R&D MANAGEMENT

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Market dominance, R&D grant funding, and innovation outcomes

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Which companies should receive government R&D grants? Should R&D grants go to already dominant firms, whom one would expect to execute fully in innovation spending to produce better outcomes? Or, should grants go to firms that are less dominant and might need the funding for innovation? Using a novel proprietary panel dataset of over 26,000 firm-year observations for Irish firms with 1,825 winning grants, this paper provides support for a strategic or efficiency effect: market dominance moderates grant innovation outcomes. Specifically, dominant firms significantly outperform other groups in terms of future R&D spending, R&D growth, and overall employment gains. However, they perform worse than other groups with respect to the employment of in-house R&D workers, suggesting that dominant firms already have significant R&D capabilities. We also show that dominant firms' future productivity is not statistically different from similar non-grant backed dominant firms, potentially implying that they use grant money to retain their existing market position, rather than to capitalize on it and increase productivity by more than their peer firms.

1. Introduction

R&D is important to both economic and corporate growth (Solow, 1956; Lucas, 1988; Morbey, 1988). However, companies might under-invest in R&D due to concerns about knowledge and technological spillovers to rivals (Nelson, 1959; Arrow, 1962; Sorensen, 2006; Audretsch and Belitski, 2020), managerial myopia (Stein, 1989), systemic failures (Carlsson and Jacobsson, 1997), shirking (Bertrand and Mullainathan, 2003), and agency conflicts (Stiglitz and Weiss, 1981).[1] To mitigate underinvestment in private R&D, governments often provide direct funding to firms to encourage innovation. Some prior studies have examined the efficacy of such schemes, with the evidence generally supporting a positive link between grants won and future R&D spending.[2]

In this paper, we also provide estimates of the direct impact of government funding on firms' future innovation performance, specifically R&D investment. However, to add to prior work (e.g., Levy and Terleckyj, 1983; Coad and Rao, 2008; Zuniga-Vicente et al., 2014), the focus of this paper is on whether the recipient's market share or dominance influences the efficacy of R&D grants.

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Prior literature shows a link between corporate returns, innovation, and market dynamics. Some literature reports increasing returns to innovation for concentrated industries, suggesting a positive or strategic effect (Schumpeter, 1934, 1942; Doukas and Switzer, 1992; Artz et al., 2010) for firms that are more dominant. This largely arises because dominant firms have strategic preemption advantages, and generate excess profits, so can hire staff to respond to competition, rather than relying on costly external markets. Nevertheless, alternative views exist and are discussed in greater detail in Section 2. For example, Hicks (1935) observed that larger firms or monopolies suffer from agency problems, so are slow to innovate. Aghion et al. (1997, 2001) also argue that competitive industries are better placed to innovate as increased competition reduces rents for those that do not innovate, thereby incentivizing firms to increase R&D spending to maintain the equilibrium or stay ahead of the competition. Zhou et al. (2017) support this by examining state-owned firms in China. They show that industrial competition can ameliorate agency costs, or inefficiencies, typically associated with state ownership in transforming R&D into innovation outputs.

We analyze how R&D grants relate to future innovation in several dimensions. We additionally examine how the firm's market position impacts any such effect. We analyze several innovation measures. These include future increased R&D investment, sales from new products, employment growth, and productivity. This paper focuses on the types of firms that might benefit from R&D grants, and whether such grants are useful for firms who are already in a dominant market position, in addition to less dominant firms who would otherwise have fewer resources to spend on R&D.

We take steps to mitigate econometric concerns. One concern with our methodological approach is that the relationship between industry market share and higher innovation could simply be an artifact, arising from unobserved heterogeneity or reverse causality (Blundell et al., 1999). That is, innovators typically grow faster, leading to greater market dominance. Our research design helps addresses this causality concern by examining the impact of government competitive R&D grants (a 'cash windfall') on the innovation outcomes for firms with different market shares.[3] Receiving an exogenous cash windfall for R&D investment allows us to better examine if the funds won are spent on R&D, and more importantly, the innovation outcomes that materialize from this investment. Comparing firms with different market shares that receive funding with similar firms that do not, also allows us to analyze whether the firm's market share drives better innovation outcomes, supporting a strategic effect, or if it leads to a crowding-out problem, whereby new funding is not spent on innovation. We also report additional analyses to ensure our findings are robust. This includes subsample analyses that examines only grant 'winning' firms. We also further address causality and omitted variable issues by using a 'placebo' test (Erel et al., 2015), and controlling for time invariant firm-fixed effects.

Our research contributes to the literature on the link between a firm's market dominance and innovation outcomes. We provide new evidence on whether a firm's market share or dominance plays a role in achieving better innovation outcomes. More importantly, the contribution has important policy perspectives in showing which types of firms benefit most from grants, and how grant-awarding agencies can avoid a crowding-out effect.

This paper is structured as follows: In Section 2, we examine the theoretical and empirical literature and establish two hypotheses. Section 3 describes the data construction process, and Section 4 outlines the econometric model, reports the results, and addresses some robustness concerns. Section 5 presents a discussion and concludes.

2. Background theory and hypotheses

2.1. *Innovation and reasons for underinvestment*

The link between R&D investment and financial constraints is well established (Hall and Lerner, 2010). Theories that explain the underinvestment in innovation include information asymmetry (Akerlof, 1970; Spence, 1973; Stiglitz, 1975; Hall, 2002; Hall and Lerner, 2010), knowledge spillovers and appropriability risk (Nelson, 1959; Arrow, 1962; Sorensen, 2006; Audretsch and Belitski, 2020) and systemic failures. Information asymmetry, which refers to the situation where one party in an economic transaction has more information or knowledge about the products than the other, is recognized as a common market failure in innovation policy. In this case, it is related to the issue that the fund providers (such as banks or investors) are not provided with enough information about the R&D projects, which are normally associated with high risk and uncertainty (Hall, 2002; Hall and Lerner, 2010; Giordani and Zamparelli, 2011; Haapanen et al., 2014). And, even when provided with information, R&D investment has uncertain outcomes. Because of that, fund providers may

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be unwilling to invest in R&D projects, leading to under-investment in innovation. This provides the rationale for public intervention. Governments, by providing firms with the funding, help share R&D risk. In turn, this provides a signal to the market about the projects' quality, which can help firms' access other sources of funding.

There is also government policy failure (Stiglitz and Wallsten, 1999; Wallsten, 2000). This refers to the argument that government intervention in the market results in worse outcomes due to funding misallocation. This could be because of information asymmetry, an active decision to pursue tangential policy objectives, or because of a sub-optimal cherry-picking strategy, as described by the public choice theory (Czarnitzki and Lopes-Bento, 2013; Zuniga-Vicente et al., 2014; Dimos and Pugh, 2016).

To help address underinvestment in R&D, many countries adopt interventionist policies. This can involve direct support to firms in the form of grants in addition to tax credits. R&D tax credits differ from publicly funded grants in that firms doing R&D, regardless of the quality of the project, more frequently apply for tax credits. Some recent evidence (Aysun and Kabukcuoglu, 2019) also suggests that tax credits may reduce R&D spending for financially constrained firms, whereas cash grants have the desired positive effect. Brown et al. (2012) also show the importance of external equity in promoting R&D investment, especially for financially constrained firms. However, unlike tax credits, publicly funded grants are competitive, so only awarded to firms whose projects gain a positive evaluation from the grant agency (Romero-Jordan et al., 2014). Mazzucato (2015) emphasizes the role of the state in fostering long-run innovation-led economic growth, and provides support for government policy interventions for R&D. She shows that the private sector is more likely to invest *after* government support for high-risk investments. In the aftermath of the 2008 financial crisis government and policy makers have become increasingly concerned about financial constraints in innovative firms (OECD, 2009, 2014; Hall et al., 2016).

2.2. *Grants and innovation outcomes: empirical evidence*

The evidence on the link between grants and innovation outcomes is mixed but appears to be largely dependent on the type of support received. Justman and Zuscovitch (2002) find that firms that won Israeli government R&D grants show a significant increase in sales and employment, especially those in Electronics. Guo et al. (2016) show that Chinese R&D grant winning SMEs generate significantly higher technological and commercialized innovation outputs than non-recipients. Bronzini and Piselli (2016) report that an Italian R&D competitive grants program had a significant impact on the number of patent applications. On the other hand, Hashi and Stojcic (2013) report that firms that have access to different types of subsidies, including tax credits and cash grants from all levels, including local, government and EU, experience lower sales from new products compared to firms that do not. Taken together, the evidence of increases in innovation is stronger for firms that win competitive grants.

Employment is the most direct measure of the impact of winning a grant and has greater societal impact. Prior research reports mixed evidence. For example, Wallsten (2000) reports that publicly funded R&D grants have no effect on employment, while Girma et al. (2010) finds that government grants encourage plants to start-up larger with more employment. Justman and Zuscovitch (2002) show that R&D grants increased overall employment by around 10% for Israeli firms. Goolsbee (1998) finds that grant-winning firms reward R&D employees with higher salaries, suggesting a substitution effect. We predict that grants are associated with an overall increase in the number of employees of winning firms, and, specifically, increases in the proportion of in-house R&D employees so firms can increase innovation capability.

Prior literature also supports a positive relationship between R&D and productivity.[4] A Cobb-Douglas production function is commonly used in these studies to analyse the impact of R&D on productivity. The impact of a firm's R&D on its future productivity likely depends on whether the R&D is backed by government funding (Levy and Terleckuj, 1983), or if it is pure private R&D funded by the firm. Government-funded R&D will likely produce greater productivity for two reasons. First, competitive government funding has an important 'certification effect' (see e.g., Justman and Zuscovitch, 2002; Kleer, 2010; Wu, 2017) in that it signals to the market that the R&D project has strong potential for success. In addition, to win funding, funding agencies typically require the firm to have sound financial standing, with regular requests to provide full audited financial statements and future financial projections. Further, agencies require that firms demonstrate sufficient technical feasibility to complete the R&D project. In the context of Ireland where most of the firms are non-public SMEs whose financial information

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is limited, selection for funding has significant added value. Specifically, the certification effect will strengthen the reputation of the firm, and so improve its relationship with key stakeholders, including investors, customers, and suppliers. Second, direct grants help relieve financial constraints, especially for smaller firms, and together with the certification effect help firms improve access to debt. Taken together, it is likely that grants will positively moderate the impact of R&D on future productivity, largely due to a certification effect, greater oversight, and increasing sources of future funding.

2.3. *Market dominance*

A firm's market position is likely to influence how much it gains from the grant. Schumpeter (1934, 1942) first proposed that innovation is likely to be greater the more concentrated or the greater dominance a firm has, and is supported by some studies (e.g., Doukas and Switzer, 1992). This largely arises because dominant firms have strategic preemption advantages, and generate excess profits, so can hire staff to respond to competition, rather than relying on costly external markets. Nevertheless, Hicks (1935) observed that larger firms or monopolies suffer from agency problems, so are slow to innovate, facilitating a 'quite life'. Aghion et al. (1997, 2001) argue that increased industry competition helps foster greater R&D spending. This is largely due to increased competition reducing rents for those that do not innovate, thereby incentivizing firms to increase R&D spending to maintain the equilibrium or stay ahead of the competition. Aghion et al. (2014) note that while increased competition may have a negative effect on those that fail to compete ('laggards'), overall, it has a positive effect on R&D investments.

