ADDITIONALITY OR OPPORTUNISM – DO HOST-COUNTRY R&D SUBSIDIES IMPACT INNOVATION IN FOREIGN MNC SUBSIDIARIES?

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ABSTRACT

Host-country policies shape the incentives and opportunities of MNC subsidiaries to innovate. However, prior research largely ignores the agency of foreign MNC subsidiaries receiving government R&D subsidies from their host countries. Subsidiaries may increase R&D investments and innovation outputs as intended by governments or merely accept the additional funds while continuing R&D programs that they would have undertaken anyway. In this exploratory study, we investigate whether R&D subsidies trigger additional input, output, and behavioral innovation effects in foreign MNC subsidiaries. Based on longitudinal data from Germany, we find that foreign MNC subsidiaries increase their R&D investments more than comparable domestic firms in response to an R&D subsidy. Moreover, MNC subsidiaries experience comparatively stronger effects in innovation performance from subsidy-induced R&D. However, subsidies also shift away the attention from the subsidiaries' original R&D activities. We interpret our findings by integrating theory from subsidy additionality literature into models of MNC subsidiary innovation. Our findings have implications for both MNC subsidiaries and policy makers who seek to attract foreign R&D investment in a host country.

Keywords: R&D subsidies, R&D investment decisions, MNC subsidiary mandates, innovation performance, technology policy

INTRODUCTION

The R&D activities of multinational corporations (MNCs) abroad are a central theme of research in international business (Cantwell & Mudambi, 2005; Cantwell, 2017). Within this literature, it is widely acknowledged that host-country governments and their policies are key determinants for MNC subsidiaries becoming increasingly innovative or explorative (Birkinshaw & Hood, 1998). However, we know comparatively little about how R&D subsidies of host-country governments affect foreign MNC subsidiaries in these countries. Most governments have technology-related policies in place and provide R&D subsidies for a substantial number of firms. For example, about a third of innovative firms in Europe received government funding for their innovation activities in 2016.[1] From a policy perspective, it is important whether R&D subsidies effectively change the innovation activities of receiving firms or whether a deadweight loss occurs.

In this study, we address this concern for the particular situation of foreign MNC subsidiaries. We focus on host-country R&D subsidies and how they affect the R&D investment decisions of foreign MNC subsidiaries as well as their innovation performance, using domestic firms as comparison groups. For this purpose, we integrate theoretical mechanisms from the literature on additionality effects of R&D subsidies (e.g., David & Hall, 2000; Blanes & Busom, 2004; Clarysse et al., 2009) with theory on MNC subsidiary R&D decisions (e.g., Cantwell & Mudambi, 2005; Un & Cuervo-Cazurra, 2008; Santangelo et al., 2016). More specifically, we decompose the "additionality effects" of subsidies for changes in R&D inputs, outputs and firm behavior (Clarysse et al., 2009).

Technology policy influences the incentives, capabilities, and resources available for firms and other actors to finance or participate in the development, integration and commercialization of knowledge (Holmes et al., 2016). The effects of technology policy, in turn, depend on the strategic response of firms, and firms may respond differently to technology policy. These responses are important given the vast

[1] Source: Eurostat, product and/or process innovative enterprises that received public funding for innovation activities, accessed October 2019.

amount of resources that governments worldwide spend on technology policy. According to recent figures from the OECD Science, Technology, and R&D Statistics, governments in OECD countries have, for the period from 2011 to 2017, on average funded about 6% of the total business enterprise expenditure on R&D (BERD). In the United States, about 9% of BERD were financed by the government, while this figure was about 4% in Germany and slightly more than 1% in Japan.[2] The evidence to date suggests that R&D subsidies may considerably advance a firm's competitiveness by enabling new technology development, patent applications, and new product introductions (e.g., Jaffe & Le, 2015). Then again, prior research finds important differences in the R&D investment behavior of domestic firms and MNC subsidiaries (Un & Cuervo-Cazurra, 2008).

Studying the effects of R&D subsidies is complex since an informative assessment of the effects requires a discussion of the counterfactual, i.e. the R&D investment behavior and performance outcomes had the firms not received an R&D subsidy (Aerts & Schmidt, 2008). In a recent contribution, Howell (2017) notes that "we have little empirical evidence about the effectiveness of R&D subsidies" (p. 1136). This is all the more true if we seek to more systematically incorporate firm heterogeneity into the study of R&D subsidies, most notably the distinction between domestic and foreign-owned firms. Given the lack of theoretical and empirical priors, we adopt an inductive and exploratory large-N research design in this study, exploiting the access to a number of large-scale datasets. This "approach is appropriate when existing theory provides a useful frame for a baseline argument but is not robust enough for precise hypotheses" (Bettis et al., 2014: 950) and has increasingly been used in management literature (e.g., Birhanu et al., 2016; Lyngsie & Foss, 2017).

Our empirical analysis uses longitudinal data on R&D investment, subsidies and innovation performance for a representative sample of 5,266 domestic firms and foreign MNC subsidiaries located in Germany. We match this information with patent statistics between 1997 and 2011. Subsequently, we rely on

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[2] Source: OECD iLibrary, Science, Technology, and R&D Statistics, date of access: August 2019.

the combination of a treatment model with the estimation of a knowledge production function as the estimation strategy. Our results are threefold. First, we find that foreign MNC subsidiaries increase their R&D investments more than comparable domestic firms in response to an R&D subsidy. However, this positive effect on R&D inputs is equally present for domestic MNCs. In other words, we identify positive R&D additionality effects of subsidies for both domestic and foreign MNCs. Second, foreign MNC subsidiaries experience comparatively stronger effects on innovation performance from subsidy-induced R&D than (a) domestic firms and (b) domestic MNCs. Finally, subsidies also shift away the attention from the foreign subsidiaries' original R&D activities, i.e. the subsidy-induced R&D investments have stronger effects on innovation performance than the ones that the subsidiary would have undertaken anyway (the counterfactual).

We conclude by offering plausible explanations of our findings (cf. Gelman & Imbens, 2013). We suggest that host-country R&D subsidies have a signaling effect for the quality of R&D performed at a subsidiary (Spence, 1973), so that MNC subsidiaries with a subsidy are more likely to obtain or extend competence-creating mandates with the MNC resulting in increased R&D investments (Cantwell & Mudambi, 2005). A subsidiary that secures R&D subsidies in its host market can therefore attract more funding internally. MNCs in that sense are distinct from domestic firms that could not use the subsidy as a signal to shift R&D investment internally. Moreover, we expect MNC subsidiaries to offer more opportunities for recombination with intra-MNC knowledge than domestic firms (Un & Cuervo-Cazurra, 2008), leading to higher innovation performance. However, R&D subsidies may also divert attention towards the subsidized activity (Clarysse et al., 2009) which implies a comparatively lower innovation performance of the R&D investment that the MNC subsidiary would have undertaken anyway.

Our contribution to the literature has three dimensions. First, our research contributes to the growing literature on MNC knowledge and technology development which has been primarily concerned with R&D decisions in the network of subsidiaries (for an overview Cantwell, 2017). It constitutes the first account of how MNC subsidiaries make decisions on R&D investment in response to R&D subsidies and how these decisions differ from comparable domestic firms. We explain these differences based on the nature of MNCs in distinction to domestic firms, i.e. based on an MNC's presence in multiple countries and the advantages that its access to other countries offer (Un & Cuervo-Cazurra, 2008). In that sense, our research facilitates a better understanding of technology development in MNC subsidiaries and the degree to which it relies on host-country government subsidies. Existing studies ignoring the effect of host-country subsidies on subsidiary R&D decisions and outcomes are likely to suffer from biases.

Second, we add to the literature on the additionality effects of R&D subsidies for input decisions, outcome performance and behavioral changes (David & Hall, 2000; Blanes & Busom, 2004; Clarysse et al., 2009). Our findings indicate that these effects are distinct for foreign MNC subsidiaries and existing theorizing about subsidy effects cannot be generalized for all firms in a country. Instead, our findings reveal that some firms, i.e. foreign MNC subsidiaries, are particularly responsive to R&D subsidies. This finding implies a need for a more systematic theoretical understanding of how the additionality effects of government subsidies for firm R&D in a country depend on whether recipient firms are MNCs.

Finally, our research holds implications for government policy. R&D subsidies have become an important instrument in FDI promotion policies and governments worldwide seek to benefit from the globalization of corporate R&D (e.g., Guimón, 2011; Alkemade et al., 2015). Our findings regarding the advantages of MNC subsidiaries in translating R&D subsidies into performance outcomes can therefore provide policymakers with a distinct rationale for the attraction of inward FDI. At the same time, our findings also caution against potential adverse outcomes on the host-country economy if R&D subsidies lead to persistent productivity advantages of foreign MNC subsidiaries over domestic firms. Moreover, when adopting a systems of innovation lens (Lundvall, 1992; Chaminade & Edquist, 2008), government policies should be particularly concerned with the relationships between MNC subsidiaries that receive R&D subsidies and other innovation system actors such as domestic firms or universities.

LITERATURE REVIEW

Since the goal of our study is to explore how the receipt of host-country R&D subsidies affects the innovation activities of foreign MNC subsidiaries, our reasoning is at the subsidiary level. We review two streams of relevant theory. First, we review international business literature explaining how differences in the innovation activities of MNC subsidiaries emerge. Second, we review innovation literature that structures relevant firm-level outcomes following government R&D subsidies. Finally, we introduce the empirical context of R&D subsidies in Germany.

Heterogeneity in MNC subsidiary innovation

The locational choices by MNCs for performing R&D activities have attracted considerable attention in prior literature (e.g., Gassmann & von Zedtwitz, 1999; Contractor et al., 2010; Castellani et al., 2013; Belderbos et al., 2015). While R&D performed in host countries has traditionally been seen as a requirement to adapt technologies and products to foreign markets and manufacturing conditions (Kuemmerle, 1997; Niosi, 1999), recent research stresses that R&D activities abroad may also facilitate knowledge sourcing and "reverse" knowledge transfer in order to increase an MNC's innovation performance and productivity in the home or other host countries (e.g., Alcacer & Chung, 2007; Belderbos et al., 2015).

The heterogeneity of innovation activities among MNC subsidiaries is generally described as a subsidiary's mandate (or charter) (Birkinshaw & Hood, 1998). Cantwell & Mudambi (2005) provide a useful framework for describing differences in mandates based on the degree to which subsidiaries are engaged in more exploitative versus explorative innovation. Within this framework, subsidiaries with competence-exploiting mandates largely adapt MNC knowledge, products or processes. Subsidiaries with competence-creating mandates, though, create knowledge, products or processes that are novel for the MNC. Birkinshaw & Hood (1998) identify three factors that allow subsidiaries to become increasingly competence-creating, i.e. assignments from global headquarters, subsidiary level choices, as well as host-country factors.

Host-country factors supporting competence-creating mandates can have multiple dimensions such as country-level technological capabilities or organizational principles (Kogut, 1991). However, the factor that is most directly under control of host-country governments is the provision of financial support (Birkinshaw & Hood, 1998). Then again, we know comparatively little about how foreign MNC subsidiaries receiving host-country R&D subsidies alter their innovation activities in terms of how it affects their R&D investments, the innovation outputs as well as the type of R&D that they undertake.

Firm responses to government R&D subsidies

Government policy refers to various forms of governmental intervention aimed at promoting productive investments that would not have occurred in market interactions in which those interventions were absent. Interventions are assumed to be particularly valuable if they lead to positive externalities across industries and activities that autonomous decision making of firms would fail to account for (Lazzarini, 2015). Technology policy, in that sense, builds on the idea that markets sometimes do not motivate firms to carry out the most economically and socially desirable innovation projects because (1) the financial returns are difficult for firms to capture, (2) firms do not command the required resources, and (3) the innovation outcomes are socially desirable and broadly shared (Bozeman, 2000; Holmes et al., 2016). In other words, technology policy justifies government intervention by highlighting market failures caused by knowledge leakage and spillovers that prevent firms from fully appropriating the returns from innovation and therefore limits their incentives to invest into R&D (Arrow, 1962). To compensate for the "underinvestment" that would consequently occur, governments worldwide have implemented R&D subsidy programs alongside other forms of intervention like tax credits, government contracts, and government-funded university research (David et al., 2000; Ceh, 2009; Rigby & Ramlogan, 2012).

