The Journal of Technology Transfer (2023) 48:1413–1445
https://doi.org/10.1007/s10961-022-09975-5

Leveraging global recombinant capabilities for green technologies: the role of ethnic diversity in MNEs' dynamics

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Accepted: 13 October 2022 / Published online: 28 October 2022

Abstract

The growing environmental pressure and the parallel policy push on eco-innovations are making the generation of green technologies more and more profitable, given the expansion of existing markets and the creation of new ones. MNEs may show a competitive advantage in this context because of their global knowledge sourcing strategies that increase heterogeneity and variety in firms' innovation processes. We accordingly argue that the inventors' teams involving higher ethnic diversity are more likely to successfully generate green inventions due to their idiosyncratic experiences and diversified knowledge bases. We rely on USPTO data from an ethnic patenting database covering US-based MNEs from 1980–2009. We find that R&D teams featured by higher levels of ethnic diversity among the US-based inventors correlate with a higher probability of green patenting, but the relationship follows a non-linear pattern. Also, ethnic diversity is found to moderate the effect of recombinant capabilities on the generation of new green technologies. Our results bring implications for the strategic management of inventors' teams by multinationals willing to run the green patent race and policymakers facing the climate change challenges.

Keywords MNEs · Green technologies · Ethnic diversity · Recombinant capabilities

1 Introduction

Global knowledge sourcing represents one of the main reasons for multinational enterprises' (MNEs) R&D internationalization strategies, which have evolved over time in terms of both firms' objectives and implementation. Most recent strategies have been grounded on multicentric approaches to knowledge generation, involving various actors in cross-border knowledge sourcing, generation, exploitation and diffusion activities (Asakawa et al.,

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2018; Cano-Kollmann et al., 2016; Papanastassiou et al., 2019; Scalera et al., 2018). In this context, talent flows have proved to be crucial in making cross-border MNEs' R&D teams successful due to the relatively better capacity of inventors' teams involving people from different countries to access, process, exchange and absorb fragmented and geographically dispersed knowledge(Marino et al., 2020; Seo et al., 2020).

External knowledge sourcing is essential to feed the recombinant dynamics underlying innovation processes. Indeed, according to the Schumpeterian tenet, innovation emerges from the recombination of diverse knowledge, which is fragmented and dispersed amongst innovating agents (Fleming & Sorenson, 2001; Kogut & Zander, 1992; Schumpeter, 2017; Weitzman, 1998). While this holds true for any innovation, the capability to combine loosely related, or highly heterogeneous, knowledge inputs has recently proven to be associated with the generation of a specific kind of innovations, i.e., high-impact innovations and green technologies (Orsatti et al., 2020; Seo et al., 2020; Zeppini and van den Bergh 2011).

In line with this reasoning, diversified R&D teams may exhibit a competitive advantage in this respect, as long as the heterogeneous background of collaborating inventors makes it easier the management of knowledge sources spanning seemingly unrelated areas of the technological landscape. In the face of the increasing environmental pressure, this competitive advantage may turn out to be particularly useful for MNEs' strategic management of inventors teams' composition. Actually, a well-established tenet in environmental studies concerns the role of eco-innovation in general, and green technologies in particular, in mitigating the negative impact of economic activities on the environment (Barbieri et al., 2016; Porter & van der Linde, 1995). Consequently, environmental policies have strongly focused on setting-up incentives for firms to adopt green technologies to improve their environmental performances (Rennings, 2000). This has had the critical implication of expanding existing markets for these technologies, as well as of opening up brand new markets and niches, and hence creating the conditions for firms producing green technologies to grow faster and to show better performances in stock markets (Colombelli et al., 2020a, b, 2021; Hoppmann et al., 2013; Nemet, 2012). In this framework, MNEs managing international inventors' teams are well suited to leverage the intrinsic capacity to manage complex innovation processes combining highly diverse knowledge sources to run the green technology race and reap the economic benefits of expanding markets.

However, while the literature in international business studies has primarily studied the impact of the management of international R&D teams on MNEs innovation performances as a whole, there is no evidence yet on the relationship between ethnically diverse teams and the recombinant dynamics underlying the generation of green technologies (GTs).[1]

This paper aims at filling this gap by investigating the impact of the involvement of ethnic inventors in R&D teams—i.e., domestic inventors based in the MNE headquarter country and characterized by a foreign ethnicity (Kerr & Kerr, 2018)—on the probability of generating green patents. To this purpose, our theoretical framework combines the collective invention and recombinant knowledge approaches with the theory about the impact of ethnic diversity on innovation. Our main argument is that the involvement of ethnic inventors in green-oriented collective invention dynamics increases the likelihood to successfully generate green inventions due to their inherent complex nature requiring the

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[1] It is worth stressing that we use the expression "ethnic diversity" here to denote the presence of one or more ethnic inventors in the R&D team. We will furher discuss the identification of US-based foreign individuals in the following sections.

recombination and integration of knowledge inputs spanning different and often loosely related technological domains (Orsatti et al., 2020; Zeppini and van den Bergh 2011).