Taking the Schumpeterian view, we predict that dominant firms in terms of market share are best placed to leverage grants to improve R&D, innovation, and other outputs (e.g., productivity). This is for several reasons. First, dominant firms are likely to show less risk of grant money merely substituting for existing R&D expenditure, rather than increasing it (i.e., crowding out effect). This substitution effect has been documented in prior grant-related research (Goolsbee, 1998; Dagg, 2006; Romero-Jordan et al., 2014; Marino et al., 2016; Boeing, 2016), and tends to undermine grant efficacy. The lower risk of substitution arises because firms toward the top of the industry are more likely to have existing cash slack and stronger cash flows, so reducing the financial pressure to merely use grant money to substitute for existing innovation expenditure.

Second, dominant firms are more likely to have existing innovation capacity and processes to which grants can contribute to provide additional capability. Firms with inadequate existing R&D capabilities face high initial costs when they seek to commence innovation. This comes from the costs associated with recruiting new personnel forming new R&D teams, building new R&D facilities, and acquiring new technology for research. By contrast, firms with existing capabilities can dedicate additional grant funding to enhancing and expanding those capabilities, rather than bearing the high initial costs associated with establishing them. In addition, firms with strong R&D capabilities can also facilitate the transformation of innovation inputs to innovation outputs and productivity gains. Thus, market leaders are likely to gain more from grants than are other firms.

Third, dominant firms also have more direct financial incentives to increase R&D. Firms with limited market share might have limited avenues to promote and distribute new products. Thus, low market share firms face more difficulty recouping the large costs associated with innovation. However, firms at the top of the industry have established production and distribution channels. This provides more scope to recoup R&D costs and provides more incentive to invest in innovation. Dominant firms also face lower appropriability or imitation risks from rivals due to their market dominance, and so they can extract greater economic rents from their innovation investments. Thus, we make the following two hypotheses.

Hypothesis 1 Grants awarded to dominant firms (in terms of market share) generate higher innovation inputs (R&D, in-house R&D employees), innovation outputs (sales from new products, and employment) than other firms, including other grant-winning firms.

Hypothesis 2 R&D funded through grants produce a greater increase in productivity for dominant firms than other firms.

3. Data construction

This study uses data from the Department of Jobs, Enterprises, and Innovation (DJEI) in August 2014. The data come directly from the Survey Unit and consists of two parts. The first dataset provides details of all R&D grants provided by the two main

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industry development agencies, Enterprise Ireland, and the IDA, from 2003 to 2012, including the amount of grants approved and the amount that firms draw down. Enterprise Ireland provide funding to domestic firms, whereas the IDA support overseas and multinational firms planning to setup in Ireland. Grant applications are evaluated by an R&D committee, who consider factors such as firm financial performance, previous R&D subsidy track record (if any), if the grant is to fund a specific project, and technical feasibility (Research Fund reference document, EI 2014).[5]

The second dataset is from the Annual Business Survey of Economic Impact (ABSEI) and includes firms' financial information from 2000 to 2013. ABSEI is an annual survey of the client companies of EI, IDA Ireland, and other agencies that employ ten or more employees in Ireland. We merge this financial information with the firm's grant data using the firm identification number as coded by the agencies. The financial information includes the total number of employees, number of in-house R&D employees, sales, export sales, sales from new products, operating profit, and industry sector.

The sample composition by year is in Table 1. The sample contains more than 26,800 firm-year observations from 2003-2012, with approximately 2,700 firms per year, and represents a 60% response rate (DJEI).[6] Approximately one-third of the sample's firm-years report R&D expenditure. This R&D reporting-level is relatively consistent with that in prior studies (see e.g., Koh and Reeb, 2015). While firms that do not report R&D are often not engaging in precisely *zero* R&D, such firms do engage in economically significantly lower levels of R&D than do other firms, on average (Koh and Reeb, 2015). The number of firms reporting R&D increases (over time both in number and as a percentage of the sample) is consistent with improvements in reporting and/or increases in innovation activity. Table 1 also reports the data on grants and shows that 1,825 (1,806) were approved (paid) over the period. The number of grants paid and approved varies from year-to-year but does not exhibit a clear year-trend. The potential for year-by-year fluctuations implies the need to include year fixed effects in the regression models.

Table 2 gives a breakdown of the sample across industries and suggests some industries tend to be more likely to receive grants, especially those that are more export-orientated as this is reflected in government R&D grants policy. For example, the mostly highly represented industries are 'Computer Consultancy', 'Food, Drink, and Tobacco', and 'Business Services'. To mitigate the potential impact of industry clustering on our results, the baseline regression models include industry and year fixed effects. In the robustness Section 4.3.2 we also report our baseline models using a firm fixed-effects approach to better capture time-invariant 'within' effects.

Much work still needs to be done in terms of the measurement of innovation both on the input/activities and outcomes/output side, and this is reflected in the ongoing work of the OECD/Eurostat in updating the original Oslo Manual for measuring innovation (OECD, 1992: OECD/Eurostat, 1997; OECD/Eurostat, 2005; OECD/Eurostat, 2018). However, the reality is that researchers must use what is easier to measure (OECD/Eurostat, 2018). Following prior studies (e.g., Koh and Reeb, 2015), we measure innovation inputs using R&D expenditures. R&D expenditures capture both product and process innovation. Since we do not have patent

Table 1. Sample composition by year

Year	R&D Exp.	Freq.	Grant approval	Freq.	Grant paid	Freq.
2003	€1,199,074	704	€207,980	207	€114,575	159
2004	€1,118,398	751	€313,850	189	€115,918	170
2005	€1,187,492	859	€493,937	181	€207,609	165
2006	€1,366,176	925	€717,216	204	€279,246	203
2007	€1,505,476	1,058	€598,308	190	€291,768	211
2008	€1,546,154	1,178	€877,080	158	€407,984	174
2009	€1,464,285	1,307	€669,999	208	€371,903	220
2010	€1,476,311	1,424	€752,293	151	€415,533	165
2011	€1,442,168	1,624	€710,667	172	€399,294	171
2012	€1,504,568	1,660	€557,403	165	€326,166	168
Total	€13,810,102	11,490	€5,898,733	1825	€2,929,996	1,806
Average	€1,413,207	1,149	€579,454	182.5	€296,166	180.6

The table reports the total and distribution of average (mean) R&D expenditures, grants approved, and grants paid over the sample period. Average R&D expenditures are reported for only those firms that have R&D > 0.

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Table 2. Industry classification and concentration

	Sector			Summary of Herfindahl Index	
	Name	Frequency	%	Mean	Std Dev
1	Agriculture, fishing, forestry, mining and quarrying	230	0.86%	0.30162	0.08122
2	Food, drink, and tobacco	2,560	9.53%	0.06267	0.01578
3	Textiles, clothing & footwear and leather	560	2.08%	0.06690	0.00361
4	Wood and wood products	370	1.38%	0.08290	0.01134
5	Paper and printing	640	2.38%	0.06142	0.02689
6	Chemicals	1,480	5.51%	0.18674	0.04047
7	Rubber and plastics	900	3.35%	0.08335	0.00491
8	Non-metallic minerals	490	1.82%	0.33760	0.10077
9	Basic and fabricated metal products	1,710	6.36%	0.09624	0.01887
10	Computer, electronic and optical products	1,310	4.87%	0.20903	0.02715
11	Electrical equipment	750	2.79%	0.08741	0.01316
12	Machinery and equipment	1,190	4.43%	0.07017	0.01190
13	Transport equipment	280	1.04%	0.26583	0.07846
14	Medical device manufacturing	650	2.42%	0.11198	0.03101
15	Other misc manufacturing	810	3.01%	0.05633	0.00476
16	Construction, energy, water & wastes	1,413	5.26%	0.21780	0.08249
17	Publishing, broadcasting, and telecommunications	1,020	3.80%	0.11394	0.05907
18	Computer programming	1,200	4.47%	0.25543	0.04446
19	Computer consultancy	3,280	12.21%	0.50947	0.19743
20	Computer facilities management	570	2.12%	0.16447	0.01259
21	Other IT & computer services	1,410	5.25%	0.31874	0.17010
22	Financial services	560	2.08%	0.15188	0.04158
23	Business services	2,080	7.74%	0.11762	0.05339
24	Education	580	2.16%	0.12190	0.02761
25	Other services	830	3.09%	0.26416	0.08412
	Total	26,873	100%	0.19346	0.16708

This table reports a list of 25 sectors that are classified by DJEI and their corresponding frequency in the data. The last two columns are the summary of Herfindahl index for 25 sectors, calculated using available data.

data for our sample firms, we measure innovation outputs as sales from new products, which meet the fundamental requirement of the OECD definition of innovation for national accounting purposes, which stipulates that an innovation must have been 'implemented' or introduced on the market (OECD/Eurostat, 2005, paragraph 150). Patent data do not necessarily fulfil this commercially relevant requirement in that not all innovations are 'patentable' and not all patented inventions become innovations (Coad and Rao, 2008). However, a weakness is that firms in the survey were not asked to specifically consider the value of sales from new processes. Given the importance of employment outcomes in the assessment of government innovation policy initiatives (OECD/Eurostat, 2018) we have included overall employment, R&D employment, and productivity as key outcome variables.

4. Model and results

We first analyze whether grants are associated with an increase in innovation outcomes for all groups of firms. We then analyze whether grants deliver better innovation outcomes for firms that have a greater market share. We test the impact of grants using a baseline regression model of the following form:

$$Y_{i,t+1} = \alpha + \beta_1 Grant\ recipient_{i,t} + \beta_2 Prior\ grant\ recipient_{i,t} + \beta_3 Domestic_{i,t} + \beta_4 Profit\ margin_{i,t} + \beta_5 Ln\ Employment_{i,t} + \beta_6 Inhouse\ R\&D\ capability_{i,t} + \beta_7 Export\ intensity_{i,t} + \beta_8 Market\ share_{i,t} + \beta_{10} Industry\ R\&D_{i,t} + \beta_{11} HHI_{i,t} + \beta_{12} HHI^2_{i,t} + \delta + \gamma + \varepsilon_{i,t} \quad (1)$$

For the innovation input models, the dependent variables are the natural log of R&D expenditure and R&D growth. For the innovation output model,

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the dependent variable is the natural log of sales from new products. In addition, for the innovation output model, we also control for R&D expenditures to capture the transformation of innovation inputs into innovation outputs. For the employment model, we use two dependent variables, which are the natural log of total employees and the log of in-house R&D employees. To test hypothesis 2, we use a model with the natural log of a firm's productivity as the dependent variable. Productivity is defined as profit before tax scaled by the number of employees.