Relatedly, government intervention has been motivated by the ambition to address "systemic problems" (Chaminade & Edquist, 2008). The systems of innovation approach highlights that firms do not innovate in isolation but are typically embedded in a system characterized by regular interaction with other actors, such as other firms, universities or other public research organizations (Lundvall, 1992). In this view, government intervention does not aim at achieving an optimal level of innovation since innovation processes are path-dependent and have evolutionary characteristics. Policy should rather address systemic problems such as transitions from one technological paradigm towards a new one, lock-in problems due to an excessive focus on existing technologies, innovation network deficiencies, or investments into human capital (Chaminade & Edquist, 2008).

Technology policy, and R&D subsidies in particular, has frequently been characterized as important for firms since they can support firms' knowledge production and the combination of knowledge from diverse sources (Holmes et al., 2016). Government funding for research hence facilitates product, process, and service innovation and fosters the creation of networks, new instruments and methods (Salter & Martin, 2001). While governments often prioritize certain sectors or technologies, knowledge may spill over to other sectors and increase the potential for recombination and innovation in those sectors as well (Feldman & Kelley, 2006).

Despite the benefits of R&D subsidies for individual firms seeking to acquire funding for their innovation projects, there has been a long-standing debate about whether such subsidies are beneficial overall (Howell, 2017). Governments may not be able to select the most promising firms and innovation projects, industries or technologies due to information asymmetries, and R&D subsidies may narrow the scope of firms' search processes to areas which do not necessarily contain the most promising solutions to innovation problems but provide access to those subsidy programs (Ely et al., 2014). Moreover, doubts have been expressed whether R&D subsidies are effective. A large number of studies embedded mainly in the economics literature has therefore applied econometric techniques to investigate the additionality of R&D subsidies in terms of inputs, outputs, and firm behavior (e.g., Czarnitzki & Toole, 2007; Gonzalez & Pazo, 2008; Jaffe & Le, 2015; Howell, 2017).

Input additionality addresses the question whether a subsidy has the intended effect and motivates firms' continued efforts in R&D or whether the subsidy merely crowds out investment that would have been undertaken anyway, inhibiting a net increase in R&D. Subsidies may also increase the costs of finite R&D inputs, and input providers such as R&D employees may appropriate a considerable share of the value of the subsidy (David et al., 2000; Clarysse et al., 2009). Overall, prior research suggests that there is no or only partial crowding out of R&D investments that firms would have undertaken anyway (e.g., Jaffe & Le, 2015).

While R&D input decisions are important, arguably the more interesting question is whether R&D subsidies also benefit innovation outcomes. In that sense, output additionality refers to the outcomes of the R&D process that could not have been attained without the R&D subsidy (Aerts & Schmidt, 2008).

The assessment of R&D outputs is complicated by measurement issues in that many other factors determine the success of innovation outcomes that hamper the attribution of outcomes to the receipt of a specific subsidy (Klette et al., 2000). A possible way out, although somewhat distant from the actual commercialization success, is an evaluation of patent or publication outputs in response to a subsidy. In a quasi-experimental study, Howell (2017) finds that R&D subsidies have statistically significant and economically large effects on measures of innovative, financial, and commercial success, confirming the notion of output additionality. Her results suggest that the benefits primarily arise because R&D subsidies enable proof-of-concept work that the firm would not be able to finance otherwise.

Finally, recent literature has begun to focus on the learning effects that take place in firms as a result of a subsidy and has referred to these effects as behavioral additionality (Clarysse et al., 2009). Many R&D subsidies seek to induce innovation collaboration between firms and/or other actors in an innovation system (e.g., OECD, 2006; Gök & Edler, 2012), which in turn have frequently been shown to increase innovation performance (e.g., Un et al., 2010). In sum, extant literature identifies the benefits of R&D subsidies. However, without subsidy-induced changes in firm behavior government funding may simply redistribute the opportunities for innovation rather than increasing them overall (Zúñiga-Vicente et al., 2014; Becker, 2015; Dimos & Pugh, 2016).

For the purpose of our study, it is important to identify distinct additionality effects for subsidiaries of foreign MNCs. Put differently, we seek to understand whether foreign MNC subsidiaries react differently to host-country R&D subsidies and not just like any other firm in the host country. In that sense, there is input additionality if foreign MNC subsidiaries increase their R&D investments more than comparable domestic firms when receiving a host-country R&D subsidy. There is output additionality if foreign MNC subsidiaries increase their innovation performance more than comparable domestic firms because of the subsidy-induced R&D investment. There is behavioral additionality if the subsidy-induced R&D investment increases innovation performance more than the R&D investment that the MNC subsidiary would have undertaken anyway. It is important to note that our conceptualization of R&D subsidies does not account for the heterogeneity in subsidy instruments. Our theorizing is based on an “average”

R&D subsidy, assuming that the mechanisms discussed are effective irrespective of the concrete subsidy design and implementation. This conceptualization is also consistent with our empirical setup.

Research context: Government R&D subsidies in Germany

Given existing insights into the heterogeneity in innovation activities of foreign MNC subsidiaries and additionality effects from government R&D subsidies, we focus on a particular host-country context. More precisely, we explore input, output and behavioral additionality effects of host-country R&D subsidies on innovation in foreign MNC subsidiaries in Germany. Germany is a particularly fitting context for both relevance as well as methodological reasons.

In terms of relevance, Germany is an interesting host country to study since its economy is both R&D intensive and highly internationalized. The R&D intensity of the German economy is approaching 3% of GDP with consistent increases from both government and business investments over several years (Sofka et al., 2018). In terms of internationalization, Germany is a major foreign direct investor both in terms of outflows (FDI outflow positions of 43.5% of GDP in 2017) as well as inflows (FDI inflow positions of 25.7% of GDP in 2017) (OECD, 2019). Besides, MNCs have operated subsidiaries in Germany for a long time, for example investments by US car manufacturers General Motors and Ford date back to the first half of the 20th century (de Faria & Sofka, 2010).

Studying Germany as a host country has also several methodological advantages. First, Germany has stable institutional conditions which could potentially affect R&D decisions such as strong intellectual property rights regimes (Park, 2008; Papageorgiadis & Sofka, 2020) as well as continuous political support for innovation (EFI, 2017). Second, Germany does not provide R&D tax credits (Sofka et al., 2018). Hence, government R&D subsidies are discernable grants based on application systems. Third, Germany has extremely low restrictions for FDI, which could potentially constrain MNC decisions. The OECD calculates the Foreign Direct Investment Regulatory Restrictiveness Index for Germany to be 0.02 in 2017 with 1 indicating maximum restrictiveness.[3] Finally, Germany provides information and administrative

[3] Source: https://goingdigital.oecd.org/en/indicator/74/, date of access: March 2019.

support for potential foreign investors (Germany Trade & Invest, GATI.de) but does not provide tax incentives.

Research and innovation policy in Germany is the shared responsibility of the Federal Government and the 16 State ("Laender") Governments. At the federal level, the Federal Ministry of Education and Research (BMBF) drives most policy initiatives while the Federal Ministry of Economics and Energy (BMWi) is involved in certain areas (Sofka et al., 2018). Support for research and innovation in private firms is an important component of Germany's High-Tech Strategy and National Reform Programmes (NRP, 2017). German firms can apply for government support, following formal application processes and the guidelines of the European Union (BMBF, 2016a). The typical support instrument is a grant.

There is a broad variety of support schemes in place which are often times operated by specialized project management organizations ("Projekttraeger") or associations like the German Federation of Industrial Research Associations (AiF) "Otto von Guericke" (Sofka & Sprutacz, 2017). Other policy initiatives target particular topical areas, e.g. IT security (BMBF, 2016c) or groups of firms like startups (e.g. High-Tech Startup Fund) or small/medium sized firms ("Mittelstand") (RKW, 2017). State Governments complement the support schemes of the Federal Government with their own measures (BMBF, 2016b). Often times these measures reflect the priorities or structures of the state. For example, the state of Baden-Wuerttemberg identifies sustainable mobility as one of its research priority topics (Sofka et al., 2018).

In sum, Germany serves as a fitting host-country context for our study combining high relevance with limited potentials for biases from confounding factors at the country level. We lay out an empirical strategy for identifying input, output and behavioral additionality in the next section.

DATA AND METHODS

Data

Our empirical study utilizes a merged dataset combining data from a representative innovation survey of firms in Germany with patent statistics from the European Patent Office (EPO). The survey data stem from the "Mannheim Innovation Panel" (MIP) which is the German contribution to the Community Innovation Survey (CIS) of the European Union. In contrast to many other CIS surveys, the MIP is conducted annually and allows the construction of an unbalanced firm panel dataset. MIP respondents are responsible for innovation topics in their firms with titles such as CEO, head of R&D or innovation management. These respondents are asked to provide answers to a comprehensive set of questions about innovation inputs as well as outputs and to assign importance ratings (Criscuolo et al., 2005). The MIP provides a stratified random sample, which is representative for firms in Germany. Non-response analyses show no systematic distortions between responding and non-responding firms (Rammer et al., 2005).

CIS surveys have been used frequently in recent leading management journal publications (e.g. Klingebiel & Rammer, 2014; Wadhwa et al., 2017) and benefit from a range of quality features. First, CIS methodology and questionnaires comply directly with the Oslo manual of the OECD for measuring innovation (OECD, 2005). Response accuracy benefits from the use of examples and detailed definitions. Second, the CIS survey process emphasizes interpretability, reliability and validity through pre-tests and pilot studies (Laursen & Salter, 2006). Given that CIS surveys have been conducted for more than a decade in the European Union, the process benefits from experience effects spanning countries, industries and firms. Third, items of the questionnaire are routinely reviewed by scientific advisory boards. Eurostat (2009) considers CIS data from Germany as high quality.

We obtain firm information from the MIP for the years 2000, 2002, 2003, 2004 and 2006. The survey waves providing information for the years 2001 and 2005 are not useful for our analysis since they do not include questions on the receipt of R&D subsidies, which is the central variable of our study. The firm information obtained from the MIP is merged with patent statistics from the EPO using assignee names and addresses. Patent statistics are available for longer periods of time than the survey data. We utilize patent applications between 1997 and 2011, i.e. we use the stock of patent applications prior to our survey period as a dynamic fixed effect (Blundell et al., 1995) and patent applications for up to five years after the survey year as outcome variables in a knowledge production function. The section on the empirical approach below provides methodological details.

After dropping observations with missing values, we obtain a dataset with 5,717 firm observations, 5,266 of these can be matched with control firms (see estimation approach below) and will be used for testing our theoretical predictions. 9.7% of these observations stem from subsidiaries of foreign MNCs (see variable definition below).

Estimation strategy

Our estimation strategy has three major components following Czarnitzki & Licht (2006):

1. We estimate a treatment model using propensity score matching to determine whether the receipt of a government R&D subsidiary results in increased R&D investments (input additionality).
2. We use the results from the propensity score matching to separate a firm's R&D investment into a component that is induced by the government subsidy and a component that a firm would have undertaken anyway (counterfactual). We enter both R&D input components into a knowledge production function and assess the effect of the subsidy-induced R&D investments on patenting (output additionality).
3. We compare the effects of subsidy-induced and counterfactual R&D investments on patenting in the knowledge production to determine the relative productivity effect of the subsidized R&D (behavioral additionality).

We determine the specific effects of foreign MNC subsidiaries in all three steps of the empirical study and compare them separately to domestic MNCs as well as domestic firms. All models use a consistent set of control variables described in the section below (Table 1 provides an overview of the variables). The subsequent methods section lays out methodological details.

Variables

Dependent Variable

Our theoretical framework has two major components. First, we investigate input additionality through changes in R&D investments that are induced by host government subsidies. Second, we explore output and behavioral additionality effects based on the outcomes of these subsidy-induced R&D investments on innovation performance. Accordingly, we use two dependent variables. We use a firm's R&D expenditures reported in the survey as the dependent variable for exploring input additionality.