The paper adds to the existing literature in many respects. First, it allows extending the analysis of the strategic management of inventors' teams for the generation of green technologies by considering the distinctive role of migrant inventors and ethnic heterogeneity in bringing variety in collective invention dynamics (Fusillo et al., 2020; Orsatti et al., 2020; Quatraro & Scandura, 2019). Second, we contribute to the literature analyzing the impact of ethnic inventors on MNEs' innovation performances (Bahar et al., 2020; Choudhury & Kim, 2019; Maksimov et al., 2019; Marino et al., 2020). Third, we provide insights into the policy debate by stressing the importance of the interplay between macro and micro-level dynamics in designing the appropriate incentives to invest in green technologies development (D'Agostino, 2015; Marin & Zanfei, 2019). Finally, our research is also close to the recent literature about the importance of extra-regional and international knowledge and talent flows in invention dynamics, including the role of global pipelines and the interaction of localized knowledge dynamics of domestic and foreign-owned firms (Bathelt et al., 2004; Boschma & Iammarino, 2009; Lorenzen et al., 2020; Morrison et al., 2013; Wang & Guo, 2016; Wang & Wu, 2016; Zhu et al., 2017). This process is relevant for recombinant innovation dynamics in general, and for green technological change in particular, as this latter is largely reliant on the combination of heterogeneous and diversified knowledge inputs (Orsatti et al., 2020; Fusillo, 2020).

We rely on data drawn from the ethnic patenting database (Kerr & Kerr, 2018), which collects harmonized USPTO records for US-based MNEs between January 1975 and May 2009. We also draw upon the Harvard Patent Dataverse database (Lai, Library, Center, D'Amour, & Fleming, 2011) to recreate the career of each inventor listed in the sample from the beginning of their patenting activity to the application year of the focal patent. The OECD EnvTech dataset has instead been used to identify patents classifiable in the green domain. The empirical analyses show that teams composed of inventors with broader recombinant capabilities also tend to have a higher propensity for developing new green technologies. Also, a higher level of ethnic diversity among the domestic inventors correlates with a higher probability of patenting GTs, but the relationship follows a non-linear pattern as it decreases with ethnic diversity. Finally, we find that patents developed by R&D teams involving a higher degree of ethnic diversity among their domestic inventors are more likely to combine technological knowledge in a novel way to develop GTs.

2 Theoretical development and hypotheses

2.1 Leveraging global recombinant capabilities for green innovation

Eco-innovation (EI) is considered by a voluminous body of empirical and theoretical research as a means by which firms may align the improvement of economic and environmental performances (Porter & van der Linde, 1995). Yet, incentives to the introduction of EIs may be weak in competitive markets, where knowledge production and environmental degradation are sources of essential externalities. While most of the empirical analyses in this strand have focused on the incentive to the adoption of EIs, relatively little attention has traditionally been given to the antecedents of green technologies, i.e., the dynamics of knowledge generation and invention in the green domain (del Río González, 2009).

Recently, studies on such neglected issues have provided new insights into the features of green technologies and the determinants and capabilities required by firms to introduce environmental innovations (Barbieri et al., 2016). Not only do green inventions show greater complexity than non-green counterparts in terms of broader technological scope encompassed (de Marchi, 2012; Ghisetti et al., 2015), but they also appear to be more likely to emerge out of novel recombination of previous knowledge base (Barbieri et al., 2020; Orsatti et al., 2020). Accordingly, the generation of green technological knowledge has been modeled as the outcome of complex processes involving the combination of highly diversified and loosely related sets of competencies (Zeppini and van den Bergh 2011; Fusillo, 2020). In this framework, the concept of recombinant capabilities—i.e., the capacity to combine together different pieces of knowledge to generate new ideas—has been successfully applied to the analysis of the antecedents of green inventions (Galunic & Rodan, 1998; Henderson & Clark, 1990; Kogut & Zander, 1992; Messeni Petruzzelli et al., 2014; Orsatti et al., 2020).