The key independent variable 'Grant recipient' is a dummy variable, equal to 1 if the firm draws down the grant in year t, and 0 otherwise. We also use natural log of the actual grant Euro value drawn down (Ln Grant paid).[7] The remaining explanatory or control variables capture factors predicted to impact firm innovation and future R&D expenditure. Specifically, if a firm previously won a grant ('Prior grant recipient') this may continue to influence future R&D spending. Further, profitable firms ('Profit margin'), larger firms ('Ln Employment'), those with greater in-house R&D capability ('In house R&D capability'), export intensity ('Export intensity'), and dominance, defined as industry market share ('Market share') are expected to invest more in innovation through greater R&D expenditures. We also control for industry innovation by including industry R&D intensity, ('Industry R&D') to capture possible spillover effects (Jones, 1995; Sorensen, 2006) on next period firm-level R&D.

We include a dummy variable to control for domestic firms, equal to one if the firm is Irish domiciled, and zero otherwise. Firms that are not Irish domiciled are multinational. The dummy variable also captures (albeit indirectly) the source of funding if domestic firms are funded by EI, and overseas or multinational domiciled are only supported by IDA. Lastly, we control for industry level competition by including the Herfindahl-Hirschman index ('HHI' and 'HHI^2'), with the squared measure capturing any non-linearity (Luong et al., 2014). As highlighted in Section 2.3, some prior work reports a correlation between industry competition and innovativeness, with some suggesting a positive relation (Aghion et al., 2001; Aghion and Howitt, 2009), while more seminal work (Schumpeter, 1934, 1942) reporting a negative relation. δ and λ represent industry and year fixed effects, respectively, and ε_i are robust-clustered (firm level) error terms. For details of variable descriptions, see Appendix A.

To help address possible selection bias and endogeneity concerns, we employ propensity score matching or PSM (following Berube and Mohnen, 2009; Girma et al., 2010; Bozio et al., 2014). While we could have adopted other methods to improve our identification strategy (e.g., Entropy Balancing; Heckman 2-stage), PSM appears to be one of the more common methods used based on recent prior literature (e.g., Li et al., 2020; Dai et al., 2020). On the positive side, PSM allows us to examine and report factors that relate to the likelihood of winning a grant (see Appendix Table B1), which provides some additional information on factors government agencies use to determine grant success.[8]

PSM involves matching firms that win and drawdown grants with 'similar' firms that do not receive grants in the same year using observable firm characteristics. The propensity score is an index of all covariates that can affect the selection of grant recipient firms. In each year, we separate firms into 'treatment' and 'control' groups. The treatment group consists of all firms that benefited from government grants, and the control group consists of all remaining firms. For details of the PSM procedure, and the results of the estimated probit model, see Appendix B.

4.1. Summary statistics

Descriptive statistics and bivariate analysis for the full sample are reported in Table 3. Panel A presents summary statistics of key variables used in our models. Appendix A contains details on how these variables are constructed. Panel B presents bivariate analysis for grant recipients and non-grant recipients, and Panel C presents a bivariate analysis for top and bottom firms to better capture dominance in terms of industry market share. Top (Bottom) is equal to one if the firm's industry market share is within the top (bottom) 30% of industry market share distribution, and zero otherwise.

On average, 6.8% of firms in our sample win grants from the Irish government over the period 2003–2012 (Panel A), which demonstrates the competitiveness of government direct funding. Grant recipients have significantly higher R&D expenditure, in-house R&D capability, export intensity, and productivity than other firms, as shown in Panel B. This is in line with our expectation that the government 'cherry-picks' grant winners based on their relative performance. Panel C indicates that top firms in terms of market share are more likely to win grants than are bottom firms, and they also win larger grants than do bottom firms, as measured by Ln Grant approval. Top firms are also more productive, more profitable, and more export and R&D intensive than bottom firms. This is in line with our prediction that top firms will likely deliver greater innovation

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Table 3. Descriptive statistics

Panel A: Summary statistics

Variables	Obs.	Mean	Std. Dev.
I (Grant recipient)	26,873	0.067	0.250
I (Grant winner)	26,873	0.068	0.252
Ln (Grant paid)	26,873	0.320	1.228
Ln (Grant approval)	26,873	0.346	1.311
Ln R&D	18,942	3.251	2.933
Profit margin	17,343	–0.162	1.378
Export Intensity	17,343	0.511	0.402
Domestic	26,170	0.774	0.418
Market share	26,230	0.010	0.039
I (Top firm)	26,230	0.285	0.451
I (Bottom firm)	26,230	0.145	0.352
Ln Employment	17,908	3.564	1.387
Ln In-house R&D employees	10,444	1.348	1.203
In-house R&D capability	17,900	0.131	0.244
Ln new product sales	5,001	2.750	3.171
Ln productivity	11,300	3.081	1.738
Industry R&D	26,873	0.027	0.043
HHI	26,873	0.194	0.167
R&D growth	9,724	0.221	1.074

Panel B: Bivariate analysis for winners versus other firms

Variables	Grant recipients (1)	Non-grant recipients (2)	Diff (1)-(2)
I (Prior grant winner)	0.658	0.158	0.500***
Ln R&D	5.955	3.064	2.892***
R&D growth	0.298	0.212	0.086**
Profit margin	–0.195	–0.160	–0.035
Export intensity	0.654	0.501	0.153***
Domestic	0.698	0.778	–0.080***
I (Top firm)	0.457	0.276	0.181***
I (Bottom firm)	0.067	0.149	–0.082***
Ln Employment	3.995	3.533	0.463***
Ln In-house R&D employees	1.993	1.270	0.723***
In-house R&D capability	0.238	0.123	0.116***
Ln new product sales	2.900	2.742	0.158
Ln productivity	3.173	3.074	0.099**
Industry R&D	0.029	0.027	0.002***
HHI	0.210	0.192	0.018***

Panel C: Bivariate analysis for top firms and bottom firms (in terms of market share)

Variables	Top firms (1)	Bottom firms (2)	Diff (1)-(2)
I (Grant recipient)	0.081	0.023	0.058***
I (Grant winner)	0.080	0.023	0.057***
Ln (Grant paid)	0.409	0.103	0.305***
Ln (Grant approval)	0.436	0.109	0.326***
Ln R&D	3.923	2.215	1.708***
R&D growth	0.190	0.298	–0.108**

(Continues)

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Table 3. (Continued)

Panel C: Bivariate analysis for top firms and bottom firms (in terms of market share)

Variables	Top firms (1)	Bottom firms (2)	Diff (1)-(2)
Profit margin	0.097	−1.063	1.159***
Export intensity	0.603	0.401	0.202***
Domestic	0.610	0.881	−0.271***
Ln employment	4.509	2.203	2.307***
Ln In-house R&D employees	1.789	0.883	0.905***
In-house R&D capability	0.082	0.238	−0.156***
Ln new product sales	2.724	2.191	0.533***
Ln productivity	3.529	2.391	1.138***
Industry R&D	0.028	0.030	−0.002***
HHI	0.188	0.179	0.008**

Panel A of this table reports summary statistics of key variables in our models. Panel B reports bivariate statistics comparing differences in characteristics between grant recipients and non-grant recipients. Non-grant recipients include firms who applied for grants but failed, and firms who did not apply for grants. Panel C reports bivariate statistics for firms at the top 30% and bottom 30% of the industry in terms of market share. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively. All continuous variables are winsorized at 1% level.

outcomes from government funding than bottom firms, who are more likely to substitute private R&D with government funding rather than increasing it.

4.2. Grants and R&D outcomes

Table 4 reports the baseline regression results. Here, we look at the relationship between winning a grant and R&D investment. In general, the results support the hypothesis that grants promote greater innovation inputs in R&D. In Panel A, the key variable of interest is the grant recipient dummy, which is positive and significant for all models confirming the prediction that grant recipients have larger future R&D expenditures over the 3 years after drawing down the grant. Grant recipients also experience significantly greater growth in R&D spending, growing R&D by 15% relative to 'similar' non-winning firms.

The dummy variable 'Prior grant recipient' is positive and statistically significant in the first four models, indicating that winning grants in the past can also facilitate increases in future R&D. However, experience in receiving grants in the past is not correlated with R&D growth (model 5), indicating that first-time grant recipients are generating higher R&D growth than second-time grant recipients. In other words, firms will substantially increase R&D in the first year after winning. After that, growth in R&D declines. Domestic (and EI funded) firms and those firms that have greater market share also appear to invest more in R&D.

Several other factors drive R&D spending. From Columns 1-4, R&D spending is significantly higher for larger firms, firms with greater inhouse R&D capabilities, and more export intensive firms. This is consistent with expectations. However, we have contrasting results when looking at R&D growth rates. Larger firms, and those with greater internal R&D capability experience lower *growth* in spending indicating a possible scale or size effect. This implies that while larger firms might spend more on R&D, they grow this expenditure at a relatively lower rate.

In Panel B of Table 4, we look at the natural log of the grant size in Euros that the government has paid to the firm. The results suggest that firms receiving larger grants deliver greater increases in R&D spending and growth, consistent with Panel A. In economic terms, a €1 increase in grants delivers a €1.41 per euro won relative to similar non-winning firms, suggesting that winners more than match public spending euro for euro.[9] The other results are consistent with those reported in Panel A and support prior literature on the returns to R&D grants.

4.3. Moderating role for dominant firms

To test hypothesis 1, we include interaction terms between the grant outcome variable (i.e., recipient, non-recipient) and a firm's relative market share position in the industry (i.e., top, middle, and bottom). This gives us six possible interactions two outcomes and three relative positions. To avoid the dummy variable trap, we exclude the 'non-recipient × middle firm' interaction term. This allows us then to compare all combinations with non-grant recipient middle firms, and with each other.[10]

First, we compare the impact of grants on innovation inputs and outputs for the three groups of firms. The results are in Table 5. Grants awarded to dominant firms deliver a significantly greater

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Table 4. Baseline PSM models for grants on R&D investment

Panel A: Grant dummy

	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D avg	R&D growth
Variables	(1)	(2)	(3)	(4)	(5)
Grant recipient dummy	0.755***	0.925***	1.083***	0.753***	0.150***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Prior grant recipient	0.660***	0.757***	0.988***	0.803***	−0.076
	(0.000)	(0.000)	(0.000)	(0.000)	(0.135)
Profit margin	−0.016	−0.013	−0.043	−0.053	−0.026**
	(0.722)	(0.844)	(0.558)	(0.301)	(0.023)
Ln Employment	1.310***	1.242***	1.296***	1.181***	−0.073***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)
In-house R&D capability	5.873***	5.600***	4.936***	5.045***	−0.451***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)
Export intensity	0.848***	0.699**	1.022***	0.782***	0.068
	(0.001)	(0.023)	(0.002)	(0.001)	(0.312)
Domestic	1.423***	1.321***	2.309***	1.265***	−0.020
	(0.000)	(0.000)	(0.000)	(0.000)	(0.774)
Market share	0.567	2.980**	5.583***	3.759***	0.483
	(0.787)	(0.044)	(0.003)	(0.006)	(0.229)
Industry R&D	3.888	10.117	14.438	14.789	−3.052
	(0.505)	(0.622)	(0.415)	(0.279)	(0.214)
HHI	−1.892	0.854	−1.617	−0.909	0.749
	(0.668)	(0.872)	(0.807)	(0.847)	(0.517)
HHI^2	1.901	−1.684	1.836	0.281	−0.543
	(0.695)	(0.779)	(0.811)	(0.959)	(0.678)
Constant	5.271***	5.148***	4.037***	1.757	0.596
	(0.000)	(0.000)	(0.010)	(0.338)	(0.206)
Observations	2,086	1,811	1,557	1,548	1,952
R-squared	0.386	0.340	0.336	0.402	0.037
F-statistic	15.857***	14.242***	12.065***	14.199***	1.610***