For exploring output and behavioral additionality, we use the number of a focal firm's EPO patent applications in the subsequent five years. Patent statistics have frequently been used to measure the innovation performance of MNC subsidiaries (e.g. Blomkvist et al., 2010). They have the advantage that patent offices define and assess the minimum degree of novelty of an invention qualifying for patent protection ('inventive step') (Encaoua et al., 2006). Hence, patented inventions can be compared across organizations based on this shared standard. While patent statistics have these central advantages for the purpose of our study, it is worth noting that firms, industries and countries vary in the degree to which patent protection is efficient, affordable and effective (Anton & Yao, 2004; Fontana et al., 2013). Hence, the inclusion of suitable control variables is warranted for addressing these characteristics of patent statistics.

Concerning the five-year period, there is a significant time delay between investing in R&D and arriving at a patentable invention. Lengthy patent filing procedures add to these delays. Then again, very long time windows for measuring patent outcomes increase the risk that confounding factors occur in between. We therefore use a five-year time window for estimating our main models and conduct consistency check estimations using shorter time windows (see details in section 'consistency checks' below).

Explanatory Variables

Our central independent variable of interest is whether a firm in our sample is a subsidiary of a foreign MNC. We identify these firms based on a dummy variable for firms indicating that they are part of a company group with headquarters abroad in line with previous research on the innovation activities of foreign MNC subsidiaries (Sofka et al., 2014).

For exploring output and behavioral additionality effects, we include an independent variable for the amount of R&D investment that was induced by host-country government subsidies. Respondents indicate in the innovation survey whether they have received an R&D subsidy from the German government (state and/or federal level).[4] We rely on a matching approach (see the detailed methodological explanation below under 'empirical approach') to separate the subsidy-induced R&D investment from the amount of R&D investment that a firm would have undertaken anyway, i.e. the counterfactual R&D investment in the absence of the government subsidy. The counterfactual R&D investment is also included in the estimation model.

We include additional control variables to capture other factors, which could potentially affect firm's innovation performance. First, we control for firms that are part of a domestic MNC by adding a control variable for firms indicating that they are part of a company group with headquarters in Germany. This implies that domestic firms are the reference group in all estimations. Second, we take into account that firms differ in their resource endowments based on their size (number of employees in logs) as well as age (number of years since foundation in Germany). Third, we control for differences in firms' innovation capacities. We control for a firm's patent applications in the year of observation since these inventions are likely to predate the R&D that was induced by a government subsidy. We capture differences in the skill-sets of employees by controlling for the share of employees with college education. We add a dummy variable for whether the firm engages in R&D continuously. This variable is frequently used to indicate the presence of a dedicated R&D department (Czarnitzki & Licht, 2006; Koehler et al., 2012). We control for the degree of internationalization through the share of exports in firm sales since internationalization has been found to affect a firm's innovation activities (Cassiman & Golovko, 2011). Additionally, we include a dummy variable for whether a firm engages in process innovation since such activities may affect its ability to patent.

Fourth, we control for potential time and industry-level effects by including four year dummy variables (the year 2000 serves as the reference group) and five industry dummy variables based on grouped

[4] The related question in the survey introduces government subsidies as support for R&D and/or innovation with a short description. Afterwards, respondents choose the funding source. Within our context, a government R&D subsidy can be obtained from the federal government or one of the 16 state governments in Germany in which the firm operates. Firms might obtain multiple grants from one or multiple government sources but this information is not available in the survey.

two-digit NACE codes which have been used frequently in previous innovation studies (Grimpe et al., 2017). The industry dummies encompass medium high-tech manufacturing (e.g., motor vehicles), high-tech manufacturing (e.g. medical devices), distributive services (e.g. logistics), knowledge-intensive services (e.g. consulting) as well as technological services (e.g. ICT-related services). Low-tech manufacturing will serve as the reference group. Appendix 1 provides the detailed industry codes and classification.

Finally, we control for any other potential factor influencing patent activity by including the patent application of firms in the three years preceding our sample, i.e. 1997, 1998 and 1999, following Blundell et al. (2002) (see empirical approach below for methodological considerations of including pre-sample information).

Method

Treatment Model

We rely on a treatment model to estimate the degree to which a firm's R&D investment was induced by an R&D subsidy. Implicit in this notion is the idea that the focal firm would have made at least some R&D investments if it had not received the subsidy, i.e. there is a counterfactual R&D investment that is not readily observable. Hence, a firm's actual R&D investment can be split up into a counterfactual R&D investment and a subsidy-induced R&D part. We would identify distinct input additionality effects if the subsidy-induced R&D of foreign MNC subsidiaries was significantly larger than the one for domestic firms.

We apply a matching estimator to establish the effect of a subsidy (i.e. the treatment) on R&D investment. Matching estimation takes into account that the receipt of a subsidy is not random, i.e. some firms are more likely than others to apply for subsidies and some applications are more likely to be granted. Matching approaches have been frequently used in the literature to assess the effects of R&D subsidies (see Zúñiga-Vicente et al., 2014, for a recent review) and receive increasing attention in International Business research (Chang & Chung, 2017, provide a review).

Matching estimators rely on observable characteristics to match each treated firm, i.e. subsidy recipients, with a comparable control firm, thereby creating a quasi-experimental setting. A comparison between such matched treated and control firms would not suffer from selection biases (Heckman et al., 1998) and the difference in R&D investment between a subsidized firm and its matched control can be interpreted as induced by the subsidy.

In line with most matching studies, we rely on propensity score matching in which we estimate the propensity for a firm to receive a subsidy based on observable characteristics using a probit estimation (Rosenbaum & Rubin, 1983).[5] Subsequently, we match treated and control firms based on the propensity score and test whether there are any remaining significant differences between the matched pairs, i.e. the matched sample is balanced. To achieve a balanced match we impose common support by dropping the 5% of treated observations for which the density of control observations is the lowest, i.e. it is increasingly unlikely to find good matches (Caliendo & Kopeinig, 2008, provide an overview of matching choices). We use the following variables in line with previous literature to predict the propensity of a firm to receive an R&D subsidy: two dummy variables for whether the firm is part of a foreign or domestic MNC respectively, firm size (number of employees in logs), firm age in years since founding, patent stock in logs, exports as a share of sales, five industry group dummies (described above) and four year dummies (2002, 2003, 2004, 2006). These variables are designed to make subsidized firms comparable to their counterparts, e.g. with regard to their historical R&D performance measured as the patent stock.

Following this matching procedure, we can describe the counterfactual R&D investment of a subsidized firm as its matched non-subsidized control firm. We subtract the counterfactual R&D investment of a subsidized firm from its actual R&D investment and obtain the subsidy-induced R&D investment. For non-subsidized firms, counterfactual R&D investment equals actual R&D investment and subsidy-induced R&D investment equals zero. There is a distinct additionality effect for R&D subsidies for foreign

[5] Ideally, we would like to use the amount of the R&D subsidy but this information is not available to us. Most studies on R&D additionality share this data availability problem.

MNC subsidiaries if the subsidy-induced R&D investment of foreign MNC subsidiaries is significantly larger than the one of domestic firms.[6]

Knowledge Production Function

We use the matched sample of 5,266 firm observations obtained in the first step of the analysis to estimate a knowledge production function predicting patent applications over the next five years. This dependent variable requires some consideration on the estimation strategy. First, the dependent variable is a count variable (i.e. patent applications) with high dispersion (mean=0.62, standard deviation=4.45). We conduct a likelihood ratio test for whether Poisson regressions or negative binomial models are more appropriate. The test rejects the former (alpha=3.96, P>chibar2=0.00).

Second, many firms in our sample do not patent which could make zero-inflated negative binomial regressions more appropriate. We conduct the test suggested by Vuong (1989) and find support for zero inflation (z=3.21, P>z=0.00). Desmarais & Harden (2013) suggest both AIC (Akaike) and BIC (Schwarz) based corrections of the original Voung test. Both correction tests support zero-inflation at the 99% significance level. Zero-inflated negative binomial regressions require the definition of a condition determining the observation of zero counts. Firms' patent propensity is typically determined by the technological and institutional conditions of the industry (Arundel & Kabla, 1998; Fontana et al., 2013). We capture these industry differences by calculating the share of firms in an industry (two-digit NACE) that has filed for EPO patent applications prior to our estimation sample between 1995 and 1999, based on the representative innovation survey for Germany.

Finally, unobserved factors may exist that influence both independent as well as dependent variables in our estimations. Given the unbalanced nature of our panel data, we include pre-sample information of the dependent variable which allows controlling for unobserved, firm-specific factors going beyond a simple dummy variable (Bond & Van Reenen, 2007; Lach & Schankerman, 2008). Salomon & Jin (2010)

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[6] We bootstrap the standard errors of all t-tests since the matched sample is not random.

apply this approach to patent statistics and use a three year time window. We follow this approach and include patent applications of firms in the three years preceding our sample, i.e. 1997, 1998 and 1999.

We use multiplicative interaction terms for exploring output and behavioral additionality effects. There would be a distinct output additionality effect from R&D subsidies for foreign MNC subsidiaries if the interaction effect between subsidy-induced R&D investment and foreign MNC was positive and significant. Behavioral additionality effects from providing R&D subsidies for foreign MNC subsidiaries would exist if the interaction effect between subsidy-induced R&D investment and foreign MNC was significantly larger than the interaction effect between counterfactual R&D investment and foreign MNC.

Robustness Checks

We conduct a number of consistency checks. First, we test whether results are sensitive to the choice of matching estimator. Matching estimations can be inefficient when they only take information from the nearest neighbor control observation into account. We repeat the matching procedure using a Gaussian kernel matching procedure as an alternative approach. Kernel matching does not rely on individual control observations for each treated firm but uses the weighted average of all control observations (Caliendo & Kopeinig, 2008). Differences in the propensity score between a treated firm and control observations serve as weights and the kernel distribution determines how averages are calculated.

Second, as discussed in the description of the dependent variable, we assume for the main model specifications of the regression analysis that it takes firms five years to turn R&D investments (subsidized or otherwise) into an invention and patent it. Confounding factors may influence patenting during this time period. Hence, we repeat all zero-inflated negative binomial regression analyses using patenting in the subsequent four as well as three years respectively.

Finally, significant effects may be driven by the fact that firms in our sample are MNCs but not necessarily that they are foreign ones. To eliminate such potential biases, we estimate the zero-inflated negative binomial regression models and include interaction terms of R&D (both subsidized and counterfactual) with domestic MNCs as well. This allows a comparison between interaction effects with foreign as well as domestic MNCs.

RESULTS

Table 2 shows the descriptive statistics of our dataset. Firms spend on average € 329,184 (4.5% of their sales) on R&D and 33% of them have received an R&D subsidy from state or federal governments. They are on average 24 years old and have 183 employees. 36% of their sales originate from exports. 31% of firms operate in low or medium tech manufacturing sectors, 19% in medium high-tech manufacturing. 9.6% of firms are part of a foreign MNC while 10.2% are part of a domestic MNC, i.e. headquartered in Germany. We inspect the data for multicollinearity based on pair-wise correlations (seeTable 3) as well as variance inflation factors (VIF) and find no indication of multicollinearity (largest VIF: 1.64, mean VIF: 1.37).[7] Appendix 4 and Appendix 5 show the respective descriptive and correlation statistics for the matched sample in the estimation of the knowledge production function. We also test for the presence of common method bias using Harman's one-factor test, which can be rejected.[8]

[Insert Table 2 about here]

[Insert Table 3 about here]

Results for input additionality effects

We estimate the probability of a firm for receiving an R&D subsidy by using a probit model. This estimation will subsequently be used to predict the propensity scores for obtaining an R&D subsidy for all firms whether they have actually received an R&D subsidy or not. Table 4 shows the results of the probit estimation.

[Insert Table 4 about here]

Subsidiaries of both foreign and domestic MNCs have a significantly lower probability (99% level) for receiving an R&D subsidy. Calculating the marginal effects, the probability for receiving an R&D sub-

[7] We perform zero-inflated negative binomial regressions using the sample of 5,266 observations that can be matched. This sample has similarly low variance inflation factors, the maximum reaching 2.08 and the mean 1.39.
[8] A principal component analysis of all model variables identifies eight factors with an eigenvalue greater than one with a maximum of 15 percent of the variance explained by a single factor. Hence, there is no indication for common method bias (Podsakoff & Organ, 1986).

sidy is 9.2% lower for foreign MNCs and 8.4% lower for domestic MNCs. However, there is no significant difference between the estimated coefficients of these two groups ($p>0.75$). The probit estimation shows also several other factors which significantly influence the probability for receiving R&D subsidies. The probability for receiving an R&D subsidy significantly increases for younger firms, with increasing patent stocks and export intensity (all significant at 99% level). There are also differences between industries. Firms in medium high-tech and high-tech manufacturing as well as technological service sectors have significantly higher probabilities (99% level) for receiving R&D subsidies. Firms in distributive (e.g. logistics) and knowledge-intensive services (e.g. consulting) have significantly lower probabilities (99% level) for receiving R&D subsidies. These patterns can emerge because of differences in the technological needs and opportunities of firms or based on subsidy programs targeting particular firms (e.g. new ventures) or sectors.

