (1.618)	−12.7608*** (1.546)	3.5489 (2.288)
Observations	3,899	3,899	3,899	3,899
Pseudo R-squared	0.158	0.155	0.232	0.159
Coefficient tests				
FDI capex in R&D: $\|entry\| = \|exit\|$	0.79 (0.3733)			
Employees: $\|entry\| = \|exit\|$	0.15 (0.7031)		2.04 (0.1530)	

Robust standard errors in parentheses—*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$—Pseudo R-squared from the original logit regression

Looking at the first threshold (top 500 R&D spenders), our first research hypothesis is fully supported (i.e. *HP1a* and *HP1b*). Once we control for their internationalization degree in other activities (*FDInonrd*), the firms with higher investments in international projects in R&D (*FDIrdexp*) get similar gains than those with the most numerous R&D international projects: the probability of joining the top 500 increases (Model 3.1), as well as that of remaining among them (Model 3.2). As in the previous models, a higher internationalization degree in non-R&D activities only helps in entering the top 500, confirming a partial support to our second hypothesis (i.e. *HP2a*, but not *HP2b*).[9]

The result we have obtained with respect to *FDIrdexp* is another interesting outcome of our application, which suggests an additional and possibly more expected channel through which the internationalization of R&D can help firms to compete for the leadership in the volumes of R&D expenditure. While Models 1 and 2 tell us that a strategy of pervasive R&D internationalization could be enough for climbing the R&D giants' shoulders, Model 3 tells us that the intensity of the R&D internationalization also matters. As we said, setting in motion international 'innovative' projects of larger amounts could actually enable companies to overcome the indivisibilities that often prevent them from implementing R&D investments.

The significance of scale effects in the internationalization of R&D is confirmed also when we look at the higher of our R&D circles (i.e. the top 250), but with an important element of differentiation. As in the previous case, larger FDI in R&D makes entry in the top-250 circle easier (Model 3.1). However, unlike the previous case, higher R&D investments in international projects do not make the top 250 more 'sticky' (Model 3.2). Once this part of the R&D 'iceberg' is reached, economies of scale in research stop constituting a reliable safeguard against the risk of falling down out. At the same level, it is only an extensive (in the way we meant it) internationalization of R&D, possibly more inclined to a diversification mode, that can help in staying within the group.

In concluding our analysis, some interesting results emerge from the analysis of the controls used in the estimation, across all of its specifications (Tables 4, 5, and 6). First of all, as expected, larger firms are more prone to make the shifts along the R&D ladder. Conversely, the smaller ones are more inclined to exit from the R&D circles at stake, pointing to an interesting extension of the hypothesis of the "liability of smallness" in industrial dynamics. No significant effect is instead found for the extension of the "liability of newness" to our realm. The coefficients attached to the variable *Age* are not statistically significant (apart from one case at 10 %): once the effects of the other variables are taken into account, the age of a company does not contribute in explaining its capacity of climbing the R&D giants' shoulders. In this specific realm, the higher opportunities which are usually recognized to younger firms in industrial dynamics do not seem to matter. Entry-in and exit-from the R&D circle do not seem an issue of industrial demography.

[9] Given the different nature of the variables we use in this robustness check for R&D and non-R&D FDI, *HP3* is not directly testable in this case.

Finally, the companies' profitability has a significant effect on the probability to enter into the top-500 circle, and the same holds true, for the probability of staying in the more restricted top-250 circle. The availability of internal financial resources, by relaxing the financial constraints that companies may face when investment decisions are taken, could explain the first result. As for the second, instead, an expected higher financial performance of the top 250 might lower the importance of the cash-flows availability for R&D investment decisions. However, more cash-flow could be needed to keep an open window on the new opportunities in the market.

5 Conclusions

In a global scenario, innovation competition also entails struggling for the leadership in large R&D investments on a worldwide scale. Climbing the ladder of the world R&D spenders can help firms to pool the risks of different research projects and/or overcome the indivisibilities that affect the use of R&D resources, especially in the discovery of path–breaking, brand new products and processes.

The internationalization of R&D through FDI can help in this respect, as multinational projects of this kind enable companies to access new knowledge sources for their technologies and discover new markets for their development. Although less directly, an impact on the firm's capacity to compete for the circles of the top R&D expenditure worldwide can also be expected from other international activities, through which MNCs can search for markets and complementary resources for implementing their larger R&D projects.

Our application to the companies of the European Scoreboard of Industrial Research and Innovation generally confirms these hypotheses, shedding new lights on the innovation advantages of internationalization. FDI in R&D give a significant and positive contribution to climb on the R&D giants' shoulders: a contribution that also take place through the economies of scale that larger foreign R&D entail, but which is not necessarily related only to them. A large portfolio of projects of this kind can work equally well. To be sure, only the number of foreign R&D projects guarantees to the investing firm to keep their leadership in R&D. On the contrary, a larger R&D expenditure abroad stops working when the very top of the worldwide ladder is reached.

From the previous results, a first set of policy implications can be drawn about the support to the internationalization of R&D. First of all, while R&D offshoring could possibly have the drawbacks that the literature has pointed to—for example, the risk of losing core-competencies and of international knowledge leakage—by helping firms source R&D knowledge internationally (for example, through initiatives of international knowledge transfer and/or qualified labor mobility and exchanges of researchers), policy makers can provide them with important opportunities. On the one hand, they could help MNCs in affording those critical levels of R&D investments from which the most path-breaking innovation outcomes often follow, with the biggest economic returns. On the other hand, supporting the internationalization of R&D, though mainly in terms of wider projects portfolios, policy makers could provide firms with a longer temporal window among the top

R&D spenders, thus augmenting the opportunities to exploit the acquired knowledge into successful innovations. Of course, additional factors are responsible for the transformation of the R&D global leadership, addressed in this paper, into prospected returns. However, we deem that the same leadership would represent an important, if not even conditional, characteristic for companies to achieve successful innovation outcomes on a global scale: an issue that we postpone to our future research agenda.

Further policy implications stem from the fact that also FDI projects in activities other than R&D could support the firms in the international technological competition at stake. As expected, their impact is lower than that of FDI in R&D for accessing the top R&D circles, while it even vanishes with respect to the firm's capacity of resisting the competition of the new R&D comers. Still, this is an important result, with a relevant policy implication. Supporting the internationalization of companies through outward FDI could have a side-effect on their overall R&D capacity. Not only can it increase the domestic investments of MNCs in R&D, as the extant literature has found. But it can also help the firms to reach a critical R&D mass, which the literature has shown important for a positive evaluation by the financial markets, and which can be used in high-scale intensive projects with larger economic returns.

Of course, the paper does not come without reservations, which future research on the topic will try to address. First of all, the empirical application does not make use yet of information on the geographical location of the host countries, which would make the identification of the FDI motivations more accurate. A similar improvement could be obtained by further disaggregating the activities other than R&D that have been internationalized by the sampled firms. In terms of methodology, the set of research hypotheses put forward could be further enriched by enhancing the micro-structure of the entry–exit model.

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