Panel B: Grant size

	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D avg	R&D growth
Variables	(1)	(2)	(3)	(4)	(5)
Ln (grant paid)	0.073***	0.087***	0.098***	0.070***	0.013***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Prior grant recipient	0.665***	0.763***	0.999***	0.809***	−0.074
	(0.000)	(0.000)	(0.000)	(0.000)	(0.142)
Profit margin	−0.016	−0.012	−0.042	−0.053	−0.026**
	(0.720)	(0.852)	(0.567)	(0.308)	(0.023)
Ln Employment	1.298***	1.226***	1.277***	1.168***	−0.076***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)
In-house R&D capability	5.825***	5.542***	4.871***	5.000***	−0.459***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)
Export intensity	0.846***	0.698**	1.018***	0.780***	0.067
	(0.001)	(0.023)	(0.002)	(0.001)	(0.319)

(Continues)

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Table 4. (Continued)

Panel B: Grant size

	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D avg	R&D growth
Variables	(1)	(2)	(3)	(4)	(5)
Domestic	1.403***	1.291***	2.274***	1.239***	−0.024
	(0.000)	(0.000)	(0.000)	(0.000)	(0.735)
Market share	0.454	2.848*	5.445***	3.650***	0.468
	(0.828)	(0.054)	(0.003)	(0.007)	(0.244)
Industry R&D	3.814	10.020	14.381	14.718	−3.065
	(0.512)	(0.624)	(0.415)	(0.279)	(0.211)
HHI	−1.959	0.731	−1.735	−0.984	0.730
	(0.655)	(0.890)	(0.793)	(0.834)	(0.527)
HHI^2	1.979	−1.538	1.984	0.376	−0.522
	(0.682)	(0.798)	(0.796)	(0.945)	(0.689)
Constant	5.290***	5.207***	4.154***	1.873	0.608
	(0.000)	(0.000)	(0.008)	(0.306)	(0.196)
Observations	2,086	1,811	1,557	1,548	1,952
R-squared	0.389	0.344	0.339	0.405	0.037
F-statistic	16.075	14.489	12.088	14.238	1.659

This table reports PSM models on the relation between grant paid on R&D expenditures. Panel A use a dummy independent variable, equals to 1 if the firm withdraws any grant in year t, 0 otherwise. Panel B use the log of grant paid as independent variable. The dependent variable is the log of a firm's R&D in year t + 1, year t + 2, and year t + 3 after receiving the grant, and log of the average R&D over the 3 years post winning. All independent variables are measured in the current year (t). Control variables include: prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Profit Margin is operating profit scaled by sales, Ln Employment is the natural log of the firm's total number of employees, In house R&D capability is the proportion of in-house R&D employees to total employees, Export Intensity is total exports scaled by sales, Domestic is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise, market share is calculated using sales scaled by industry total sales. Industry R&D is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively. All models control for industry and year fixed effects (untabulated). All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

increase in R&D expenditure and growth than non-grant middle firms (missing interaction), and all other categories, including grant recipients from the bottom and middle of the industry. This provides some support for hypothesis 1. Noteworthy is the difference in coefficients between the bottom firms who receive grants (recipient × bottom firm) and bottom firms who do not receive grants (non-recipient × bottom firm). While the latter perform significantly worse in terms of R&D compared to the average firm from the middle group, (no grants), those bottom firms who receive grants mostly perform no differently from the average firm. This suggests that when a bottom firm, or laggard, receives a grant, it allows the firm to at least keep pace with the average firm.

Table 5 also reports (model 6) the impact on innovation outputs (i.e., sales from new products) for grant recipients and non-grant recipients with different market shares. The results suggest that while dominant firms increase innovation inputs, this does not lead to greater innovation outputs in the form of new product sales the following year.[11]

Table 6 examines the impact of grants on employment (both total employment and in-house R&D employment), conditioning on the firm's market position. We show that dominant firms (after receiving a grant) significantly increase their employment levels, while the other two groups (middle and bottom firms) either shows no significant increase or a decrease (for bottom). Of the three groups, only middle and bottom show a significant increase in the number of in-house R&D employees relative to non-winning average middle firms, signaling the effective use of government grants on strengthening in-house R&D capability.

In addition, the differences in variable coefficients suggest that bottom firms who receive grants increase the number of in-house R&D employees at the highest rate among the three groups of grant recipients, despite a decrease in overall employment. This provides some support for a 'catch up' effect for bottom firms who receive grants. We also show that non-grant winning dominant firms also increase the total number of employees, relative to the average firm (non-winning middle). However, compared

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Table 5. Grants, R&D, and innovation outputs: moderating role of a firm's market position using PSM

Variables	Ln R&D t + 1 (1)	Ln R&D t + 2 (2)	Ln R&D t + 3 (3)	Ln R&D 3 yr avg (4)	R&D growth (5)	New product sales t + 1 (6)
Recipient × Top firm	0.556***	0.615***	0.605***	0.585***	0.256***	−0.186
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.678)
Recipient × Middle firm	0.392***	0.378***	0.487***	0.390***	0.198***	−0.321
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.339)
Recipient × Bottom firm	−0.283	−0.725*	−0.069	−0.386	0.222	0.002
	(0.301)	(0.078)	(0.893)	(0.318)	(0.176)	(0.998)
Non-recipient × Top firm	0.454***	0.366***	0.233	0.370***	0.103	−0.015
	(0.000)	(0.006)	(0.145)	(0.002)	(0.124)	(0.971)
Non-recipient × Bottom firm	−1.353***	−1.366***	−1.012**	−1.336***	−0.102	−1.454***
	(0.000)	(0.000)	(0.021)	(0.000)	(0.545)	(0.009)
Prior grant recipient	0.251***	0.295***	0.322***	0.258***	0.028	0.215
	(0.001)	(0.001)	(0.002)	(0.001)	(0.504)	(0.388)
Profit margin	−0.062**	−0.106***	−0.065*	−0.104***	−0.040**	0.106
	(0.018)	(0.001)	(0.080)	(0.000)	(0.011)	(0.281)
Ln Employment	0.856***	0.857***	0.917***	0.847***	−0.088***	0.058
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.729)
In-house R&D capability	3.580***	3.472***	2.857***	3.038***	−0.339***	0.226
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.744)
Export intensity	0.650***	0.560***	0.819***	0.613***	−0.007	0.293
	(0.000)	(0.000)	(0.000)	(0.000)	(0.913)	(0.451)
Domestic	0.412***	0.378***	0.649***	0.295**	0.028	5.326***
	(0.000)	(0.003)	(0.000)	(0.011)	(0.653)	(0.000)
Industry R&D	−2.006	−7.011	1.736	1.498	−3.482	0.674
	(0.589)	(0.263)	(0.855)	(0.834)	(0.103)	(0.967)
HHI	−1.352	0.013	−1.465	−2.100	0.163	−36.391
	(0.482)	(0.996)	(0.645)	(0.381)	(0.887)	(0.328)

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Table 5. (Continued)

Variables	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D 3 yr avg	R&D growth	New product sales t + 1
	(1)	(2)	(3)	(4)	(5)	(6)
HHI^2	1.232	−0.263	0.962	1.860	−0.178	108.923
	(0.577)	0.925)	(0.799)	(0.514)	(0.892)	(0.292)
Ln R&D						0.154
						(0.120)
Constant	−0.737	0.039	−3.838**	1.019	0.398	1.319
	(0.230)	(0.958)	(0.035)	(0.175)	(0.291)	(0.738)
Observations	2,086	1,811	1,563	1,550	1,953	511
R-squared	0.581	0.525	0.466	0.590	0.043	0.537
F-statistic	61.543***	43.284***	30.083***	49.153***	1.873***	13.997***

This table reports moderating role of a firm's position on the relationship between grants and future R&D or innovation output using PSM. Dependent variables (model 1-4) are the log of R&D in year t + 12, t + 2, t + 3, and log of average R&D over the 3 years post winning. Model 5 uses R&D growth in year t + 1 as dependent variable Model 6 uses Ln (new product sales) in year t + 1 as dependent variable. Key interaction variables are interactions between Recipient (Non-recipient) is dummy, equals to 1 if the firm withdraws (or not) any grant in year t, 0 otherwise; Top firm, middle firm and bottom firm indicators are dummy variables equal to 1 if the firm's market share ranks within the top 30%, middle 40% and bottom 30% of their industry market share, where market share is calculated using sales. Independent variables are measured in the current year (t). Control variables include: Prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Profit Margin is operating profit scaled by sales, Ln Employment is the natural log of the firm's total number of employees, In house R&D capability is the proportion of in-house R&D employees to total employees, Export Intensity is total exports scaled by sales, Domestic is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise. Industry R&D is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively. All models control for industry and year fixed effects (untabulated). All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

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Table 6. Grants and employment: moderating role of a firm's market position using PSM

	Ln Employment 3-year avg	Ln Inhouse R&D employees 3-year avg
Variables	(1)	(2)
Recipient × Top firm	1.020***	0.027
	(0.000)	(0.722)
Recipient × Middle firm	−0.045	0.184***
	(0.391)	(0.004)
Recipient × Bottom firm	−0.339*	0.414*
	(0.076)	(0.101)
Non-recipient × Top firm	0.930***	−0.236***
	(0.000)	(0.001)
Non-recipient × Bottom firm	−0.358**	0.190
	(0.011)	(0.486)
Prior grant recipient	0.061	0.151***
	(0.122)	(0.001)
Ln R&D	0.248***	0.341***
	(0.000)	(0.000)
Profit margin	−0.026*	−0.032*
	(0.080)	(0.063)
Inhouse R&D capability	−1.705***	
	(0.000)	
Ln Employment		0.364***
		(0.000)
Export intensity	−0.125**	0.299***
	(0.031)	(0.000)
Domestic	−0.618***	0.207***
	(0.000)	(0.004)
Industry R&D	0.377	−2.254
	(0.897)	(0.599)
HHI	−2.384**	0.163
	(0.033)	(0.911)
HHI^2	3.545***	−0.430
	(0.006)	(0.804)
Constant	2.338***	−1.870***
	(0.002)	(0.000)
Observations	1,799	1,450
R-squared	0.740	0.685
F-statistic	110.845***	71.122***

This table reports moderating role of a firm's position on the relationship between grants and future employment/in-house R&D employment using PSM. Dependent variable in model 1 is the log of average number of employees over the 3 years post winning. Dependent variable in model 2 is the log of average number of in-house R&D employees over the 3-year post winning. Key interaction variables are interactions between Recipient (Non-recipient) is dummy, equals to 1 if the firm withdraws (or not) any grant in year t, 0 otherwise; Top firm, middle firm and bottom firm indicators are dummy variables equal to 1 if the firm's market share ranks within the top 30%, middle 40% and bottom 30% of their industry market share, where market share is calculated using sales. Independent variables are measured in the current year (t). Control variables include: Prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Profit Margin is operating profit scaled by sales, Ln Employment is the natural log of the firm's total number of employees, In house R&D capability is the proportion of in-house R&D employees to total employees, Export Intensity is total exports scaled by sales, Domestic is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise. Industry R&D is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively. All models control for industry and year fixed effects (untabulated). All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

to grant recipient dominant firms, they experience a significant decrease in the number of future in-house R&D employees, which further indicates the impact of grants in stimulating future investment in in-house R&D employees.