We use the probit model to predict propensity scores for each firm observation of receiving an R&D subsidy. Subsequently, we implement the nearest neighbor matching described in the empirical approach and match each treated firm which had received an R&D subsidy with a control firm that had the most similar propensity score but did not receive a subsidy. Caliendo & Kopeinig (2008) suggest a number of steps to verify the quality of the matching procedure. Most importantly, we test for remaining, significant differences between treated and control firms across all independent variables that we had used in the probit estimation. Appendix 2 shows details of this mean comparison. No significant differences between treated and matched control firms remain. Besides, we repeat the probit estimation for the sample of treated and matched control firms. The model fit for this model is significantly lower (McKelvey and Zavoina's R2 is 0.01) compared with the original probit model (0.26). This drop in model fit indicates that the matched sample is so well balanced that the receipt of an R&D subsidy is difficult to predict.

We calculate the difference between each treated firm's R&D investment and the R&D investment of its matched control firm. The difference represents the average treatment effect on the treated (ATT) firms, i.e. the amount of R&D that was induced by receiving a subsidy. The ATT amounts to € 202,096 (boostrapped standard error 46,298). The R&D investment of the matched control group can be interpreted as the counterfactual R&D investment that a subsidized firm would have undertaken anyway. We conduct a mean comparison test for the subsidy-induced R&D investment using bootstrapped standard errors given that the matched sample is not random. We find a positive and significant average effect of the subsidy-induced R&D (99% level). Positive values indicate that firms have not simply replaced R&D investments that they would have undertaken anyway with subsidized ones.

For exploring additionality effects that are distinct for foreign MNC subsidiaries, we apply a mean comparison t-test using bootstrapped standard errors. We test whether subsidy-induced R&D investment is significantly different for subsidiaries of foreign MNCs compared to domestic firms. This test is supported with a significance level of 99%. The average subsidy-induced R&D investment for foreign MNC subsidiaries is € 809,060 (s.e. 257,728) compared to € 137,614 (s.e. 36,269) for the average domestic firm. We repeat the t-test using domestic MNCs as reference group with subsidy-induced R&D investments of € 360,498. While the subsidy effect is still nominally stronger for foreign MNCs, the difference in subsidy-induced R&D investment is not significantly different compared with domestic MNCs (80% level).

Taken together, we find positive input additionality effects from host-country R&D subsidies for foreign MNC subsidiaries when compared with domestic firms but not when compared with domestic MNCs. These results suggest that distinct input additionality effects emerge from an MNC effect but not necessarily from a distinction between foreign and domestic MNCs.

Results for output and behavioral additionality effects

We estimate a knowledge production function utilizing counterfactual and subsidy-induced R&D investments obtained in the matching procedure. We estimate zero-inflated negative binomial regression models predicting patent applications in the subsequent five years. Table 5 shows the results.

[Insert Table 5 about here]

We rely on the patent propensity of a focal firm's industry (share of firms with patent application 1995-1999) to predict zero patent applications within our zero-inflated negative binomial model. This variable is consistently negative and significant at the 99% level, i.e. indicating that firms in industries with high patent propensity are less likely to experience zero patent applications. We introduce the variables of interest for testing output and behavioral additionality stepwise. Model 1 contains all control variables. For exploring output additionality, we include the interaction term between foreign MNC and subsidy-induced R&D investment in model 2. The estimated coefficient is positive and significant at the 92% level. This result supports output additionality effects in the sense that subsidy-induced R&D investment in subsidiaries of foreign MNCs will have a higher effect on innovation performance than in a comparable domestic firm.

We include an additional interaction effect in model 3 for exploring behavioral additionality. The added interaction multiplies foreign MNC with counterfactual R&D. The coefficient of this interaction is negative and significant at the 97% level. Behavioral additionality is supported if the coefficient of the interaction of foreign MNC with subsidy-induced R&D was significantly larger than for the interaction with counterfactual R&D. The main effect of the interaction with subsidy-induced R&D remains positive and significant in model 3, albeit at the 88% level. We conduct a Wald test for equality of the coefficients of the two interaction terms. The test rejects equality with a significance level of 99% (chi2=7.26). Hence, we find support for behavioral additionality effects, which implies that the subsidy-induced R&D investment in foreign MNC subsidiaries has a larger effect on innovation performance than the R&D investment that the subsidiary would have undertaken in the absence of the subsidy.

Focusing on the control variables in the models, we find that subsidy-induced as well as counterfactual R&D do on average not significantly increase patent applications in the subsequent five years. However, many structural features of firms have significant positive effects. Patent applications increase significantly with firm size and age as well as having a larger share of employees with college education. Similarly, export intensity increases patent applications. Firms engaging in continuous R&D as well as with patent applications in the year of the observation are also significantly more likely to increase their patent applications. Process innovations lower a firm's patent applications significantly. We find similar industry effects on patent activity as previous studies (e.g. Arundel & Kabla, 1998). Firms in medium and high-tech manufacturing as well as in technological services have significantly more patent applications. Finally, the pre-sample information about patent applications three years prior to our observation period is positive and significant, indicating that firm-specific, otherwise unobserved factors increase the number of patent applications.

Robustness Checks

We conduct several robustness check estimations to demonstrate the consistency of our results. All results are available from the authors upon request if not referenced differently. First, we use an alternative matching estimator by relying on Gaussian kernel matching. Kernel matching uses all control observations and uses the propensity score for calculating a weighted average, which can be compared to treated firms. We rely on the same propensity score estimates as for the nearest neighbor matching and can also obtain a balanced sample with no remaining significant difference between treated firms and matched controls after matching (Appendix 3 provides details). We calculate subsidy-induced R&D investments and test whether the effect is stronger for foreign MNCs using a mean-comparison test with bootstrapped standard errors (mean difference € 802,846; s.e. 324,441). We find support at the 98% significance level. Hence, matching results are consistent with our main models for input additionality.

Second, we repeat all zero-inflated negative binomial regressions taking only patent applications as dependent variable into account that occur in the subsequent 3 and 4 years. While shorter time periods reduce the odds of confounding factors occurring in the meantime, they also reduce the odds of capturing patent applications originating from subsidy-induced R&D taking more time to develop. Appendix 6 shows the equivalent regression tables to models 2 and 3 from the main models. All relationships for output and behavioral additionality are consistently supported.

Third, we test to what degree the effects of subsidized and counterfactual R&D on innovation performance would equally apply to subsidiaries of foreign and domestic MNCs. We create analogous interaction terms and re-estimate zero-inflated negative binomial regressions using the specification of our main models. Appendix 7 shows the results. We find no significant interaction effects of domestic MNC with neither subsidy-induced R&D nor counterfactual R&D. The respective interaction effects with foreign

MNC remain, however, fully consistent with the main models. We conclude that output and behavioral additionality effects are specific to subsidiaries of foreign MNCs and cannot be generalized to all MNC subsidiaries.

Finally, we conduct a difference-in-difference matching approach (DDM) which compares R&D investment before and after treatment (R&D subsidy) while using firm-fixed effects (Hijzen et al., 2013). This approach requires a balanced sample. However, few firms in our sample respond to the innovation survey twice in a row. Eventually, we retain a small sample of 641 observations from 432 firms. Given the drastic drop in sample size, the fit of the models is low and the results, although supportive of the main models, are not completely robust. The estimations show that foreign MNC subsidiaries spend less on R&D prior to the subsidy and more afterwards (at a 90% significance level). When we distinguish between domestic firms and domestic MNCs as a reference group, in line with the approach of our main models, the overall pattern for foreign MNC subsidiaries is supported. However, the significance level for the positive effect of the subsidy drops to 79%. Given the low number of observations, the DDM approach provides a certain measure of confidence in the matching approach of the main models.

INTERPRETING THE FINDINGS

Following these empirical findings, we connect them with a theoretical logic. We structure the discussion along the dimensions of input, output and behavioral additionality effects.

Input additionality effects

Our empirical findings support input additionality effects from host-country R&D subsidies on R&D investments of foreign MNC subsidiaries. However, the effect depends on the comparison group. Foreign MNC subsidiaries invest significantly more in R&D when receiving an R&D subsidy than comparable domestic firms do but we find no significant difference compared with domestic MNCs. In other words, we identify a general MNC effect (both foreign and domestic).

We suspect that this general MNC effect on input additionality originates from the relationship between MNC subsidiaries and the headquarters, which is typically characterized by information asymmetries. Headquarters associate uncertainty with the extent to which subsidiaries are actually capable of fulfilling a competence-creating mandate. As a result, subsidiary decisions on R&D investments are largely controlled by the headquarters that seek to optimize R&D investment across all subsidiaries in the MNC network. Kuemmerle (1997) argues that parent firms often demand coordination and control of foreign R&D activities in order to facilitate certain behavior. We suggest that the receipt of an R&D subsidy can have a signaling effect for the quality of R&D at a subsidiary. Receiving a subsidy has frequently been characterized as a form of certification (e.g., Howell, 2017) in the sense that the subsidy conveys positive information about the firm's technology. Subsidies may therefore serve as positive signals that reduce information asymmetries within the MNC network. Subsidiaries with a subsidy are hence more likely to receive an increasingly explorative mandate and to spend more on R&D. In other words, a subsidiary that secures R&D subsidies in its host market can attract more funding internally.

Signaling theory describes the process by which one party can credibly convey information about itself to another party in situations of information asymmetry (Spence, 1973; Connelly et al., 2011). A credible signal needs to be both observable and costly to imitate (Ross, 1977). R&D subsidies can signal research capability because they are typically awarded through funding competitions in which individual firms or consortia of organizations compete for the allocation of research funding in order to realize a certain R&D project (Olsen et al., 2016). R&D subsidies are reliable or credible to the receiver of the signal because they correspond with the sought-after quality of the party sending the signal ("signal fit"). Conversely, a domestic firm could not use an R&D subsidy as a signal to shift R&D investment internally. In other words, R&D subsidies result in higher input additionality for MNC subsidiaries compared to domestic firms but not necessarily with domestic MNCs. Since multi-location firms are less dependent on any single location, locally based subsidiaries have a strong incentive to signal their competence through the receipt of R&D subsidies (Cantwell & Mudambi, 2005).

Obviously, this interpretation of the empirical findings based on signaling theory rests on the assumption that R&D management at global headquarters is not fully informed about the quality of R&D

capabilities in all subsidiaries, so that host-country subsidies can reveal additional information. If this assumption is true, foreign MNC subsidiaries receiving host-country R&D subsidies could be of exceptionally high quality since they overcame this additional hurdle in the first place. On the one hand, our selection equation points in this direction by identifying a significant negative effect of foreign MNC subsidiaries receiving an R&D subsidy in the first place. On the other hand, the same negative effect exists for domestic MNCs. This is remarkable, given that domestic MNCs are likely to be comparatively more embedded in a host-country innovation system. In sum, while we cannot rule out such selection effects, the empirical findings cannot identify it based on the observable data. Our first proposition therefore reads:

Proposition 1: Host-country R&D subsidies are positively related to the R&D investments of foreign MNC subsidiaries and domestic MNCs while the relationship with domestic firms that are not part of an MNC is comparatively weaker.

Output additionality effects

We find distinct, positive output additionality effects for foreign MNC subsidiaries receiving host-country R&D subsidies irrespective of the reference group. Put differently, R&D investments induced by R&D subsidies result in significantly larger patent outputs than similar subsidy-induced R&D investments of domestic firms (including domestic MNCs).