Recombinant capabilities are strictly related to the collective dimension of knowledge generation (Allen, 1983). Insofar as new ideas stem from the recombination of knowledge inputs, which are fragmented and dispersed across innovating agents, recombinant processes are more likely to successfully occur when invention is organized in teams gathering together people with heterogeneous competencies (Gruber et al., 2012; Teodoridis, 2017). A substantial body of literature has documented the increasing weight of teamwork knowledge production (Adams et al., 2005; de Solla Price, 1963; Wuchty et al., 2007). The increasing specialization and the narrowing of expertise required for advancing the knowledge frontier, as well as the augmented complexity of knowledge-based activities, have been proposed as possible—and not mutually exclusive—explanations of this (Agrawal et al., 2016; Arora & Gambardella, 1994; Harvey et al., 2014; Jones, 2009; Marrone, 2010). Consequently, the concept of recombinant capabilities has been fruitfully extended from the individual to the team level, proposing that inventors' teams may have different familiarity with recombinant creation vis-à-vis reuse dynamics. Therefore, inventor teams may show a different tendency to generate green inventions, depending on the extent to which recombinant creation dynamics are constitutive elements of team members (Orsatti et al., 2020). Because of the high complexity of green technological knowledge and the need to combine highly heterogeneous inputs for its production, recombinant dynamics are deemed particularly important for the generation of green technologies (de Marchi, 2012; Fusillo et al., 2020; Ghisetti et al., 2015). The reason relies on the fact that green patenting requires leveraging complexity and, in turn, boundary spanning capabilities, which are pivotal to lead strategic actions in knowledge sourcing deeply embedded at different organizational and technological levels.

A milestone in the literature on the international management of technological innovation is that a distinctive feature of MNEs, and maybe the most important one, is their ability to transfer, integrate and exploit knowledge from their geographically dispersed networks. MNEs geographically distribute their R&D activities in order to source foreign knowledge that is critical to feed the innovation process with new and diverse inputs from different locations as well as to adapt their existing knowledge assets to other locations to exploit extant innovative efforts and avoid technological lock-in (Cantwell & Salmon, 2018) Also, MNEs proactively build more robust organizational capabilities for integrating knowledge (Cano-Kollmann et al., 2016; Scalera et al., 2018).

Recently, this idea has been applied to the eco-innovation fields, thus identifying MNEs as better positioned to leverage so-called «dynamic global green capabilities» (Maksimov et al., 2019). In other words, MNEs show a comparative advantage in developing green technologies because of their multiple embeddedness. In particular, they find themselves in a unique position to leverage individual competencies and skills to bridge different expertise—i.e., technological, cultural or social—through intra- and inter-organizational R&D collaborations. Thus, embracing the micro-foundations perspective of recombinant capabilities, we focus on individual-based conduits in this study.

Building upon established empirical findings in the eco-innovation literature, we push forward our understanding of the relationship between the production of green technologies and recombinant capabilities in the global knowledge setting.

2.2 Team composition, ethnic diversity and the generation of green technologies

As previously discussed, inventors need to leverage knowledge diversity to engage in recombinant creation (Ahuja & Lampert, 2001; Carnabuci & Operti, 2013; Cohen & Levinthal, 1989). However, recombinant capabilities are very much related to both the distribution of knowledge sources and the composition of R&D teams (Choudhury & Haas, 2018). In this context, establishing collaborations and networks is crucial for accessing competencies that enable the ability to leverage external and widely dispersed pieces of knowledge (Savino et al., 2017). Therefore, team composition represents an effective mechanism for boosting firms' innovative performance, recombination capabilities and absorptive capacity (Carnabuci & Operti, 2013; Cohen & Levinthal, 1989; Zahra & George, 2002). For example, firms could strategically leverage the configuration of inventors' teams and their pool of knowledge to increase the chances of generating breakthrough innovation (Haas & Ham, 2015), broader patent scope (Choudhury & Haas, 2018) or generally steer the innovative outcomes in a specific direction (Tzabbar & Vestal, 2015).

All in all, these considerations have relevant implications in terms of human resource management for the purpose of eco-innovation. Accordingly, extant literature has shown that inventors who have already experienced recombinant creation dynamics positively impact teams' success in generating green inventions (Orsatti et al., 2020). Other works have documented that the inclusion of academic staff in inventors' teams may increase the capacity to generate green inventions because of its capacity to command and combine knowledge spanning heterogeneous and loosely related scientific domains (Quatraro & Scandura, 2019).