Table 7 examines the moderating impact of a firm's market position on the relationship between grant-backed R&D and future productivity (Hypothesis 2). The results show that for dominant firms with or without government funding support, R&D results

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Table 7. Grant, R&D and future productivity: moderating impact of a firm's market position using PSM

Variables	Ln productivity t + 1 (1)	Ln productivity t + 2 (2)	Ln productivity t + 3 (3)	Ln productivity 3-year avg (4)
Ln R&D × Recipient × Top firm	0.197***	0.192***	0.173***	0.181***
	(0.000)	(0.000)	(0.000)	(0.000)
Ln R&D × Recipient × Middle firm	−0.004	−0.002	−0.037	−0.003
	(0.849)	(0.920)	(0.162)	(0.897)
Ln R&D × Recipient × Bottom firm	−0.038	0.133	−0.274	−0.256
	(0.691)	(0.445)	(0.106)	(0.370)
Ln R&D × Non-recipient × Top firm	0.205***	0.210***	0.172***	0.194***
	(0.000)	(0.000)	(0.000)	(0.000)
Ln R&D × Non-recipient × Bottom firm	0.155	−0.034	0.051	0.157
	(0.149)	(0.759)	(0.807)	(0.379)
Prior grant recipient	0.015	0.016	0.012	−0.062
	(0.873)	(0.871)	(0.909)	(0.559)
Ln Employment	−0.362***	−0.318***	−0.359***	−0.317***
	(0.000)	(0.000)	(0.000)	(0.000)
Inhouse R&D capability	−0.267	−0.613**	−0.658**	−0.746**
	(0.274)	(0.024)	(0.023)	(0.011)
Export intensity	0.573***	0.557***	0.584***	0.532***
	(0.000)	(0.000)	(0.000)	(0.001)
Domestic	−0.809***	−0.769***	−0.885***	−0.903***
	(0.000)	(0.000)	(0.000)	(0.000)
Industry R&D	2.805	1.565	21.422**	14.532
	(0.518)	(0.830)	(0.027)	(0.117)
HHI	−3.885	−5.260*	−7.483**	−7.459**
	(0.114)	(0.069)	(0.027)	(0.022)
HHI^2	4.512	6.447*	8.260**	8.956**
	(0.111)	(0.057)	(0.041)	(0.022)
Constant	4.158***	3.717***	4.800***	6.716***
	(0.000)	(0.001)	(0.000)	(0.000)
Observations	1,403	1,199	1,050	1,037
R-squared	0.282	0.293	0.270	0.301
F-statistic	12.010***	10.855***	8.855***	10.181***

This table reports moderating role of a firm's position on the relationship between R&D backed by grants or (non-grants) and productivity using PSM. Dependent variables in model 1-4 are the log of productivity in year t + 1, t + 2, t + 3 and the log of average productivity over the 3 years post winning. Productivity is calculated as net profit before tax scaled by number of employees. Key interaction variables are interactions between Ln R&D and Recipient (Non-recipient) is dummy, equals to 1 if the firm withdraws (or not) any grant in year t, 0 otherwise; Top firm, middle firm and bottom firm indicators are dummy variables equal to 1 if the firm's market share ranks within the top 30%, middle 40% and bottom 30% of their industry market share, where market share is calculated using sales. Independent variables are measured in the current year (t). Control variables include: Prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Ln Employment is the natural log of the firm's total number of employees, In house R&D capability is the proportion of in-house R&D employees to total employees, Export Intensity is total exports scaled by sales, Domestic is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise. Industry R&D is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively. All models control for industry and year fixed effects (untabulated). All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

in the highest and most significant increase in future productivity relative to the average non-winning firm. However, the absence of any incremental effect on future productivity for grant winning dominant firms versus non-winning dominant firms suggests that grant monies might be used for other non-R&D purposes.

The other interaction terms are insignificant suggesting that grants won by middle and bottom firms have no impact on future productivity. The control variables have the expected signs, including a negative relation with the number of employees and in-house R&D employees, as larger

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values for these variables would reduce productivity ratios. Interestingly, we find some evidence of a knowledge spillover effect in later years (year 3), suggesting that industry-specific knowledge from R&D spending positively influences future productivity rates (Audretsch and Belitski, 2020). Not surprisingly, firms that are more export intensive, and multinational, experience significantly greater productivity across all years.

4.4. Robustness checks

4.4.1. Subsample analysis

To better examine the impact of grant size on innovation inputs, we use a subsample of grant winning firms only, and re-estimate our models using this subsample. The results in Appendix C (Table C3) confirm that larger grants result in greater future R&D investment, and bottom firms appear to win most. Further, larger grants increase innovation outputs for bottom firms in terms of new product sales. Similar analysis on the impact of grant size on employment and productivity is estimated. Results (untabulated) confirm that larger grants lead to a greater increase in the level of total employment, and in-house R&D employment.

4.4.2. Unobserved fixed effects, simultaneity, and causality

We first examine if the results are robust to controlling for unobserved firm ('within') fixed effects. The regression models reported in our main analysis include industry and year fixed effects. This is appropriate because many firms in the full sample never win a grant, so the grant indicator does not change over time for these firms. Nevertheless, we check that all baseline model results hold when we control for firm-fixed effects and find that they do (Table C4 in the appendix). We also expand on the models estimated by including a new specification that scales R&D expenditures by sales (Table C4, models 6 and 7). We show that the findings are consistent.

Some prior work (e.g., Gorodnichenko and Schnitzer, 2013; Hadhri et al., 2016; Ayalew et al., 2020) suggests that export intensity and innovation outcomes (R&D, new product sales) might be simultaneously determined, giving rise to an endogeneity concern. To address this issue, we remove export intensity from the regression models and show in untabulated results no significant impact on the reported regression models, in particular the significance and size of our key variable of interest, grants won and interactions with dominance. This is not surprising as in Table B1 in the appendix we show that export intensity does not significantly drive grant selection. Lastly, we further address the causality issue by using a 'placebo' test (Erel et al., 2015). The details of this test and the models estimated are reported in Table C5 in the appendix.

5. Discussion and conclusions

The paper examines if government funded innovation initiatives result in improvements in firm innovation inputs (R&D), outputs (new products), employment and future productivity for different groups of firms. The results show that government agencies discriminate when allocating R&D grants. Winning firms' characteristics fit well with awarding agencies' publicized evaluation strategies. This suggests that grant agencies can, and do, target grants based on firms' perceived capabilities, project fit, and feasibility.

The baseline results confirm prior work (e.g., Coad and Rao, 2008; Zuniga-Vicente et al., 2014). We show that grants encourage recipients to increase innovation-related expenditure, as captured by increased future R&D spending. Larger firms, and those with greater market share, R&D capabilities, and an export focus, also deliver greater increases in R&D spending, suggesting that agencies' *ex-ante* targeted strategies are more likely to deliver better innovation outcomes.

Should governments allocate grants to dominant firms? The key findings in our paper suggest that the impact of grants on future innovation performance is *conditional* on the firm's market position. Grants awarded to top firms deliver a significantly greater increase in R&D expenditures, R&D growth, and total employment relative to other firms. This has an important government policy implication as it provides important feedback to funding authorities that the impact of government funding is not the same for all groups of firms within an industry. Apart from the average impact of funding, governments or the funding authorities should be able to determine for which types of firms the funding is most effective.

We show that the Irish government awarding agencies tend to give funding to firms who are 'average' in their industry in terms of market share (i.e., middle firms), which is shown by a significantly higher probability of winning government grants for middle firms (see Appendix B, Table B1). However, among grant recipients, firms at the top of the industry have the highest increase

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in R&D spending, R&D growth, and total employment among the three groups.

Noteworthy though, is that while top winning firms deliver greater productivity than the average non-winning firm, they do not perform any better than similar top firms who do not win. This echoes findings from a recent study by Audretsch and Belitski (2020), who show that while R&D is an important factor for innovation and productivity, it is less important for productivity than knowledge spillovers. Clearly, if the objective is to increase future productivity, awarding grants to top firms is unlikely to achieve this.

Further, from a managerial perspective, it also suggests that managers of dominant firms may use their grants to pursue their own strategic objectives to retain market share, rather than the productivity-increasing objectives sought by government agencies. Although R&D activity is typically human captain intensive, managers of dominant firms do not appear to use grant winnings to employ additional R&D personal, suggesting they already have significant R&D capacity.

Lastly, we show that among grant recipients, middle and bottom firms appear to focus more on building their in-house R&D teams to increase internal innovation capability. This 'catch up' effect displayed by these firms is interesting, and noteworthy for funding agencies about how each type of firm spends their grant monies. It also provides support for the provision of targeted grants to smaller firms and start-ups to mitigate barriers to scale in accessing innovation grants. This explains why the European Innovation Council and SMEs Executive Agency (EISMEA) has been allocated a budget allocation of €10.1 billion to finance breakthrough innovations from laboratory to market start-ups and SMEs across Europe (European Commission, 2020). At a local level, Enterprise Ireland has a set of instruments to support innovative SMEs by stage of development, including the High Potential Start-Up (HPSU) scheme, Exploring Innovation Grant; The Agile Innovation Fund; The Research and Development (R&D) Fund; and The Intellectual Property (IP) Strategy.[12]

The research has several limitations, and this is largely due to the use of survey data that do not report more detailed information on factors that might influence innovation outcomes. It also impacts on research design and the availability of acceptable instrumental variables to better address sample selection issues. Importantly, the data do not contain information on process innovation. The digital transformation of society has facilitated process innovation across all business activities. OECD/Eurostat definition of process innovation incorporate improvements in marketing and managerial functions, distribution and logistics, information and communication systems, and product and business process development forms of innovation. The challenge for researchers is finding usable measures to match these increasingly complex definitions.