We suspect that this distinct output additionality effect for foreign MNC subsidiaries emerges from their particular internal and external embeddedness in larger communities and networks (Song et al., 2011). These networks have frequently been shown to exert significant influence on innovation and learning in MNCs (e.g., Kogut & Zander, 1993; Andersson et al., 2001). While internal embeddedness refers to the exchange of knowledge and adaptation of resources in the relationship between the subsidiary and the other units of the MNC, external embeddedness describes the network with research and engineering communities in the host location (Asakawa, 1996).

Subsidy-induced R&D investment by a foreign MNC subsidiary will have a more positive effect on innovation performance than subsidy-induced R&D by comparable domestic firms because of the subsidiary's internal embeddedness. Based on the notion of MNCs as social communities which facilitate knowledge transfer and recombination within the MNC network (Kogut & Zander, 1993), the patterns of knowledge flows within the MNC lead to reciprocity and enable a more comprehensive exploitation of newly acquired knowledge (Cantwell, 2017). The embeddedness into an MNC network increases the knowledge pool available for recombination, and internal embeddedness grants access to more diverse knowledge elements that enhance the scope for new useful recombination (Katila & Ahuja, 2002). In that sense, our results for foreign MNC subsidiaries advance prior research which has found large effects of R&D subsidies on innovative, financial, and commercial success (Howell, 2017). We conclude in our second proposition:

> *Proposition 2: Host-country R&D subsidies are positively related to the innovation performance of foreign MNC subsidiaries while the relationship with domestic firms, both MNCs and non-MNC related, is comparatively weaker.*

Behavioral additionality effects

Finally, our empirical results indicate distinct behavioral additionality effects from host-country R&D subsidies for foreign MNC subsidiaries. More precisely, we find that foreign MNC subsidiaries use subsidy-induced R&D investments more productively, i.e. resulting in more patent applications than the counterfactual R&D investments that they would have undertaken anyway. Hence, there seems to be a shift in the nature of R&D activities at foreign MNC subsidiaries once they have received a host-country subsidy.

We attribute this behavioral effect to subsidiary evolution (Birkinshaw & Hood, 1998) in response to the support from the host country. In other words, we suggest that the host-country subsidy effectuates behavioral additionality in that it leads to learning effects within the firm. Subsidiaries have frequently been characterized as evolving over time by accumulating resources and developing specialized capabilities (e.g., Hedlund, 1986). Birkinshaw and Hood (1998) argue that subsidiary evolution is driven by head-office assignments, the subsidiary's own choices, and the local environment. They suggest a cyclical process in which one determinant causes change in another, leading to transformations in the subsidiary's role over time. In that sense, head-office assignments typically determine subsidiary evolution in the early stages of the process, particularly when the subsidiary's resources and capabilities are not too advanced. Subsidiaries then evolve oftentimes through their own initiative toward more sophisticated and higher value-added R&D activities (Distel et al., 2019). Furthermore, the local environment shapes subsidiary evolution: Hood, Young, and Lal (1994), for example, document how government agencies help existing subsidiaries improve their activities. In sum, this evolutionary process can bring about the development of specialized capabilities on which the MNC network is dependent. As a result, it is reflected in the subsidiary's charter which describes the shared understanding between the subsidiary and the headquarters about the scope and responsibilities of the subsidiary's activities (Birkinshaw & Hood, 1998).

We suspect that the receipt of an R&D subsidy offers opportunities for the subsidiary to change the direction of its R&D activities. These changes may be particularly driven by a subsidiary's engagement in innovation collaboration, which innovation subsidies frequently seek to induce (e.g., Gök & Edler, 2012; OECD, 2006; Veugelers, 2015). Although our empirical models do not explicitly address innovation collaboration due to data availability limitations, prior research has frequently documented the positive effect of collaboration on innovation performance (e.g., Un et al., 2010). Innovation collaboration enables joint learning (Bäck & Kohtamäki, 2016) and access to complementary knowledge and technology (Fitjar & Rodríguez-Pose, 2013). In that sense, collaboration may allow subsidiaries to develop capabilities that the rest of the MNC is dependent on to a higher degree, which likely increases the attention that the subsidiary will get and in turn also the access to resources from the MNC network. This increases the potential for recombination and therefore also innovation performance while these productivity effects cannot be expected to occur for a subsidiary's counterfactual (and relatively less collaborative) R&D activities that the subsidiary would have engaged in without the R&D subsidy. Our third proposition thus reads:

> *Proposition 3: The MNC subsidiary investments in R&D that are induced by a host-country R&D subsidy are associated with higher innovation performance than the counterfactual R&D investments that the MNC subsidiary would have undertaken anyway.*

CONCLUSIONS

Adding to the literature on how host-country policy influences MNC behavior and activities, this study examines the role that host-country technology policy, particularly R&D subsidies, plays in motivating MNC subsidiaries to expand their activities towards innovation and exploration. We rely on longitudinal data on R&D investment, subsidies and innovation performance for a representative sample of 5,266 domestic firms and foreign MNC subsidiaries located in Germany. Our research indicates that host-country R&D subsidies increase R&D investment more in foreign MNC subsidiaries compared to domestic firms but not relative to domestic MNCs (Proposition 1), that R&D subsidies increase the innovation performance more for foreign MNC subsidiaries compared with both domestic firms and domestic MNCs (Proposition 2), and that R&D subsidies redirect innovation activities in foreign MNC subsidiaries in that the subsidy induced R&D is associated with higher innovation performance than the impact of R&D that the subsidiaries would have carried out without the subsidy (Proposition 3). Hence, our research provides a systematic account of how host-country technology policy influences MNCs' innovation activities.

We conclude that foreign MNC subsidiaries are distinct from domestic firms in their reaction to host-country R&D subsidies which we attribute to the nature of MNCs, i.e. the presence of MNCs in multiple countries and the advantages that the access to other countries offer (Un & Cuervo-Cazurra, 2008). In that regard, we highlight potentials for theory integration of mechanisms from the literature on additionality effects of R&D subsidies (e.g., David & Hall, 2000; Blanes & Busom, 2004; Clarysse et al., 2009) with theory on MNC subsidiary R&D decisions (e.g., Cantwell & Mudambi, 2005; Un & Cuervo-Cazurra, 2008; Santangelo et al., 2016). We suggest that MNC subsidiaries can use subsidies as a signal towards the headquarters in order to receive a new or extended competence-creating mandate that stresses innovation and exploration (Cantwell & Mudambi, 2005). As a result, MNC subsidiaries not only spend comparatively more on R&D but they are also able to turn this investment into performance more effectively.

Hence, our research answers a question that is important at a theoretical level because theories on R&D additionality require qualification in the context of comparing MNCs with domestic firms. This specific insight adds to prior literature that has investigated differences in the R&D investments of domestic firms and MNC subsidiaries (Un & Cuervo-Cazurra, 2008). In particular, we introduce the idea that host-country subsidies can function as a signal that can be used by MNC subsidiaries to an extent it could not be used by domestic firms. Our research therefore facilitates a better understanding of technology development in MNCs and suggests that studies ignoring the effect of host-country subsidies on subsidiary R&D decisions and outcomes are likely to suffer from biases. Similarly, we advance research on the input, output and behavioral effects of R&D subsidies (David & Hall, 2000; Blanes & Busom, 2004; Clarysse et al., 2009; Howell, 2017). We uncover that (a) MNCs are per se distinct in their degree of input additionality as a result of R&D subsidies and (b) foreign MNC subsidiaries show unique output and behavioral additionality effects. Taken together, we provide pathways for future theorizing on how the effects of government subsidies for R&D in a country depend on how internationally the recipient firms are organized.

Our research holds important implications for both management and government policy. Managers of MNC subsidiaries not only need to be aware of the – oftentimes – plentiful opportunities to acquire government funding for R&D activities but also to better understand the behavior of domestic competitors in funding competitions. This includes considerations about an "acceptable" degree of opportunistic behavior when deciding on the subsidy-induced R&D investment without jeopardizing the chances of being awarded a subsidy in the future. Most research to date suggests that there is no or only partial crowding out of R&D investments that firms would have undertaken anyway (e.g., Jaffe & Le, 2015), and our research provides further indications that managers use R&D subsidies to advance their firm's competitiveness by enabling new technology development, patent application, and new product introduction. R&D subsidies in that sense seem to be part of a long-term strategy by MNCs to benefit from research carried out at the subsidiary's location.

Moreover, our research is important for policy makers to understand the reaction of different types of firms to R&D subsidies and what can be expected from MNC subsidiaries with regard to R&D investment in the host country. Increasing the R&D activities within subsidiaries also increases the pool of knowledge within a host country, which may eventually spill over to domestic firms. Hence, governments should have strong incentives to encourage R&D investments by foreign MNC subsidiaries to facilitate knowledge spillovers to domestic firms as a by-product (Aitken & Harrison, 1999).

This discussion can be connected to the broader question as to how governments should devise policies to benefit from the globalization of corporate R&D (e.g., Guimón, 2011; Alkemade et al., 2015). Governments across the EU have increasingly sought to connect innovation and FDI promotion policies, and the decision to hand out innovation subsidies may thus have repercussions for the localization of R&D. Our findings regarding the advantages of MNC subsidiaries in translating R&D subsidies into performance outcomes may therefore provide policymakers with an additional rationale for the attraction of inward FDI.

However, this may lead to two, potentially adverse effects. On the one hand, host-country R&D subsidies may lead to an increasing and persistent productivity advantage of foreign MNC subsidiaries over domestic firms. MNCs are often able to enter host-country markets due to their existing productivity advantages (e.g., Haskel et al., 2007). As a consequence, foreign MNC subsidiaries may be able to pay higher wages, attracting the most talented individuals on host-country labour markets which, in turn, stifles domestic firms' ability to catch up (Girma et al., 2019; Becker et al., 2020). While the literature on FDI spillovers has suggested that exposure to foreign firms in the host country through inward FDI can increase the productivity of domestic firms through competition and demonstration effects (Görg & Strobl, 2001; Haskel et al., 2007) and by learning from foreign affiliates in their roles of suppliers and clients of domestic firms (Belderbos & Grimpe, 2020; Kugler, 2006), providing R&D subsidies to foreign MNC subsidiaries may thus be contentious. Our results, however, do not indicate this to be problematic since both foreign and domestic MNCs, relative to non-MNC domestic firms, have a lower probability of receiving an R&D subsidy.

On the other hand, generous R&D subsidies may encourage other countries to provide comparatively higher incentives in order to attract R&D activities by MNCs. Even though our results do not suggest crowding-out effects to be a major problem, one might suspect that an "R&D subsidy race" between different countries may lead to funding those innovation projects that MNCs and their subsidiaries might have undertaken anyway.

In addition, our findings can be connected to the systems of innovation approach, highlighting the interrelationships between innovation system actors that can be influenced by policy (Lundvall, 1992; Chaminade & Edquist, 2008). According to this view, government policy should be particularly concerned with the relationships between MNC subsidiaries that receive R&D subsidies and other innovation system actors such as domestic firms or universities. Governments will likely have higher incentives to provide R&D subsidies to specific actors, such as MNC subsidiaries, if those subsidies lead to positive externalities to other domestic actors, for example through knowledge spillovers. This could be achieved by facilitating collaborative activities between MNC subsidiaries and domestic actors to enable knowledge and technology transfer.

LIMITATIONS AND FUTURE RESEARCH

While our research makes an important contribution to the study of host-country technology policy, several limitations have to be taken into account that in turn provide ample opportunities for further research. From a subsidy perspective, we are constrained in our econometric modeling by the possibilities to observe the size of the R&D subsidy and how often subsidies were received. Such data would allow cost-benefit analyses. Future research may benefit from dedicated research designs that can identify "optimal" levels of R&D subsidies. Moreover, we have no further information about the funding bodies allocating the R&D subsidies, except for a distinction between state and federal levels, or the thematic focus of the subsidy. It would be interesting to study differences in subsidies provided for more basic or more applied research as these might impact the incentives of firms to work with these subsidies. Similarly, heterogeneity among firms may exist because some obtain R&D subsidies regularly and build up capabilities for obtaining them.

On the methodological side, we follow large parts of the literature studying the additionality effects of R&D subsidies by combining matching approaches with regression models. However, all matching approaches are limited by the observable variables on which one can match. Future studies may have access to balanced panel data and apply difference-in-difference matching approaches (e.g. Hijzen et al., 2013) or rule out potential selection biases differently with dedicated research designs. We are also limited in the availability of data on innovation collaboration, which we suggest to be a mechanism through which behavioral additionality effects emerge. Finally, our empirical results are limited to Germany as a host country and cannot be readily generalized to other settings, e.g. to developing counties. We encourage therefore comparative country studies, which compare and contrast our findings. These comparisons could also investigate the directions and strengths of effects during periods of economic crises, which are likely to affect foreign MNC subsidiaries and domestic firms differently.