In this debate, a somewhat neglected dimension concerns the spatial dependence of technological specialization, and hence the overlap of geographical and technological proximity (Antonelli, 2001). The evolutionary economic geography approach has stressed that lock-in and path-dependency are indeed frequent in the patterns of regional technological specialization and diversification. Local technological capabilities emerge from a historical process of accumulation of competencies, which renders knowledge very much embedded in the context in which it has been produced (Neffke et al., 2018; Quatraro, 2009). Therefore, access to loosely related knowledge inputs often requires the capacity to activate channels for importing knowledge from geographically dispersed sources, increasing the chances of introducing unrelated diversification in knowledge bases. Regional evidence has also pointed to the importance of nonlocal agents in this respect, like entrepreneurs, highly-skilled migrants or MNEs (Boschma et al., 2017; Colombelli et al., 2020a, b; Elekes et al., 2019; Marino et al., 2020; Neffke et al., 2018; Miguelez & Morrison, 2022). Indeed, not only do international businesses find themselves in a peculiar position to leverage R&D collaborations at large, but they also have facilitated access to diaspora-established contacts elsewhere in the world (Lorenzen & Mudambi, 2013; Thomas, 2016).

In this regard, a fruitful strain of research has recently focused on the role of highly-skilled migrants in the innovative outcomes of firms and regions (e.g., (Choudhury, 2016; Foley & Kerr, 2013a; Nathan, 2015; Useche et al., 2020). These authors generally refer to ethnic—or migrant—innovators as inventors based in the MNE headquarter country, but with names that evoke a foreign ethnicity based on available commercial databases (Breschi et al., 2017a, b; W. R. Kerr, 2008). For example, inventors with Chinese or Hispanic names disclosing a US address in the patent application would likely indicate foreign-born or later generations of immigrants who share a profound connection with their family's communities and traditional cultural roots while experiencing some level of social integration in the host country (S. P. Kerr & Kerr, 2018).

The literature has widely highlighted the role of ethnic migrants in helping MNEs overcome their organizational boundaries and limit the downfalls in knowledge integration processes in terms of their emotional and personal relationships with the country of origin—i.e., own-ethnic ties—or other socio-cognitive and cultural attributes broadly defined. Similarly, ethnic inventors are likely to have several attributes that could help firms operate in industries with a high degree of complexity, which requires extraordinary efforts to exploit the interdependence between different technological fields (Choudhury & Kim, 2019; Thomas, 2016).

From a strategic perspective, the presence of an ethnic inventor in an ethnically diverse team is in a position to sustain original recombinant opportunities across geographical and technological borders (Choudhury & Kim, 2019). The role of ethnic inventors also appears to be enhanced when transferring to the host firm context-specific knowledge previously locked within the cultural context of their home regions (Bahar et al., 2020; Bartholomew, 1997; Boschma, 2005; Marino et al., 2020). Furthermore, inventors' teams involving migrants are likely to benefit from cognitive diversity, allowing for the orientation of research efforts in many directions (Crescenzi et al., 2016). Accordingly, they are considered exceptional contributors to the advancement of the knowledge frontier because of gains from specialty matching and knowledge recombination enabled by migration (Franzoni et al., 2014; Kerr et al., 2016).

Ethnic inventors could also facilitate innovation because their distinct knowledge bases and experiences might enhance creativity (Parrotta et al., 2014) and complex problem-solving (Cooke & Kemeny, 2017). Ultimately, ethnic inventors provide a hedge thanks to their transnational social capital that creates trust, openness, and collaboration with other peers within the diverse team (S. Katila & Wahlbeck, 2011; Saxenian, 2009). The experience matured in different cultural contexts increases their ability to deal with intercultural issues, helping their employers to connect with culturally diverse partners (Solheim & Fitjar, 2016). Hence, ethnic inventors show the capability to further support other individuals with different knowledge and backgrounds to bridge and connect their diverse knowledge. Also, inventors teams composed of both non-ethnic inventors and ethnic migrants would produce more innovative patents and have greater knowledge and cognitive diversity than either of the inventor groups working separately, thus pursue knowledge recombination (Choudhury & Kim, 2019; Crescenzi et al., 2016; Kerr & Kerr, 2018).

Altogether, these arguments suggest that ethnic inventors possess specific attributes that could facilitate knowledge recombination encompassing both technological and socio-cultural boundaries within the organization and, ultimately, enable the firm to exploit more complex—and green, among the others—technologies. In fact, eco-innovations are more complex, novel, and impactful than non-green ones (Barbieri et al., 2020) and they have broader scope inputs and a multi-purpose and systemic nature (de Marchi, 2012; Ghisetti et al., 2015). Jobs in the fields also exhibit higher levels of non-routine analytical skills, such as creative problem solving, information interpretation or establishing and maintaining interpersonal relationships (Consoli et al., 2016).