Firm governance is also likely to be an important driver of future innovation outcomes, but unfortunately board and ownership-type variables are not reported in the survey. Future research could examine models that capture these additional factors. More importantly, the identification strategy in fully establishing causality is challenging, but this could be addressed if survey datasets contained information on firms who applied for grants but did not win. This would provide a useful control sample to better establish causality. Nevertheless, our evidence shows that the impact of grants on future innovation outcomes and performance largely depends on the firm's position within its market, which could form a useful input to government agencies when developing models to select optimal winners.

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Notes

[1] Market failures can also cause overinvestment, e.g., with firms engaging in the first to patent innovation races, which can lead to duplication and inefficiency (Steger, 2005; Montmartin and Massard, 2014).

[2] See Zuniga-Vicente et al. (2014) for a review, and Yigitcanlar et al. (2018) for a broader range of funding sources.

[3] The term 'cash windfall' may seem overly ambitious, but the average grant approved during our sample period is €579,454, and average R&D is €1,413,207, so grants are just over 40% suggesting that managers are likely to regard them as a windfall.

[4] See e.g., Hall et al. (2009), and Mohnen and Hall (2013).

[5] For details on the application and evaluation process, see: https://www.enterprise-ireland.com/en/Research-Innovation/Companies/R-D-Funding/Funding-for-independant-and-collaborative-R-D.html

[6] Relative to the population of Irish firms, our sample of 2,700 per year captures about 41% of firms based on 2-digit NACE or 6,607 firms, which excludes Education and Financial Services in 2012. Including Education and Financial Services, the sample reflects about 16% of the population.

[7] Differences in the value of the grant awarded and drawn down can occur for several reasons. For example, consistent with agencies actively monitoring winners, larger grants are typically paid in installments, with future payments conditional on the firm reaching performance targets for the funded project. Further, firms may decide to exercise real options, e.g., abandon the project, in which case the grant approved will be greater than the actual amount drawn down, or delay investment, so the grant is drawn down at a future period.

[8] We would like to thank the anonymous reviewer for suggesting the Heckman 2-stage model based on predicting the likelihood of investment in R&D (1st stage) to control for R&D selection bias. Unfortunately, instrumental variables (IVs) we examined (e.g., industry R&D, prior R&D, tech dummy, prior grant winner) failed the exclusion requirement making the Heckman model unreliable.

[9] For similar firms (using the PSM sample), average grant paid is €143,291, average R&D is €2,763,589, and the coefficient is 0.073 as reported in Table 4, Panel B (model 1). A 1% increase in grant paid (€1,432.91) gives rise to a 0.073% or €2,017.42 (=0.073% × 2,763,589). A €1 increase in grants leads to an increase in R&D of €1.41 (2017.42/1432.91 = 1.41).

[10] We also estimate a conditional model that only includes grant winners, and the results (untabulated) are similar to those reported in Table 5. Baseline models that exclude the interaction of grants and market share are also reported in Appendix C.

[11] This may be due to a delay in producing innovation outputs from greater innovation investment. To examine this, we estimate a model (untabulated) with five interactions using the past grant recipient identifier (prior grant recipient, non-prior grant recipient) with a firm's position (top, bottom, and middle). The results indicate that no group produces greater innovation outputs relative to the average (middle) non-winning firm.

[12] Full details on the supports based on the stage of development is available at the Enterprise Ireland Webpage: https://www.enterprise-ireland.com/en/funding-supports/Company/.

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APPENDIX A
Variable definitions

Variable	Definition
I (Grant winner)	Binary variable, equals to 1 if the firm wins grant in year t and 0 otherwise
I (Grant recipient)	Binary variable, equals to 1 if the firm withdraws grant in year t and 0 otherwise
Ln (Grant approval)	Natural log of 1+ grant value approved in (euros)
Ln Grant paid	Natural log of 1+ grant value withdrawn in (euros)
Prior grant winner	Binary variable, equals to 1 if the firm won any grant prior to year t, 0 otherwise
Prior grant recipient	Binary variable, equals to 1 if the firm won and withdrew any grant prior to year t, 0 otherwise
Ln (R&D)	Natural log of 1 + R&D expenditure
Domestic	Binary variable, taking value of 1 if the firm is Irish-domiciled, 0 otherwise
Profit margin	Net profit before tax scaled by sales
Ln Productivity	Natural log of productivity (Productivity = Net profit before tax scaled by number of employees)
Ln Employment	Natural log of the number of employees
Ln Employment 3-year avg	Natural log of average employment from year t + 1 to t + 3
Ln In-house R&D 3-year avg	Natural log of average in-house R&D employees from year t + 1 to year t + 3
In-house R&D capability	Proportion of in-house R&D employees to total employees
Export intensity	Export intensity measured as the ratio of exports to sales
Top firm	Binary variable, taking value of 1 if the firm's market share is within top 30% of industry market share distribution
Bottom firm	Binary variable, taking value of 1 if the firm's market share is within bottom 30% of industry market share distribution
Industry R&D	Median of industry R&D intensity (R&D/sales)
HHI	Industry concentration (Herfindahl index)
HHI^2	Square of the Herfindahl index

The table reports the key variables used in the analysis. Continuous variables and ratios are measured contemporaneously.

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APPENDIX B

Propensity score matching (PSM)

This section describes the propensity score-matching procedure in more detail. PSM aims to match grant recipients with similar firms that did not receive grants; and thus, to mitigate selection bias. To do this, we estimate a first stage regression to predict the likelihood that a firm receives a grant in a year using observable covariates in the model below:

$$\begin{aligned} Grant\ paid\ dummy_{i,t} = \alpha + \beta_1 Prior\ grant\ paid\ dummy_{i,t} + \beta_2\, Ln\, R\&D_{i,t} + \beta_3\, Domestic_{i,t} + \beta_4 \\ Profit\ margin_{i,t} + \beta_5 Ln\ Employment + \beta_6 Inhouse\ R\&D\ capability_{i,t} + \beta_7 Export\ intensity_{i,t} + \beta_8 HHI_{i,t} + \\ \beta_9 HHI_{i,t}^{\ 2} + \beta_{10}\, Top\ Firm_{i,t} + \beta_{11}\, Bottom\ Firm_{i,t} + \beta_{12} Industry\ R\&D_{i,t} + \varepsilon_{i,t} \end{aligned} \quad \text{(B1)}$$

The dependent variable of this model is an indicator that equals one if the firm receives grant money and equals zero otherwise. The independent variables are described in the Appendix A.

We obtain the propensity scores (i.e., predicted values) from this regression. Next, we select the control firm in the same year and industry as the treatment firm that has the closest propensity score. To match a treated firm with control firm in the same year and industry, we generate a new propensity score:

$$Pscore2 = pscore + 10 \times Industry + 100 \times year \quad \text{(B2)}$$

We run psmatch2 using this new propensity score using nearest neighbor matching and select control firms without replacement. The matching results in 1,043 matches for 1,043 treatment firms, which generate a sample of 2,086 observations.

To test if the match is properly done, we check to see if there are significant differences in terms of covariates between treatment group (firms that *receive* grants) and control group (firms that *do not receive* grants) before and after matching. Results are reported in Table B2 below. Before matching, the covariates are significantly different between treatment and control groups for all variables, except profit margin. After matching, the covariates are comparable with

Table B1. PSM estimation

	Probability (Grant paid)
Variables	(1)
Prior grant recipient	0.031***
	(0.000)
Ln R&D	0.015***
	(0.000)
Profit margin	0.001
	(0.503)
Ln Employment	–0.001
	(0.627)
In-house R&D capability	0.003
	(0.702)
Export intensity	0.007
	(0.106)
Domestic	0.001
	(0.756)
Top firm	–0.006*
	(0.085)
Bottom firm	–0.026***
	(0.000)
Industry R&D	0.229***
	(0.000)
HHI	0.011
	(0.753)
HHI^2	–0.098**
	(0.028)
Observations	17,244
Pseudo R-squared	0.144

This table contains the results of probit models that predict the likelihood that a firm wins a grant in year t as a function of characteristics in year t. The model uses clustered standard errors (clustered by firm id). Parentheses contain *P*-values and superscripts ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

Table B2. Differences in covariates before and after matching

	Treatment	Control	Diff
	(1)	(2)	(1-2)
Panel A: Before matching			
Prior grant recipient	0.597	0.196	0.401***
Ln Employment	4.051	3.574	0.477***
Industry R&D	0.029	0.026	0.003***
Profit margin	–0.195	–0.147	–0.048
Export intensity	0.664	0.506	0.158***
Ln R&D	5.955	3.032	2.923***
In-house R&D capability	25.400	4.956	20.444***
Top firm	0.466	0.273	0.193***
Bottom firm	0.068	0.128	–0.060***
HHI	0.209	0.196	0.013***
Panel B: After matching			
Prior grant recipient	0.435	0.390	0.045
Ln Employment	4.017	3.978	0.039
Industry R&D	0.039	0.037	0.002
Profit margin	–0.183	–0.183	0.000
Export intensity	0.643	0.622	0.0214
Ln R&D	5.946	5.716	0.230**
In-house R&D capability	0.216	0.202	0.013
Top firm	0.522	0.546	–0.024
Bottom firm	0.031	0.058	–0.028**
HHI	0.205	0.201	0.004
Number of firms	1,043	1,043	1,043

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mostly no significant differences in terms of mean values, suggesting a reasonable match. There are only two variables that report differences at the 5% level, which are Ln (R&D) and bottom firm.

APPENDIX C

See Tables C1 and C2

C5 : PLACEBO TEST

We hypothesize that grants *cause* firms to increase R&D, so firms that do not receive grants should not witness the same increase in R&D. However, one possible concern with our reported results in Table 4 is that the government may simply 'cherry pick' industries, or types of firms, that were likely to be innovative anyway, and that the grant does not itself drive any increase in R&D. If this were the case,

Table C1. Baseline PSM model of the impact of grants on total employment and in-house R&D employment

	Ln Employment 3-year average	Ln In-house R&D Employment 3-year average
Variables	(1)	(2)
Grant recipient	0.030	0.229***
	(0.393)	(0.000)
Prior grant recipient	0.063	0.152***
	(0.109)	(0.001)
Ln R&D	0.247***	0.341***
	(0.000)	(0.000)
Profit margin	−0.026*	−0.032*
	(0.076)	(0.062)
In-house R&D capability	−1.707***	
	(0.000)	
Ln Employment		0.365***
		(0.000)
Export intensity	−0.125**	0.301***
	(0.032)	(0.000)
Domestic	−0.619***	0.208***
	(0.000)	(0.003)
Top firm	0.999***	−0.197***
	(0.000)	(0.001)
Bottom firm	−0.320***	0.212
	(0.005)	(0.264)
Industry R&D	0.403	−2.312
	(0.890)	(0.589)
HHI	−2.344**	0.202
	(0.036)	(0.890)
HHI^2	3.490***	−0.481
	(0.007)	(0.780)
Constant	2.335***	−1.907***
	(0.002)	(0.000)
Observations	1,799	1,450
R-squared	0.739	0.685
F-statistic	115.808***	74.631***