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BIOGRAPHICAL SKETCH

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TABLES

Table 1: Variable overview

Variable	**Definition**	**Source**
Company age (years)	No. of years since registration in Germany	CREFO company panel
Continuous R&D (d)	Firm performed R&D continuously in the reporting period	MIP survey
Domestic MNC (d)	Firm is part of a multinational group with headquarters in Germany	MIP survey
Foreign MNC subsidiary (d)	Firm is part of a multinational group with headquarters outside Germany	MIP survey
No. of employees (log)	Number of employees in reporting year (log transformed)	MIP survey
Patent appl. (t)	Number of EPO patent applications in reporting year	EPO patent statistics
Patent appl. (t+1, t+5)	Number of EPO patent applications 5 years after the reporting year	EPO patent statistics
Patent appl. 1997-1999	Number of EPO patent applications in the pre-sample period 1997-1999	EPO patent statistics
Process innovator (d)	Firm has introduced a process innovation during the reporting period	MIP survey
R&D investment (€ mn)	Total R&D investment in mn € in reporting year	MIP survey
Receipt domestic R&D subs. (d)	Firm has received an R&D subsidy from the Federal Government of Germany or a State Government during the reporting period	MIP survey
Share empl. w/ college educ.	Share of employees with college education in reporting year	MIP survey
Share exports of sales (ratio)	Share of exports on total sales in reporting year	MIP survey
Total patent stock	Number of EPO patent applications until reporting year	EPO patent statistics
Industry dummies	Industry classification according to Appendix 1	MIP survey
Year dummies	Reporting year	MIP survey

(d) indicates a dummy variable

Table 2: Descriptive statistics

Sample	***All***				***Domestic firms***				***Domestic MNCs***				***Foreign MNC subsidiaries***			
Variable	***Mean***	***Std. Dev.***	***Min***	***Max***	***Mean***	***Std. Dev.***	***Min***	***Max***	***Mean***	***Std. Dev.***	***Min***	***Max***	***Mean***	***Std. Dev.***	***Min***	***Max***
Receipt domestic R&D subs. (d)	0.33	0.47	0.00	1.00	0.34	0.47	0.00	1.00	0.29	0.45	0.00	1.00	0.32	0.47	0.00	1.00
R&D investment (€ mn)	0.34	1.48	0.00	31.37	0.20	1.07	0.00	31.37	0.91	2.23	0.00	27.44	0.95	2.63	0.00	26.14
Foreign MNC subsidiary (d)	0.10	0.29	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
Domestic MNC (d)	0.10	0.30	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
No of employees (log)	4.12	1.47	1.61	8.01	3.82	1.36	1.61	8.01	5.50	1.29	1.79	8.01	5.14	1.24	1.61	8.01
Company age (years)	23.99	22.03	0.00	99.00	23.20	21.60	0.00	99.00	31.25	25.74	0.00	99.00	22.77	19.84	0.00	99.00
Total patent stock	0.81	3.20	0.00	38.25	0.49	2.37	0.00	38.25	2.27	5.55	0.00	37.87	1.93	4.73	0.00	36.04
Share exports of sales (ratio)	0.36	0.48	0.00	2.06	0.29	0.44	0.00	2.00	0.57	0.54	0.00	2.06	0.68	0.57	0.00	1.96
Low-tech manuf. (d)	0.31	0.46	0.00	1.00	0.31	0.46	0.00	1.00	0.34	0.47	0.00	1.00	0.30	0.46	0.00	1.00
Medium high-tech manuf. (d)	0.19	0.39	0.00	1.00	0.17	0.37	0.00	1.00	0.26	0.44	0.00	1.00	0.28	0.45	0.00	1.00
High-tech manuf. (d)	0.11	0.31	0.00	1.00	0.10	0.30	0.00	1.00	0.12	0.32	0.00	1.00	0.17	0.37	0.00	1.00
Distributive services (d)	0.14	0.34	0.00	1.00	0.14	0.35	0.00	1.00	0.11	0.31	0.00	1.00	0.10	0.30	0.00	1.00
Knowledge-intens. services (d)	0.09	0.28	0.00	1.00	0.09	0.29	0.00	1.00	0.07	0.25	0.00	1.00	0.05	0.22	0.00	1.00
Technological services (d)	0.17	0.38	0.00	1.00	0.19	0.39	0.00	1.00	0.11	0.31	0.00	1.00	0.10	0.30	0.00	1.00
Year 2000 (d)	0.22	0.42	0.00	1.00	0.23	0.42	0.00	1.00	0.21	0.41	0.00	1.00	0.20	0.40	0.00	1.00
Year 2002 (d)	0.18	0.38	0.00	1.00	0.18	0.38	0.00	1.00	0.18	0.38	0.00	1.00	0.18	0.39	0.00	1.00
Year 2003 (d)	0.10	0.30	0.00	1.00	0.10	0.30	0.00	1.00	0.12	0.32	0.00	1.00	0.08	0.28	0.00	1.00
Year 2004 (d)	0.28	0.45	0.00	1.00	0.28	0.45	0.00	1.00	0.24	0.43	0.00	1.00	0.27	0.44	0.00	1.00
Year 2006 (d)	0.22	0.42	0.00	1.00	0.21	0.41	0.00	1.00	0.24	0.43	0.00	1.00	0.26	0.44	0.00	1.00
Number of obs.	5,717				4,582				588				547			

Table 3: Pairwise correlations matching sample (n = 5,717)

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Foreign MNC subsidiary (d)	1.00														
2	Domestic MNC (d)	-0.11	1.00													
3	No of employees (log)	0.23	0.32	1.00												
4	Company age (years)	-0.02	0.11	0.32	1.00											
5	Patent stock (ln)	0.16	0.18	0.33	0.16	1.00										
6	Share exports of sales (ratio)	0.21	0.15	0.23	0.10	0.42	1.00									
7	Medium high-tech manuf. (d)	0.08	0.06	0.12	0.05	0.25	0.33	1.00								
8	High-tech manuf. (d)	0.06	0.01	-0.02	-0.06	0.16	0.14	-0.17	1.00							
9	Distributive services (d)	-0.03	-0.03	-0.04	0.02	-0.17	-0.19	-0.19	-0.14	1.00						
10	Knowledge-intens. services (d)	-0.04	-0.02	0.01	-0.01	-0.14	-0.20	-0.15	-0.11	-0.12	1.00					
11	Technological services (d)	-0.06	-0.05	-0.25	-0.20	-0.08	-0.15	-0.22	-0.16	-0.18	-0.14	1.00				
12	Year 2002 (d)	0.01	0.00	0.00	-0.02	0.00	0.00	0.00	0.02	-0.01	0.00	0.05	1.00			
13	Year 2003 (d)	-0.02	0.01	0.01	0.02	0.05	0.01	0.02	0.00	-0.02	0.00	0.01	-0.16	1.00		
14	Year 2004 (d)	0.00	-0.02	-0.03	0.01	-0.03	-0.02	-0.03	-0.01	0.00	0.00	-0.04	-0.29	-0.21	1.00	
15	Year 2006 (d)	0.03	0.02	-0.01	0.02	0.05	0.09	0.05	0.06	-0.07	-0.04	-0.01	-0.25	-0.18	-0.33	1.00
	Variance inflation factor (VIF)	1.16	1.18	1.49	1.17	1.4	1.44	1.42	1.28	1.3	1.22	1.44	1.49	1.32	1.64	1.59
	Mean VIF	1.37														

Table 4: Probit estimation for the probability of receiving an R&D subsidy from state or federal government (standard errors in parentheses)

Variable	**Coeff.**	**Sign.**
Foreign MNC subsidiary (d)	-0.28	[0.00]
	(0.07)	
Domestic MNC (d)	-0.26	[0.00]
	(0.07)	
No of employees (log)	-0.01	[0.34]
	(0.02)	
Company age (years)	-0.01	[0.00]
	(0.00)	
Patent stock (ln)	0.09	[0.00]
	(0.01)	
Share exports of sales (ratio)	0.18	[0.00]
	(0.04)	
Medium high-tech manuf. (d)	0.24	[0.00]
	(0.05)	
High-tech manuf. (d)	0.54	[0.00]
	(0.06)	
Distributive services (d)	-0.40	[0.00]
	(0.07)	
Knowledge-intens. services (d)	-0.76	[0.00]
	(0.09)	
Technological services (d)	0.46	[0.00]
	(0.06)	
Year 2002 (d)	0.08	[0.16]
	(0.06)	
Year 2003 (d)	-0.01	[0.89]
	(0.07)	
Year 2004 (d)	-0.33	[0.00]
	(0.05)	
Year 2006 (d)	-0.22	[0.00]
	(0.06)	
Constant	0.19	[0.05]
	(0.10)	
McKelvey and Zavoina's R2	0.26	
N	5717	
LR Chi2	943.32	
P-value	0.00	

Table 5: Estimation results of zero-inflated negative binomial regression on the patent applications over the subsequent five years (standard errors in parentheses; p-values in square brackets)

Variable	***Model 1***	***Model 2***	***Model 3***
Interact.: Foreign MNC x subsidized R&D		0.15	0.13
		(0.08)	(0.08)
		[0.08]	[0.12]
Interact.: Foreign MNC x counterfact. R&D			-0.33
			(0.16)
			[0.03]
Counterfact. R&D	-0.08	-0.10	-0.04
	(0.06)	(0.06)	(0.07)
	[0.17]	[0.10]	[0.59]

Variable	*Model 1*	*Model 2*	*Model 3*
Subsidy-induced R&D	0.02	-0.08	-0.07
	(0.04)	(0.07)	(0.07)
	[0.56]	[0.20]	[0.29]
Foreign MNC subsidiary (d)	0.04	0.00	0.18
	(0.16)	(0.16)	(0.18)
	[0.82]	[0.99]	[0.32]
Domestic MNC (d)	0.24	0.25	0.21
	(0.16)	(0.16)	(0.16)
	[0.13]	[0.12]	[0.18]
No of employees (log)	0.55	0.56	0.55
	(0.06)	(0.06)	(0.06)
	[0.00]	[0.00]	[0.00]
Company age (years)	0.01	0.01	0.01
	(0.00)	(0.00)	(0.00)
	[0.03]	[0.02]	[0.02]
Share empl. w/ college educ.	0.01	0.01	0.01
	(0.00)	(0.00)	(0.00)
	[0.00]	[0.00]	[0.00]
No. patent appl.in t	0.51	0.52	0.51
	(0.08)	(0.08)	(0.08)
	[0.00]	[0.00]	[0.00]
Contin. R&D activities (d)	0.74	0.76	0.76
	(0.12)	(0.12)	(0.12)
	[0.00]	[0.00]	[0.00]
Share exports of sales (ratio)	0.72	0.73	0.73
	(0.12)	(0.12)	(0.12)
	[0.00]	[0.00]	[0.00]
Process innovator (d)	-0.29	-0.29	-0.31
	(0.11)	(0.11)	(0.11)
	[0.01]	[0.01]	[0.01]
Year 2002 (d)	0.17	0.16	0.17
	(0.14)	(0.14)	(0.14)
	[0.23]	[0.26]	[0.23]
Year 2003 (d)	0.19	0.19	0.17
	(0.17)	(0.17)	(0.17)
	[0.24]	[0.26]	[0.30]
Year 2004 (d)	-0.19	-0.20	-0.18
	(0.14)	(0.14)	(0.14)
	[0.17]	[0.15]	[0.18]
Year 2006 (d)	-19.03	-19.00	-17.44
	(1032.56)	(1027.06)	(468.32)
	[0.99]	[0.99]	[0.97]
Medium high-tech manuf. (d)	0.27	0.27	0.26
	(0.14)	(0.14)	(0.14)
	[0.05]	[0.06]	[0.07]