However, firms might face several challenges and barriers in accessing and absorbing external resources, especially those technologically and geographically distant from their core knowledge base. As such, it is essential to acknowledge the coexistence of both the positive and negative effects of team-level heterogeneity—and precisely ethnic diversity—on knowledge creation and integration. For example, (Ozgen et al., 2014) show that employees' ethnic diversity positively contributes to firms' innovation, but the impact is modest and very much depends on contextual factors. In general, complex and sticky knowledge appears to be harder to share and understand (Dougherty, 1992), especially in knowledge-intensive sectors with a heterogeneous technological and cognitive base. In fact, language barriers, conflicts, internal clashes, and distrust all count among the potential costs of high team-level heterogeneity (Solheim & Fitjar, 2016). Even though innovation can stem from rich sources of knowledge (R. Katila & Ahuja, 2017), too many diverse ideas may also be detrimental to firms' recombinant capabilities. Hence, the picture addresses the existence of a well-known quandary because while innovation and creativity are more likely in heterogeneous groups, the ability to implement and integrate divergent ideas declines with increasing heterogeneity (DiTomaso et al., 2007).

Given these arguments, we, therefore, hypothesize the existence of a direct inverse U-shaped relationship between the extent of the presence of domestic ethnic inventors in R&D and the propensity to innovate in the green field, other things being equal. In particular, we state:

Hypothesis 1 (a) Higher the degree of ethnic diversity in the R&D team, the higher the probability of green patenting. (b) However, the relationship is decreasing at an increasing scale.

2.3 The moderator effect between ethnic diversity and recombinant capabilities

Building on the previous discussions, there are several reasons to expect that the impact of ethnic diversity on innovation may interact with recombinant capabilities in green invention dynamics. First, mainly because of ethnic inventors' connection with context-specific knowledge from their country of origin, knowledge recombination in teams involving ethnic inventors might be more likely to be directed to the experimentation of unprecedented combinations (Choudhury & Kim, 2019). Moreover, when individuals with different knowledge and backgrounds interact, they may stimulate and help each other stretch their knowledge to bridge and connect diverse knowledge (Nooteboom et al., 2007; Solheim & Fitjar, 2016). We argue that ethnic inventors, because of their intrinsic characteristics—i.e., transnational social capital, openness, trust and collaboration experience—might act as facilitators for knowledge sharing. Also, ethnic inventors are expected to improve firms' absorptive capacity and thus recombination capabilities, especially when dealing with dispersed knowledge sources (Cohen & Levinthal, 1989; Zahra & George, 2002).

In this direction, we aim to investigate the role of ethnic diversity in alleviating the challenges for knowledge recombination by acting as a bridge within the team's diverse knowledge base and contributing to the successful creation of green technologies in the organizational boundaries. Therefore, we spell out the second research hypothesis as it follows:

Hypothesis 2 Although our contribution relies on specific dimensions of diversity—such as technological recombination and ethnic origin –, further exploration of the team composition is needed to understand better the implications for the firms' strategic management of inventors' teams to grasp the opportunities set by the hybridization of existing knowledge to create innovation in the green field. With this in mind, in this study, we also perform thorough robustness checks to isolate the effect of ethnic diversity from other individuals' characteristics that might enact similar bridging abilities in the R&D team, such as the inventors' experience living in other countries or working in cross-cultural environments and the extent of their individual collaborative network. We further discuss the relevance of these mechanisms in Sect. 3.2.4.

Ethnic diversity favors the integration of external knowledge and the recombinant creation capabilities of the R&D team, thus increasing the likelihood of generating green technologies.