The table reports the impact of grants and R&D on employment, including total employment and in-house R&D employment using PSM. The dependent variables are the log value of firm's total employment, log of the firms' in-house R&D employees, average of three years after winning grant. Independent variables include the grant recipient dummy 1 if firm withdraws grant money in year t, 0 otherwise. Control variables include: Prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Ln R&D is natural log of R&D, profit margin is operating profit scaled by sales, ln employment is the natural log of the firm's total number of employees, In-house R&D capability is the proportion of in-house R&D employees to total employees, export intensity is total exports scaled by sales, domestic firm is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise, top (bottom) firm indicators are dummy variables equal to 1 if the firm's market share ranks within the top (bottom) 30% of their industry market share, where market share is calculated using sales. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively, and Industry Innov is the median industry R&D to sales ratio. All models include industry and year fixed effects. All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

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Table C2. Baseline PSM model on the moderating effect of grants on the relationship between R&D and productivity

	Ln Productivity t + 1	Ln Productivity t + 2	Ln Productivity t + 3	Ln Productivity 3-year avg
Variables	(1)	(2)	(3)	(4)
Grant recipient	–0.480**	–0.505**	–0.450*	–0.278
	(0.046)	(0.050)	(0.087)	(0.283)
Prior grant recipient	–0.010	–0.018	–0.002	–0.089
	(0.917)	(0.862)	(0.986)	(0.412)
Grant recipient × Ln R&D	0.063*	0.064	0.056	0.030
	(0.094)	(0.115)	(0.185)	(0.465)
Ln R&D	0.106***	0.097***	0.073*	0.107***
	(0.002)	(0.008)	(0.056)	(0.005)
Ln Employment	–0.333***	–0.299***	–0.307***	–0.282***
	(0.000)	(0.000)	(0.000)	(0.000)
In-house R&D capability	–0.423	–0.683**	–0.744**	–0.822**
	(0.120)	(0.022)	(0.020)	(0.011)
Export intensity	0.585***	0.546***	0.608***	0.539***
	(0.000)	(0.000)	(0.000)	(0.001)
Domestic	–0.813***	–0.791***	–0.858***	–0.911***
	(0.000)	(0.000)	(0.000)	(0.000)
Top firm	1.049***	1.086***	0.944***	0.918***
	(0.000)	(0.000)	(0.000)	(0.000)
Bottom firm	0.556**	0.281	0.465	0.206
	(0.045)	(0.420)	(0.292)	(0.653)
Industry R&D	2.701	0.980	22.029**	15.036
	(0.537)	(0.894)	(0.025)	(0.111)
HHI	–4.328*	–5.733**	–7.482**	–7.862**
	(0.081)	(0.049)	(0.029)	(0.017)
HHI^2	4.916*	7.007**	8.156**	9.384**
	(0.085)	(0.041)	(0.046)	(0.018)
Constant	3.632***	3.384***	4.375***	6.061***
	(0.000)	(0.003)	(0.000)	(0.000)
Observations	1,403	1,199	1,050	1,037
R-squared	0.269	0.283	0.255	0.284
F-statistic	11.362***	10.350***	8.199***	9.397***

This table reports the moderation effect of grants on the relationship between R&D and productivity using PSM. The dependent variable is the log of a firm's productivity in year t + 1, year t + 2, and year t + 3 after receiving the grant, and log of the average productivity over the 3 years post winning. All independent variables are measured in the current year (t). Interaction term of grant recipient dummy and Ln R&D captures the moderation effects. Control variables include: Grant recipient dummy is equal to 1 if the firm withdraw any grant in year t, Prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Profit Margin is operating profit scaled by sales, Ln Employment is the natural log of the firm's total number of employees, In house R&D capability is the proportion of in-house R&D employees to total employees, Export Intensity is total exports scaled by sales, Domestic is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise, top (bottom) firm indicators are dummy variables equal to 1 if the firm's market share ranks within the top (bottom) 30% of their industry market share, where market share is calculated using sales. Industry Innov is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively. All models control for industry and year fixed effects (untabulated). All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

we would expect 'similar' non-recipients of grants to also experience increases in R&D. Thus, one way to check that the results are robust to this concern is to look at the future R&D expenditures of similar firms that did not receive a grant when one firm in that industry receives a grant. Put differently, we look at whether mere extraneous factors that are correlated with receiving a grant (and would be present in competitors) are associated with increases in future R&D.

To examine this, we run 'placebo' tests that restrict our sample to non-winning firms, defined as firms that never won a grant during our sample time-period. We create a 'winning

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Table C3. Impact of grant size on innovation inputs and outputs: moderating role of a firm's market position using sample of grant winners and PSM

	Ln R&D_1	Ln R&D_2	Ln R&D_3	Ln R&D 3-year avg	R&D growth	Ln new product sales
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Ln Grant paid	0.397***	0.443***	0.422***	0.391***	0.141***	0.021
	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.932)
Prior grant recipient	0.269***	0.353***	0.441***	0.326***	0.115	−0.108
	(0.004)	(0.000)	(0.000)	(0.000)	(0.138)	(0.741)
Ln Grant paid × Top firm	0.229**	0.164*	0.115	0.113	−0.142*	0.133
	(0.018)	(0.094)	(0.276)	(0.217)	(0.056)	(0.695)
Ln Grant paid × Bottom firm	0.459**	0.338**	0.372*	0.375***	0.108	1.472*
	(0.013)	(0.029)	(0.077)	(0.004)	(0.436)	(0.072)
Profit margin	−0.002	−0.080***	−0.027	−0.057**	−0.039	−0.085
	(0.942)	(0.002)	(0.679)	(0.033)	(0.166)	(0.588)
Ln Employment	0.735***	0.726***	0.744***	0.719***	−0.125***	0.089
	(0.000)	(0.000)	(0.000)	(0.000)	(0.007)	(0.676)
In-house R&D capability	3.031***	2.644***	1.874***	2.334***	−0.552**	0.924
	(0.000)	(0.000)	(0.000)	(0.000)	(0.033)	(0.375)
Export intensity	0.308**	0.369**	0.685***	0.412***	−0.045	0.452
	(0.017)	(0.017)	(0.000)	(0.001)	(0.700)	(0.425)
Domestic	0.163	0.058	0.131	−0.048	−0.041	5.851***
	(0.278)	(0.743)	(0.496)	(0.735)	(0.698)	(0.000)
Top firm	−1.049**	−0.721	−0.573	−0.473	0.735*	−0.047
	(0.033)	(0.156)	(0.293)	(0.323)	(0.057)	(0.977)
Bottom firm	−2.325***	−2.032***	−1.576*	−1.799***	−0.363	−6.835*
	(0.006)	(0.006)	(0.059)	(0.001)	(0.522)	(0.061)
Industry R&D	−2.044	−15.256	−6.718	−3.036	−3.802	4.065
	(0.557)	(0.174)	(0.486)	(0.667)	(0.275)	(0.761)
HHI	−1.029	1.750	0.906	−0.340	0.308	−79.125
	(0.688)	(0.571)	(0.814)	(0.906)	(0.861)	(0.126)
HHI^2	0.455	−2.182	−0.628	0.227	−0.267	215.515
	(0.878)	(0.561)	(0.891)	(0.949)	(0.897)	(0.141)
Ln R&D						−0.053
						(0.606)
Constant	−1.126	−0.678	−4.205***	−3.272***	−0.141	6.196
	(0.248)	(0.425)	(0.001)	(0.003)	(0.802)	(0.226)
Observations	1,043	915	797	786	992	245
R-squared	0.624	0.605	0.551	0.678	0.067	0.659
F-statistic	36.845***	29.614***	20.977***	36.394***	1.509	10.148***

This table reports the relation between grant size on innovation inputs and outputs using PSM. Model 1-4 dependent variables are the log of R&D in year t + 1, t + 2, t + 3 and the log of average R&D 3 year post winning. Model 5 dependent variable is R&D growth in year t + 1. Model 6 dependent variable is log of innovative sales. Independent variable is the log of grant amount the firm withdraws in year t. Control variables include: Prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Ln R&D is natural log of R&D, profit margin is operating profit scaled by sales, ln employment is the natural log of the firm's total number of employees, In-house R&D capability is the proportion of in-house R&D employees to total employees, export intensity is total exports scaled by sales, domestic firm is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise, top (bottom) firm indicators are dummy variables equal to 1 if the firm's market share ranks within the top (bottom) 30% of their industry market share, where market share is calculated using sales. Industry Innov is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively. All models include industry and year fixed effects. All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

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Table C4. Baseline firm fixed effects models for grants on R&D investment

	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D avg	R&D growth	Ln R&D/sales t + 1	Ln R&D/sales avg
Panel A: Grant dummy	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	0.641***	0.441***	0.263***	0.227***	0.019	0.167***	0.096***
	(0.000)	(0.000)	(0.005)	(0.002)	(0.601)	(0.000)	(0.000)
Prior grant recipient	0.439***	0.045	−0.271*	−0.057	−0.127***	0.048	−0.093**
	(0.008)	(0.770)	(0.083)	(0.670)	(0.007)	(0.234)	(0.029)
Profit margin	0.025	0.027	0.028	0.031	−0.037**	−0.097***	−0.053***
	(0.462)	(0.512)	(0.600)	(0.502)	(0.031)	(0.000)	(0.003)
Ln Employment	1.289***	0.887***	0.591***	1.041***	−0.326***	−0.056	−0.010
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.139)	(0.831)
In-house R&D capability	6.211***	2.502***	0.368	3.025***	−1.530***	1.170***	0.464***
	(0.000)	(0.000)	(0.487)	(0.000)	(0.000)	(0.000)	(0.004)
Export intensity	0.097	−0.225	−0.285	−0.015	−0.246**	−0.226**	−0.133
	(0.769)	(0.517)	(0.481)	(0.963)	(0.043)	(0.043)	(0.266)
Market share	−1.024	1.252	0.327	1.140	−0.013	−3.315**	−2.057
	(0.820)	(0.765)	(0.917)	(0.679)	(0.980)	(0.042)	(0.248)
Industry R&D	0.280**	0.230*	0.395***	0.301***	−0.023	0.045	0.099*
	(0.029)	(0.084)	(0.002)	(0.004)	(0.720)	(0.343)	(0.063)
HHI	−2.455	−4.974**	−2.807	−3.686*	1.201*	0.274	0.166
	(0.254)	(0.035)	(0.238)	(0.088)	(0.067)	(0.616)	(0.796)
HHI^2	2.648	6.363**	4.209	4.170*	−1.100	−0.397	−0.097
	(0.273)	(0.015)	(0.126)	(0.084)	(0.138)	(0.536)	(0.892)
Constant	−0.760	2.140	1.339	1.270	2.032**	−3.915***	−4.924***
	(0.649)	(0.222)	(0.456)	(0.386)	(0.016)	(0.000)	(0.000)
Observations	14,527	12,070	10,040	9,787	9,425	9,439	6,834
Number of firms	2,476	2,191	2,050	2,022	1,812	1,829	1,504
R-squared (between)	0.278	0.148	0.058	0.132	0.000	0.585	0.397
R-squared (within)	0.059	0.019	0.010	0.033	0.038	0.069	0.030
R-squared (overall)	0.244	0.146	0.07	0.143	0.004	0.482	0.327
F-statistic	15.889***	5.204***	3.074***	6.354***	9.890***	14.985***	4.871***