Variable	*Model 1*	*Model 2*	*Model 3*
High-tech manuf. (d)	0.32	0.30	0.28
	(0.18)	(0.18)	(0.18)
	[0.08]	[0.10]	[0.13]
Distributive services (d)	0.14	0.15	0.16
	(0.27)	(0.27)	(0.27)
	[0.60]	[0.59]	[0.54]
Knowledge-intens. services (d)	-1.64	-1.65	-1.64
	(0.48)	(0.48)	(0.48)
	[0.00]	[0.00]	[0.00]
Technological services (d)	0.71	0.71	0.70
	(0.24)	(0.24)	(0.24)
	[0.00]	[0.00]	[0.00]
No. of patent applic. 3 years prior to sample	0.24	0.24	0.24
	(0.03)	(0.03)	(0.03)
	[0.00]	[0.00]	[0.00]
Constant	-4.93	-4.97	-4.94
	(0.32)	(0.32)	(0.32)
	[0.00]	[0.00]	[0.00]
inflate			
Share of firms with patent application 1995-1999	-81.77	-81.52	-80.01
	(28.50)	(28.22)	(27.34)
	[0.00]	[0.00]	[0.00]
Constant	1.60	1.61	1.61
	(0.33)	(0.33)	(0.32)
	[0.00]	[0.00]	[0.00]
lnalpha	1.33	1.32	1.31
	(0.07)	(0.07)	(0.07)
	[0.00]	[0.00]	[0.00]
R2	0.23	0.23	0.24
N	5266	5266	5266
LR Chi2	1095.91	1098.78	1103.96
P-value	0.00	0.00	0.00

APPENDICES

Appendix 1: Industry classification

Industry	NACE Code	Industry Group
Mining and quarrying	10 – 14	Low-tech manufacturing
Food and tobacco	15 – 16	Low-tech manufacturing
Textiles and leather	17 – 19	Low-tech manufacturing
Wood / paper / publishing	20 – 22	Low-tech manufacturing
Chemicals / petroleum	23 – 24	Medium high-tech manufacturing
Plastic / rubber	25	Low-tech manufacturing
Glass / ceramics	26	Low-tech manufacturing
Metal	27 – 28	Low-tech manufacturing
Manufacture of machinery and equipment	29	Medium high-tech manufacturing
Manufacture of electrical machinery	30 – 32	High-tech manufacturing
Medical, precision and optical instruments	33	High-tech manufacturing
Manufacture of motor vehicles	34 – 35	Medium high-tech manufacturing
Manufacture of furniture, jewellery, sports equipment and toys	36 – 37	Low-tech manufacturing
Electricity, gas and water supply	40 – 41	Low-tech manufacturing
Construction	45	Low-tech manufacturing
Retail and motor trade	50, 52	Distributive services
Wholesale trade	51	Distributive services
Transportation and communication	60 – 63, 64.1	Distributive services
Financial intermediation	65 – 67	Knowledge-intensive services
Real estate and renting	70 – 71	Distributive services
ICT services	72, 64.2	Technological services
Technical services	73, 74.2, 74.3	Technological services
Consulting	74.1, 74.4	Knowledge-intensive services
Other business-oriented services	74.5 – 74.8, 90	Distributive services

Appendix 2: Mean comparison following nearest neighbour matching

Variable	Mean treated	Mean control	t-test	P < t
Propensity score	0.42	0.41	1.24	0.21
Foreign MNC subsidiary (d)	0.10	0.10	0.00	1.00
Domestic MNC (d)	0.09	0.09	0.00	1.00
No of employees (log)	3.99	3.99	-0.03	0.98
Company age (years)	18.93	19.26	-0.53	0.60
Patent stock (ln)	-3.17	-3.24	1.00	0.32
Share exports of sales (ratio)	0.43	0.40	1.45	0.15
Medium high-tech manuf. (d)	0.24	0.24	0.00	1.00
High-tech manuf. (d)	0.16	0.16	0.00	1.00
Distributive services (d)	0.06	0.06	0.00	1.00
Knowledge-intens. services (d)	0.02	0.02	0.00	1.00
Technological services (d)	0.25	0.25	0.08	0.94
Year 2002 (d)	0.20	0.20	0.00	1.00
Year 2003 (d)	0.11	0.11	0.00	1.00
Year 2004 (d)	0.22	0.22	-0.04	0.97
Year 2006 (d)	0.23	0.22	0.04	0.97

Appendix 3: Mean comparison following Gaussian matching

Variable	**Mean treated**	**Mean control**	**t-test**	**P < t**
Propensity score	0.41	0.41	0.59	0.55
Foreign MNC subsidiary (d)	0.08	0.08	0.00	1.00
Domestic MNC (d)	0.07	0.07	0.00	1.00
No of employees (log)	3.92	3.91	0.04	0.97
Company age (years)	18.17	18.55	-0.60	0.55
Patent stock (ln)	-3.39	-3.39	0.09	0.93
Share exports of sales (ratio)	0.39	0.38	0.78	0.43
Medium high-tech manuf. (d)	0.24	0.24	0.00	1.00
High-tech manuf. (d)	0.15	0.15	0.00	1.00
Distributive services (d)	0.07	0.07	0.00	1.00
Knowledge-intens. services (d)	0.02	0.02	0.00	1.00
Technological services (d)	0.24	0.24	0.00	1.00
Year 2002 (d)	0.20	0.20	0.00	1.00
Year 2003 (d)	0.11	0.11	0.00	1.00
Year 2004 (d)	0.23	0.23	0.00	1.00
Year 2006 (d)	0.23	0.23	0.00	1.00

Appendix 4: Descriptive statistics matched sample for knowledge production estimations

Sample	***All***				***Domestic firms***				***Domestic MNCs***				***Foreign MNC subsidiaries***			
Variable	***Mean***	***Std. Dev.***	***Min***	***Max***	***Mean***	***Std. Dev.***	***Min***	***Max***	***Mean***	***Std. Dev.***	***Min***	***Max***	***Mean***	***Std. Dev.***	***Min***	***Max***
Patent appl. (t+1, t+5)	0.65	4.49	0.00	181.00	0.41	3.22	0.00	86.00	2.16	10.18	0.00	181.00	1.22	3.97	0.00	37.00
Counter-fact. R&D investment (€ mn)	0.25	1.29	0.00	31.37	0.14	0.92	0.00	31.37	0.77	2.27	0.00	27.44	0.63	2.20	0.00	26.14
Subsidy-ind. R&D investment (€ mn)	0.06	1.05	-25.80	28.76	0.04	0.68	-11.96	28.76	0.07	1.66	-24.05	18.92	0.21	2.23	-25.80	22.44
Foreign MNC sub-sidiary (d)	0.09	0.28	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
Domestic MNC (d)	0.10	0.30	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
No of em-ployees (log)	4.08	1.46	1.61	8.01	3.80	1.35	1.61	8.01	5.46	1.31	1.79	8.01	5.10	1.26	1.79	8.01
Company age (years)	23.75	21.86	0.00	99.00	23.08	21.50	0.00	99.00	30.46	25.37	0.00	99.00	22.52	19.66	0.00	97.00
Share empl. w/ college educ.	24.77	25.55	0.00	100.00	24.91	26.10	0.00	100.00	24.00	23.36	0.00	100.00	24.28	22.53	0.00	95.00
Patent appl. (t)	0.12	0.75	0.00	21.00	0.08	0.68	0.00	21.00	0.30	1.09	0.00	12.00	0.28	0.89	0.00	9.00
Continuous R&D (d)	0.44	0.50	0.00	1.00	0.40	0.49	0.00	1.00	0.61	0.49	0.00	1.00	0.58	0.49	0.00	1.00
Share ex-ports of sales (ratio)	0.32	0.46	0.00	2.06	0.26	0.41	0.00	2.00	0.52	0.52	0.00	2.06	0.63	0.56	0.00	1.96
Process in-novator (d)	0.66	0.47	0.00	1.00	0.65	0.48	0.00	1.00	0.70	0.46	0.00	1.00	0.67	0.47	0.00	1.00
Year 2000 (d)	0.24	0.43	0.00	1.00	0.24	0.43	0.00	1.00	0.24	0.43	0.00	1.00	0.24	0.43	0.00	1.00

Sample	*All*				*Domestic firms*				*Domestic MNCs*				*Foreign MNC subsidiaries*			
Variable	*Mean*	*Std. Dev.*	*Min*	*Max*	*Mean*	*Std. Dev.*	*Min*	*Max*	*Mean*	*Std. Dev.*	*Min*	*Max*	*Mean*	*Std. Dev.*	*Min*	*Max*
Year 2002 (d)	0.18	0.39	0.00	1.00	0.18	0.38	0.00	1.00	0.21	0.41	0.00	1.00	0.21	0.41	0.00	1.00
Year 2003 (d)	0.11	0.31	0.00	1.00	0.11	0.31	0.00	1.00	0.13	0.34	0.00	1.00	0.09	0.29	0.00	1.00
Year 2004 (d)	0.30	0.46	0.00	1.00	0.30	0.46	0.00	1.00	0.28	0.45	0.00	1.00	0.31	0.46	0.00	1.00
Year 2006 (d)	0.17	0.38	0.00	1.00	0.18	0.38	0.00	1.00	0.14	0.34	0.00	1.00	0.15	0.35	0.00	1.00
Low-tech manuf (d)	0.32	0.47	0.00	1.00	0.32	0.47	0.00	1.00	0.33	0.47	0.00	1.00	0.31	0.46	0.00	1.00
Medium high-tech manuf. (d)	0.17	0.38	0.00	1.00	0.15	0.36	0.00	1.00	0.25	0.43	0.00	1.00	0.27	0.44	0.00	1.00
High-tech manuf. (d)	0.09	0.29	0.00	1.00	0.09	0.28	0.00	1.00	0.11	0.31	0.00	1.00	0.14	0.35	0.00	1.00
Distributive services (d)	0.15	0.35	0.00	1.00	0.15	0.36	0.00	1.00	0.12	0.33	0.00	1.00	0.12	0.32	0.00	1.00
Knowledge-intens. ser-vices (d)	0.09	0.29	0.00	1.00	0.10	0.30	0.00	1.00	0.08	0.27	0.00	1.00	0.06	0.24	0.00	1.00
Technologi-cal services (d)	0.17	0.38	0.00	1.00	0.19	0.39	0.00	1.00	0.12	0.32	0.00	1.00	0.10	0.30	0.00	1.00
Patent appl. 1997-1999	0.31	1.48	0.00	23.00	0.19	1.04	0.00	16.00	0.94	2.83	0.00	23.00	0.72	2.27	0.00	20.00
Number of obs.	5,266				4,287				512				467			

Appendix 5: Pairwise correlations matched sample for knowledge production estimations (n = 5,266)

	Variable	***1***	***2***	***3***	***4***	***5***	***6***	***7***
1	Counterfact. R&D investment (€ mn)	1.00						
2	Subsidy-ind. R&D investment (€ mn)	-0.25	1.00					
3	Foreign MNC subsidiary (d)	0.09	0.05	1.00				
4	Domestic MNC (d)	0.13	0.01	-0.10	1.00			
5	No of employees (log)	0.24	0.09	0.22	0.31	1.00		
6	Company age (years)	0.05	0.03	-0.02	0.10	0.31	1.00	
7	Share of college ed. Empl.	0.00	0.04	-0.01	-0.01	-0.29	-0.26	1.00
8	Patent appl. (t)	0.13	0.13	0.06	0.08	0.19	0.06	-0.01
9	Continuous R&D (d)	0.16	0.06	0.09	0.12	0.14	-0.04	0.21
10	Share exports of sales (ratio)	0.10	0.05	0.21	0.15	0.23	0.10	-0.06
11	Process innovator (d)	0.00	0.02	0.01	0.03	0.12	0.02	-0.12
12	Year 2002 (d)	0.04	-0.01	0.02	0.02	0.03	-0.01	0.07
13	Year 2003 (d)	0.01	0.01	-0.01	0.03	0.03	0.03	-0.01
14	Year 2004 (d)	0.00	0.00	0.01	-0.01	-0.01	0.03	-0.08
15	Year 2006 (d)	-0.03	0.00	-0.02	-0.03	-0.09	-0.03	0.03
16	Medium high-tech manuf. (d)	0.05	0.03	0.08	0.06	0.11	0.04	-0.08
17	High-tech manuf. (d)	0.07	0.02	0.05	0.02	-0.02	-0.05	0.07
18	Distributive services (d)	-0.05	-0.02	-0.03	-0.02	-0.03	0.02	-0.15
19	Knowledge-intens. services (d)	0.01	-0.03	-0.03	-0.01	0.02	-0.01	0.05
20	Technological services (d)	-0.03	0.03	-0.06	-0.05	-0.25	-0.21	0.57
21	Patent appl. 1997-1999	0.15	0.11	0.09	0.14	0.22	0.08	-0.01
	Variance inflation factor (VIF)	1.22	1.14	1.15	1.19	1.60	1.17	1.81