3 Research methodology

3.1 Data

Our empirical analysis primarily relies on the public available *ethnic patenting database*, which covers harmonized USPTO patent records granted to US-based MNEs between January 1975 and May 2009, as designed by (Kerr, 2008) and further described in (Kerr & Kerr, 2018). In the database, US-based MNEs are identified as public companies with their main headquarters in the US and conducting global technology development via «entering into patenting abroad after first patenting in the US» (Kerr & Kerr, 2018: 10).[2] Exploiting commercial ethnic names databases and name-matching algorithms, the authors determine the probable ethnicities of the inventors listed in the companies' patents, distinguishing between nine ethnic groups: Anglo-Saxon, European, Hispanic, Indian, Chinese, Japanese, Korean, Russian and Vietnamese. Despite the immigration status of inventors not being known, we can determine the probable ethnicities of inventors through their names. In other words, inventors with the surnames Lee or Kim are assigned a high probability of being of Korean ethnicity, while innovators with the surnames Banerjee or Patel are assigned a high probability of being of Indian descendants. The data separately reports the ethnicity information for domestic and foreign inventors in the R&D teams for each patent.[3] For instance, the ethnic probability is computed as the average score for the inventors belonging to each geographic group. Following previous analogous studies (Breschi et al., 2017a, b; Kerr & Kerr, 2018; Marino et al., 2020), we identify patents whose domestic US-based inventors have a non-null non-Anglo-Saxon ethnic score as including ethnic inventors in their R&D team. For these patents, we compute the Herfindahl–Hirschman index over the distribution of the ethnic probabilities to measure the degree of ethnic diversity in the R&D teams.

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[2] In other words, the authors select those firms which files exclusively domestic patents in the US – i.e., documents filing only inventors residing in the country – before applying for patents that include inventors in foreign regions.

[3] Since we focus on US companies, we define as domestic those inventors who declare to reside in the United States at the moment of the patent application.

To investigate the role of inventors' recombinant capabilities in the MNEs' context, we recreate the career of each inventor listed in the focal sample from the beginning of their patenting activity relying on the Harvard Patent Dataverse database (Lai et al., 2011), which uniquely identifies inventors listed in USPTO patents, leveraging a thorough disambiguation process.[4] We then collect information on the technological classification of the inventors' patent portfolio, specifically on the co-occurrences of 4-digit IPC subclasses in the same patent.[5]

The final sample employed to test our hypotheses contains all the patents with at least one domestic inventor in their R&D team and granted to US-based MNEs from 1980 to 2008. We restrict the focal sample to patents with application years starting from 1980 to allow for a more homogeneous retrospective reconstruction of each inventor's career. The process of sample identification and information merging leads us to 476,888 observations at the patent level granted to 2,045 firms, of which only 214 never employed any ethnic inventors in their innovation activities.

Notwithstanding the limitations in the use of patent data for empirical studies, the information contained in patent documents provides a uniquely detailed and broadly available source of information on inventive the development and evolution of technological knowledge (Griliches, 1979; OECD, 2009; Pavitt, 1985). Analogously, the ethnic-name procedure does not distinguish foreign-born inventors working in the US from second or later generations of immigrants. However, these concerns have been reduces by extensive comparisons with the Census and INS records on US immigration of scientists and engineers. The procedure aggregates the ethnic groups at a wide level, thus suffering both from lack of precision in imputing ethnicity and country of origin or analyzing names with roots in the European continent. Despite these limitation, ethnic name database are nonetheless considered a tractable platform for examining migration and innovation (Kerr, 2008).

3.2 Empirical strategy

3.2.1 Regression model

In the first set of analyses, we investigate our main hypotheses by running a Linear Probability Model (LPM) at the patent level with robust standard errors[6]:

$$\begin{aligned} GT = {} & \alpha_0 + \alpha_1 Recomb + \alpha_2 EthnDiv \\ & + \alpha_{12} EthnDiv * Recomb + \alpha_3 EthnDiv^2 \\ & + \beta' \mathrm{Z} + \tau_{\mathrm{j}} + \gamma_{\mathrm{k}} + \delta_{\mathrm{t}} + \varepsilon_{\mathrm{jkt}} \end{aligned}$$

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[4] For more detailed information on the algorithm, see the original methodological note in Lai et al. (2011).

[5] Specifically, we refer to the open source database Patent Grant Data Project (2017) available via https://sites.google.com/site/patgrantdata/.

[6] Following recent similar studies (e.g., Breschi et al., 2017a, b; Marino et al., 2020; Orsatti et al., 2020), we privileged the use of LPM over probit/logit models, as the former provide a more direct interpretation of the estimated coefficients, which directly represent the marginal effects.

where **Z** is the vector of control variables presented in the following sections; τ_j are the industry fixed effects[7]; γ_k are the fixed effects for the main technological sub-category of the focal patent *à-la-HJT*; δ_t are application year dummies.