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Panel B: Grant size

Variables	Ln R&D t + 1 (1)	Ln R&D t + 2 (2)	Ln R&D t + 3 (3)	Ln R&D avg (4)	R&D growth (5)	Ln R&D/sales t + 1 (6)	Ln R&D/sales avg (7)
Ln (grant paid)	0.055***	0.038***	0.021***	0.019***	0.001	0.015***	0.008***
	(0.000)	(0.000)	(0.006)	(0.001)	(0.633)	(0.000)	(0.000)
Prior grant recipient	0.436***	0.041	−0.278*	−0.059	−0.127***	0.048	−0.093**
	(0.009)	(0.789)	(0.075)	(0.655)	(0.007)	(0.232)	(0.029)
Profit margin	0.025	0.027	0.028	0.031	−0.037**	−0.097***	−0.053***
	(0.464)	(0.514)	(0.601)	(0.502)	(0.031)	(0.000)	(0.003)
Ln Employment	1.288***	0.886***	0.592***	1.040***	−0.326***	−0.056	−0.011
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.134)	(0.822)
In-house R&D capability	6.206***	2.499***	0.368	3.023***	−1.529***	1.168***	0.463***
	(0.000)	(0.000)	(0.487)	(0.000)	(0.000)	(0.000)	(0.004)
Export intensity	0.099	−0.224	−0.284	−0.014	−0.246**	−0.226**	−0.132
	(0.765)	(0.520)	(0.482)	(0.965)	(0.043)	(0.043)	(0.267)
Market share	−1.026	1.247	0.319	1.139	−0.014	−3.315**	−2.055
	(0.820)	(0.767)	(0.919)	(0.679)	(0.979)	(0.042)	(0.248)
Industry R&D	0.279**	0.230*	0.395***	0.301***	−0.023	0.044	0.099*
	(0.029)	(0.084)	(0.002)	(0.004)	(0.720)	(0.348)	(0.063)
HHI	−2.479	−4.991**	−2.815	−3.694*	1.201*	0.264	0.162
	(0.250)	(0.035)	(0.237)	(0.087)	(0.067)	(0.629)	(0.800)
HHI^2	2.678	6.384**	4.220	4.179*	−1.099	−0.383	−0.093
	(0.268)	(0.015)	(0.125)	(0.084)	(0.138)	(0.550)	(0.897)
Constant	−0.742	2.150	1.340	1.274	2.031**	−3.906***	−4.920***
	(0.657)	(0.220)	(0.456)	(0.384)	(0.016)	(0.000)	(0.000)
Observations	14,527	12,070	10,040	9,787	9,425	9,439	6,834
Number of firms	2,476	2,191	2,050	2,022	1,812	1,829	1,504
R-squared (between)	0.279	0.148	0.057	0.132	0.001	0.585	0.398
R-squared (within)	0.059	0.019	0.010	0.033	0.037	0.069	0.030
R-squared (overall)	0.244	0.146	0.069	0.143	0.004	0.482	0.328
F-statistic	15.936***	5.276***	3.066***	6.448***	9.896***	15.141***	5.042***

This table reports firm fixed effects models on the relation between grant paid on R&D expenditures. Panel A use a dummy independent variable, equals to 1 if the firm withdraws any grant in year t, 0 otherwise. Panel B use the log of grant paid as independent variable. The dependent variable is the log of a firm's R&D in year t + 1, year t + 2, and year t + 3 after receiving the grant, the log of the average R&D over the 3 years post winning, the log of R&D scaled by sales in year t + 1, and the log of the average log of R&D scaled by sales over 3 years post winning. All independent variables are measured in the current year (t). Control variables include: prior grant recipient is a dummy equal to 1 if a firm withdrew any grant in prior years, and 0 otherwise, Profit Margin is operating profit scaled by sales, Ln Employment is the natural log of the firm's total number of employees, In house R&D capability is the proportion of in-house R&D employees to total employees, Export Intensity is total exports scaled by sales, market share is calculated using sales scaled by industry total sales. Domestic dummy drops out of the model due to controlling for firm fixed effect. Industry R&D is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value, respectively. All models control for firm and year fixed effects (untabulated). All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

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Table C5. Placebo test: sample of non-winning firms

Panel A: Full sample

	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D 3-year avg	R&D growth
Variables	(1)	(2)	(3)	(4)	(5)
Winning competitor indicator	−0.453	0.039	−0.538	−0.202	0.294
	(0.524)	(0.968)	(0.626)	(0.818)	(0.308)
Profit margin	−0.076	−0.080	0.043	0.016	−0.060**
	(0.339)	(0.466)	(0.831)	(0.920)	(0.045)
Ln Employment	0.854***	0.939***	0.987***	0.923***	−0.044
	(0.000)	(0.000)	(0.000)	(0.000)	(0.259)
In-house R&D capability	4.455***	4.946***	5.138***	5.081***	−0.288*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.099)
Export intensity	0.965***	0.730**	0.894**	0.696**	0.005
	(0.001)	(0.043)	(0.043)	(0.049)	(0.959)
Domestic	0.279	0.444	0.775*	0.360	0.174*
	(0.335)	(0.216)	(0.071)	(0.300)	(0.074)
Top firm	0.336	−0.040	0.045	0.196	0.045
	(0.215)	(0.905)	(0.911)	(0.547)	(0.623)
Bottom firm	−1.621***	−1.399***	−0.754	−1.198**	−0.019
	(0.000)	(0.007)	(0.299)	(0.038)	(0.910)
Industry R&D	−5.271	−10.949	0.920	−6.579	2.054
	(0.620)	(0.548)	(0.978)	(0.809)	(0.542)
HHI	−4.301	−2.329	−11.298	−2.895	−2.112
	(0.427)	(0.742)	(0.244)	(0.709)	(0.238)
HHI^2	6.642	4.102	13.998	4.157	2.718
	(0.289)	(0.616)	(0.224)	(0.651)	(0.189)
Constant	−0.489	−0.718	−4.046	−5.082**	−0.765
	(0.778)	(0.757)	(0.127)	(0.020)	(0.214)
Observations	435	371	317	311	365
R-squared	0.606	0.516	0.469	0.576	0.139
F-statistic	14.009***	8.327***	5.926***	8.924***	1.202

Panel B: PSM matched sample

	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D 3-year avg	R&D growth
Variables	(1)	(2)	(3)	(4)	(5)
Winning competitor indicator	−0.453	0.039	−0.538	−0.202	0.294
	(0.524)	(0.968)	(0.626)	(0.818)	(0.308)
Profit margin	−0.076	−0.080	0.043	0.016	−0.060**
	(0.339)	(0.466)	(0.831)	(0.920)	(0.045)
Ln Employment	0.854***	0.939***	0.987***	0.923***	−0.044
	(0.000)	(0.000)	(0.000)	(0.000)	(0.259)
Inhouse R&D capability	4.455***	4.946***	5.138***	5.081***	−0.288*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.099)
Export intensity	0.965***	0.730**	0.894**	0.696**	0.005
	(0.001)	(0.043)	(0.043)	(0.049)	(0.959)

(Continues)

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Table C5. (Continued)

Panel B: PSM matched sample

	Ln R&D t + 1	Ln R&D t + 2	Ln R&D t + 3	Ln R&D 3-year avg	R&D growth
Variables	(1)	(2)	(3)	(4)	(5)
Domestic	0.279	0.444	0.775*	0.360	0.174*
	(0.335)	(0.216)	(0.071)	(0.300)	(0.074)
Top firm	0.336	−0.040	0.045	0.196	0.045
	(0.215)	(0.905)	(0.911)	(0.547)	(0.623)
Bottom firm	−1.621***	−1.399***	−0.754	−1.198**	−0.019
	(0.000)	(0.007)	(0.299)	(0.038)	(0.910)
Industry R&D	−5.271	−10.949	0.920	−6.579	2.054
	(0.620)	(0.548)	(0.978)	(0.809)	(0.542)
HHI	−4.301	−2.329	−11.298	−2.895	−2.112
	(0.427)	(0.742)	(0.244)	(0.709)	(0.238)
HHI^2	6.642	4.102	13.998	4.157	2.718
	(0.289)	(0.616)	(0.224)	(0.651)	(0.189)
Constant	−0.489	−0.718	−4.046	−5.082**	−0.765
	(0.778)	(0.757)	(0.127)	(0.020)	(0.214)
Observations	435	371	317	311	365
R-squared	0.606	0.516	0.469	0.576	0.139
F-statistic	14.009***	8.327***	5.926***	8.924***	1.202

This table reports placebo test of Table 4. Panel A uses the full sample, and Panel B uses PSM. Model 1-4-dependent variables are the log of R&D in year t + 1, t + 2, t + 3 and the log of average R&D 3 year post winning. Model 5-dependent variable is R&D growth in year t + 1. Model 6-dependent variable is log of innovative sales. Independent variable is Winning competitor indicator, a dummy variable that equals to 1 if at least one firm in the same industry wins a grant in year t. Control variables include: Profit margin is operating profit scaled by sales, ln employment is the natural log of the firm's total number of employees, In-house R&D capability is the proportion of in-house R&D employees to total employees, export intensity is total exports scaled by sales, domestic firm is a dummy variable equal to 1 if the firm is a local firm, 0 otherwise, top (bottom) firm indicators are dummy variables equal to 1 if the firm's market share ranks within the top (bottom) 30% of their industry market share, where market share is calculated using sales. Industry R&D is the median industry R&D to sales ratio. HHI and HHI^2 is the Herfindahl index of the industry and its squared value. All models include industry and year fixed effects. All continuous variables are winsorized at 1% level. Standard errors are robust-clustered at the firm level. ***, **, and * denote statistical significance at 1%, 5% and 10% levels, respectively.

competitor' indicator that equals to one if there is at least one firm in the same industry that receives a grant in a particular year and equals zero if no firms in the industry received a grant. If grants, on average, *cause* R&D to increase, holding other variables constant, we expect an insignificant relationship between the winning competitor indicator and the R&D level of the non-winning competitors in subsequent year(s).

We estimate the same regression as in Equation (1) using a sample of only non-grant winning firms. The results reported in Table C5 (Panel A) below and show no significant relationship between the winning competitor indicator and the R&D levels for the years t + 1, t + 2, and, t + 3, as well as R&D growth. This supports our hypothesis that firms that do not win grants do not show similar increases in R&D as firms that do receive grants. In other words, grants *cause* a significant increase in R&D expenditures and R&D growth.

To mitigate the issue that some non-winning firms basically do not invest in R&D at all or differ significantly from winners with respect to other characteristics, we also examine a sample of non-winning firms from our matched sample (i.e., using propensity score matching). The results in Table C5 (Panel B) again confirm no significant relationship between the winning competitor indicator and future R&D, providing further support that grants indeed *cause* increases in R&D expenditures and growth.

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