	Variable	***8***	***9***	***10***	***11***	***12***	***13***	***14***
8	Patent appl. (t)	1.00						
9	Continuous R&D (d)	0.13	1.00					
10	Share exports of sales (ratio)	0.20	0.29	1.00				
11	Process innovator (d)	-0.01	-0.05	-0.04	1.00			
12	Year 2002 (d)	0.02	0.12	0.01	-0.04	1.00		
13	Year 2003 (d)	0.03	0.01	0.03	0.01	-0.17	1.00	
14	Year 2004 (d)	0.03	-0.08	0.02	0.03	-0.31	-0.23	1.00
15	Year 2006 (d)	-0.07	0.01	-0.01	0.01	-0.22	-0.16	-0.30
16	Medium high-tech manuf. (d)	0.13	0.18	0.31	-0.06	0.02	0.04	-0.01
17	High-tech manuf. (d)	0.03	0.18	0.13	-0.07	0.02	0.00	0.02
18	Distributive services (d)	-0.06	-0.21	-0.18	0.03	-0.02	-0.02	-0.02
19	Knowledge-intens. services (d)	-0.05	-0.12	-0.19	0.07	-0.01	-0.01	-0.01
20	Technological services (d)	-0.04	0.10	-0.15	-0.06	0.05	0.00	-0.05
21	Patent appl. 1997-1999	0.56	0.15	0.23	-0.01	0.03	0.04	0.02
	Variance inflation factor (VIF)	1.50	1.29	1.38	1.04	1.46	1.30	1.60

	Variable	*15*	*16*	*17*	*18*	*19*	*20*	*21*
15	Year 2006 (d)	1.00						
16	Medium high-tech manuf. (d)	-0.02	1.00					
17	High-tech manuf. (d)	0.02	-0.15	1.00				
18	Distributive services (d)	-0.03	-0.19	-0.13	1.00			
19	Knowledge-intens. services (d)	0.00	-0.15	-0.10	-0.13	1.00		
20	Technological services (d)	0.01	-0.21	-0.15	-0.19	-0.15	1.00	
21	Patent appl. 1997-1999	-0.09	0.14	0.04	-0.07	-0.05	-0.03	1.00
	Variance inflation factor (VIF)	1.45	1.40	1.30	1.32	1.30	2.08	1.54
	Mean VIF	1.39						

Appendix 6: Estimation results of zero-inflated negative binomial regression on the patent applications over the subsequent three and four years (standard errors in parentheses; p-values in square brackets)

Variable	**3 year patents**	**3 year patents**	**4 year patents**	**4 year patents**
Interact.: Foreign MNC x subsidized R&D	0.13	0.11	0.14	0.12
	(0.08)	(0.08)	(0.08)	(0.08)
	[0.11]	[0.18]	[0.08]	[0.13]
Interact.: Foreign MNC x counterfact. R&D		-0.37		-0.38
		(0.17)		(0.17)
		[0.03]		[0.03]
Counterfact. R&D	-0.11	-0.04	-0.13	-0.07
	(0.06)	(0.07)	(0.06)	(0.07)
	[0.08]	[0.53]	[0.03]	[0.32]
Subsidy-induced R&D	-0.08	-0.07	-0.09	-0.08
	(0.06)	(0.06)	(0.06)	(0.07)
	[0.18]	[0.26]	[0.16]	[0.25]
Foreign MNC subsidiary (d)	-0.02	0.19	-0.02	0.18
	(0.17)	(0.19)	(0.16)	(0.19)
	[0.92]	[0.33]	[0.89]	[0.34]
Domestic MNC (d)	0.19	0.15	0.26	0.22
	(0.17)	(0.17)	(0.16)	(0.16)
	[0.25]	[0.38]	[0.10]	[0.16]
No of employees (log)	0.52	0.52	0.56	0.55
	(0.06)	(0.06)	(0.06)	(0.06)
	[0.00]	[0.00]	[0.00]	[0.00]
Company age (years)	0.01	0.01	0.01	0.01
	(0.00)	(0.00)	(0.00)	(0.00)
	[0.03]	[0.03]	[0.03]	[0.04]
Share empl. w/ college educ.	0.01	0.01	0.01	0.01
	(0.00)	(0.00)	(0.00)	(0.00)
	[0.01]	[0.01]	[0.00]	[0.00]
No. patent appl.in t	0.45	0.45	0.50	0.49

Variable	3 year patents	3 year patents	4 year patents	4 year patents
	(0.08)	(0.08)	(0.08)	(0.08)
	[0.00]	[0.00]	[0.00]	[0.00]
Contin. R&D activities (d)	0.58	0.59	0.72	0.72
	(0.13)	(0.13)	(0.12)	(0.12)
	[0.00]	[0.00]	[0.00]	[0.00]
Share exports of sales (ratio)	0.71	0.71	0.70	0.71
	(0.12)	(0.12)	(0.12)	(0.12)
	[0.00]	[0.00]	[0.00]	[0.00]
Process innovator (d)	-0.24	-0.26	-0.26	-0.28
	(0.12)	(0.12)	(0.12)	(0.12)
	[0.04]	[0.03]	[0.02]	[0.02]
Year 2002 (d)	0.03	0.04	0.09	0.11
	(0.16)	(0.16)	(0.15)	(0.15)
	[0.84]	[0.78]	[0.55]	[0.48]
Year 2003 (d)	0.21	0.20	0.22	0.21
	(0.18)	(0.18)	(0.17)	(0.17)
	[0.25]	[0.27]	[0.19]	[0.21]
Year 2004 (d)	0.04	0.06	-0.02	0.00
	(0.15)	(0.15)	(0.14)	(0.14)
	[0.80]	[0.70]	[0.87]	[0.98]
Year 2006 (d)	-16.97	-18.19	-16.85	-17.00
	(469.33)	(861.39)	(389.83)	(420.09)
	[0.97]	[0.98]	[0.97]	[0.97]
Medium high-tech manuf. (d)	0.32	0.31	0.32	0.31
	(0.15)	(0.15)	(0.14)	(0.14)
	[0.03]	[0.03]	[0.03]	[0.03]
High-tech manuf. (d)	0.47	0.45	0.41	0.38
	(0.19)	(0.19)	(0.18)	(0.18)
	[0.01]	[0.02]	[0.03]	[0.04]
Distributive services (d)	0.42	0.44	0.26	0.29
	(0.30)	(0.30)	(0.28)	(0.28)
	[0.16]	[0.14]	[0.35]	[0.31]
Knowledge-intens. services (d)	-1.75	-1.75	-1.93	-1.92
	(0.62)	(0.62)	(0.58)	(0.58)
	[0.00]	[0.00]	[0.00]	[0.00]
Technological services (d)	0.87	0.86	0.79	0.78
	(0.25)	(0.25)	(0.24)	(0.24)
	[0.00]	[0.00]	[0.00]	[0.00]
No. of patent applic. 3 years prior to sample	0.24	0.24	0.25	0.25
	(0.03)	(0.03)	(0.03)	(0.03)
	[0.00]	[0.00]	[0.00]	[0.00]
Constant	-5.17	-5.15	-5.16	-5.14
	(0.34)	(0.34)	(0.33)	(0.33)

Variable	3 year patents	3 year patents	4 year patents	4 year patents
	[0.00]	[0.00]	[0.00]	[0.00]
inflate				
Share of firms with patent application 1995-1999	-79.12	-78.23	-87.46	-86.16
	(20.12)	(19.78)	(32.01)	(31.21)
	[0.00]	[0.00]	[0.01]	[0.01]
Constant	1.89	1.90	1.76	1.76
	(0.31)	(0.31)	(0.36)	(0.35)
	[0.00]	[0.00]	[0.00]	[0.00]
lnalpha	1.24	1.22	1.28	1.27
	(0.08)	(0.09)	(0.08)	(0.08)
	[0.00]	[0.00]	[0.00]	[0.00]
R2	0.25	0.25	0.24	0.24
N	5266	5266	5266	5266
LR Chi2	937.78	943.30	1048.36	1054.08
P-value	0.00	0.00	0.00	0.00

Appendix 7: Estimation results of zero-inflated negative binomial regression on the patent applications over the subsequent five years including interaction effects with domestic MNCs (standard errors in parentheses; p-values in square brackets)

Variable	Interactions subsidized R&D	Interactions counterf. R&D
Interact.: Foreign MNC x subsidized R&D	0.14	
	(0.09)	
	[0.12]	
Interact.: Foreign MNC x counterfact. R&D		-0.35
		(0.17)
		[0.04]
Interact.: Domestic MNC x subsidized R&D	-0.01	
	(0.14)	
	[0.94]	
Interact.: Domestic MNC x counterfact. R&D		0.01
		(0.13)
		[0.93]
Counterfact. R&D	-0.10	-0.02
	(0.06)	(0.10)
	[0.10]	[0.81]
Subsidy-induced R&D	-0.08	0.02
	(0.08)	(0.04)
	[0.30]	[0.54]
Foreign MNC subsidiary (d)	0.00	0.22
	(0.16)	(0.19)
	[0.99]	[0.23]
Domestic MNC (d)	0.25	0.20

Variable	**Interactions subsidized R&D**	**Interactions counterf. R&D**
	(0.16)	(0.17)
	[0.12]	[0.26]
No of employees (log)	0.56	0.55
	(0.06)	(0.06)
	[0.00]	[0.00]
Company age (years)	0.01	0.01
	(0.00)	(0.00)
	[0.02]	[0.03]
Share empl. w/ college educ.	0.01	0.01
	(0.00)	(0.00)
	[0.00]	[0.00]
No. patent appl.in t	0.52	0.50
	(0.08)	(0.08)
	[0.00]	[0.00]
Contin. R&D activities (d)	0.76	0.75
	(0.12)	(0.12)
	[0.00]	[0.00]
Share exports of sales (ratio)	0.73	0.72
	(0.12)	(0.12)
	[0.00]	[0.00]
Process innovator (d)	-0.29	-0.31
	(0.11)	(0.11)
	[0.01]	[0.01]
Year 2002 (d)	0.16	0.19
	(0.14)	(0.15)
	[0.26]	[0.20]
Year 2003 (d)	0.19	0.18
	(0.17)	(0.17)
	[0.26]	[0.29]
Year 2004 (d)	-0.20	-0.18
	(0.14)	(0.14)
	[0.15]	[0.20]
Year 2006 (d)	-17.43	-17.41
	(468.26)	(457.63)
	[0.97]	[0.97]
Medium high-tech manuf. (d)	0.27	0.26
	(0.14)	(0.14)
	[0.06]	[0.06]
High-tech manuf. (d)	0.30	0.29
	(0.18)	(0.18)
	[0.10]	[0.11]
Distributive services (d)	0.14	0.16
	(0.27)	(0.27)
	[0.59]	[0.55]

Variable	**Interactions subsidized R&D**	**Interactions counterf. R&D**
Knowledge-intens. services (d)	-1.65	-1.63
	(0.48)	(0.48)
	[0.00]	[0.00]
Technological services (d)	0.71	0.69
	(0.24)	(0.24)
	[0.00]	[0.00]
No. of patent applic. 3 years prior to sample	0.24	0.24
	(0.03)	(0.03)
	[0.00]	[0.00]
Constant	-4.97	-4.91
	(0.32)	(0.32)
	[0.00]	[0.00]
inflate		
Share of firms with patent application 1995-1999	-81.59	-80.34
	(28.35)	(27.71)
	[0.00]	[0.00]
Constant	1.61	1.60
	(0.33)	(0.32)
	[0.00]	[0.00]
lnalpha	1.32	1.32
	(0.07)	(0.07)
	[0.00]	[0.00]
R2	0.23	0.23
N	5266	5266
LR Chi2	1098.78	1101.84
P-value	0.00	0.00