3.2.2 Dependent variable

Following previous literature in the field (Fusillo et al., 2020; Orsatti et al., 2021), we identify the focal patents as being related to green technologies (GTs) according to two established international classifications based on IPC technological codes: WIPO IPC Green Inventory (WIPO, 2012) and OECD ENV-TECH (Haščič & Migotto, 2015). In detail, our dependent variable *GT* is a dummy that equals one if at least one IPC technological code of the focal patent is included in either the classifications and zero otherwise. By applying this definition of GTs, we identify 34,440 green technology patents applied at the USPTO by US-based MNEs between 1980 and 2008 (7.22% of the total sample).[8]

3.2.3 Main explanatory variables

The first main explanatory variable *Recomb* represents a proxy for the technological recombinant capabilities of the inventors involved in the focal patent. Building on (Carnabuci & Operti, 2013), we adapt their measure of *recombinant creation* to measure the probability that patents' inventors would produce innovation using new technological combinations. Specifically, we focused on the technological classifications of each inventor's patent portfolio rather than their patents' backward citations. In fact, despite the USPTO requires the applicants to disclose any prior art known or believed to be relevant to the application—the so-called "duty of candor" –, patent citations might be biased by firms' strategic considerations (Carnabuci & Operti, 2013). In particular, several limitations are associated with using citations as a proxy for knowledge flows at the inventor level (for a review, see Jaffe & Rassenfosse, 2019). On the contrary, relying on the stock of knowledge accumulated by the inventor through direct involvement in the development process of a patented innovation—i.e., being a member of the inventor team listed in the application—would reduce the risk of measurement errors. Also, patents are assigned to technological classes by the USPTO through objective technical criteria. In our opinion, the technological classification of the inventors' patent portfolio better suits our need to determine the technological combinations that led to a patented innovation (Fleming, 2001; Fleming et al., 2007). Following this rationale, we compute the Recomb variable as the number of first co-occurrences of technological subclasses *j* and *m* normalized by the total number of technological co-assignments the inventors have been patenting during their careers. By definition, the variable ranges between 0 and 1: zero indicates that none of the technological combinations used by the inventors to create their current patents is new to their experience, while a value of one indicates that the inventors had used none of the current technological combinations in the past. Since we conduct our analysis at the focal patent level, we compute the

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[7] We define the industry as the technological specialization of the companies' portfolio based on the prevalent technological category of their patents. Specifically, we follow the taxonomy developed by Hall et al. (2001): Chemical, Computers & Communications, Drugs & Medical, Electrical & Electronical, Mechanical, Others. We will refer to this classification as "HJT taxonomy" throughout the paper.

[8] This results is also in line with previous empirical findings in the field.

variable as the average value of the recombinant capabilities measure for all the inventors' team members at the application year.

The second explanatory variable of interest, EthnDiv, measures the degree of ethnic diversity among the domestic members of the inventors' team.[9] The variable is computed as the inverse of a concentration index *à-la-Herfindahl* using the domestic ethnicity score attributed to the patent. A value of zero signals that all the domestic inventors in the focal patents belong to the same ethnic base. In contrast, as the value of the index approaches one, the degree of ethnic diversity in the group increases. Following extant theories acknowledging both the costs and benefits of ethnic diversity on knowledge creation and integration (DiTomaso et al., 2007; Ozgen et al., 2014; Parrotta et al., 2014; Solheim & Fitjar, 2016), we also include the squared term of ethnic diversity to account for the possible non-linear relationship between the variable and the creation of green technologies.

As per our theoretical hypotheses, we test for the existence of a moderator effect of ethnic diversity on the recombinant capabilities of the inventors' team to develop technologies for green purposes through the interaction term Recomb*EthDiv.

3.2.4 Control variables and alternative explanations

All the regressions contain an extensive set of control variables at the inventors' team and firm-level. First, we include a set of covariates controlling both for the structural characteristics of the R&D team and the average experience, productivity and quality of their members. Namely, we consider team size and experience, inventors' patent stock, their share of triadic patents, and previous green technologies experience.[10] Since GTs are featured by higher complexity and require, on average, the combination of a broader knowledge base to be performed (Horbach et al., 2012; Nemet, 2012; Rennings & Rammer, 2011), we would expect team size to be correlated with the probability to generate GTs. On the contrary, we might expect more experienced teams –in terms of length of their tenure and stock of patents produced—to be subject to lower incentives to pursue distant innovative attempts due to path dependence reasons and to operate in more established, traditional technological domains. As such, we might expect, on average, a negative relationship between these controls and the probability of generating GTs. Finally, both the quality of the inventors' patent portfolio—as proxied by their share of triadic patents—and previous experience in the green domain might signal the presence of individual capabilities and competencies that might foster the generation of complex and high-value innovations such as GTs.

Second, we control for MNEs' features that might influence their ability to leverage the recombinant capabilities of the inventors they employ. Following extant literature, we add the number of years since the firm's first patent, a measure of innovative productivity and whether the companies had previous experience in patenting GTs. The rationale for these controls derives from considerations similar to those articulated for the team-level confounding factors. In particular, we aim at capturing the quality and characteristics of the environment in which the team operates.

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[9] We decided to exclude from the computation of the ethnic diversity index the inventors residing in a foreign country to avoid any bias that might derive from alternative channels of cognitive, cultural or geographical heterogeneity. However, we will check for the robustness of our results later in the section.

[10] We introduce the measures based on inventor-level patent counts by the inverse of their tenure time to clear out any temporal bias due to the length of their patenting activity and avoid collinearity with the team experience variable.

However, the literature highlights the existence of mechanisms alternative to ethnicity for facilitating or hindering the recombinant capabilities of the domestic inventors to create complex knowledge—specifically, GTs –. Building on previous insights on the role that inventors' experience and career may play in shaping their capabilities (e.g., (Melero & Palomeras, 2015; Murray, 2004), we focus on those individuals' characteristics—not directly linked to ethnicity—that might enact their abilities to bridge across the diverse knowledge base of the R&D team and contribute to the successful creation of GTs within the organizational boundaries. For instance, the breadth of the inventors' network—i.e., the number of unique collaborators they have been working with during their careers—might affect the team's ability to recognize innovative ways to recombine knowledge from different technological bases. Similarly, the inventors' experience in a cross-cultural working environment—i.e., collaborating with non-US inventors or working in global teams—might influence the individuals' capabilities to produce innovation through novel combinations of technologies. Also, mobile inventors—i.e., inventors who have been residing in more than one country during their career—being exposed to different environments and cultures might enable integrative mechanisms—such as openness, trust, visibility—that facilitate the firms' knowledge recombination. For these reasons, we further consider an augmented model specification to test the robustness of our main hypotheses to these ulterior moderator channels. Detailed definitions of all the variables and descriptive statistics are reported in the Appendix (Tables 3, 4 and 5).

4 Econometric evidence

4.1 Main results

In Table 1, Model 1 and 2 confirms, in line with previous literature, that inventors' teams leveraging more intense recombinant capabilities are associated with a higher probability of patenting green technologies, other things being equals. In other words, teams composed of individuals with a higher propensity to create new technological combinations between previously unrelated technologies also tend to have a higher probability of developing new green technologies. Most importantly, the higher the level of ethnic diversity among the US-based inventors, the higher the probability of patenting green technologies (H1a). However, such a relationship shows a non-linear pattern as it decreases with the level of ethnic diversity (H1b). These results provide a first test for determining whether ethnic diversity among the US-based inventors acts as a complementary channel reinforcing the knowledge recombinant capabilities leveraged to develop new green technologies (H2). The positive and significant coefficient of the interaction term suggests that patents developed by R&D teams involving a higher degree of ethnic diversity among their domestic inventors might be more likely to combine technological knowledge in a novel way to develop green technologies. Models 3 and 4 reiterate our specifications introducing the complete set of control variables at the team and firm level. All the previous results are confirmed, the adjusted R-squared statistic increases significantly, and the control variables' coefficients are coherent with the theoretical perspective. The first set of results seems to confirm that ethnic

Table 1 Baseline regressions

	(1)	(2)	(3)	(4)
Recombinant capabilities	0.0275	0.0247	0.0058	0.0036
	(0.000)	(0.000)	(0.000)	(0.000)
Ethnic diversity	0.0210	0.0135	0.0272	0.0216
	(0.000)	(0.023)	(0.000)	(0.000)
Interaction term		0.0178		0.0134
		(0.000)		(0.000)
Ethnic Diversity sq	– 0.0287	– 0.0307	– 0.0460	– 0.0475
	(0.005)	(0.003)	(0.000)	(0.000)
Controls:				
Team size			0.0027	0.0027
			(0.000)	(0.000)
Tenure			– 0.0052	– 0.0052
			(0.000)	(0.000)
Patent stock			– 0.0041	– 0.0041
			(0.000)	(0.000)
Triadic patents (%)			0.0032	0.0032
			(0.000)	(0.000)
Green inventions			0.2880	0.2880
			(0.000)	(0.000)
Firm age			– 0.0000	– 0.0000
			(0.906)	(0.872)
Firm productivity			– 0.0007	– 0.0007
			(0.006)	(0.005)
Green experience			0.0050	0.0050
			(0.000)	(0.000)
Constant	0.0580	0.0593	0.0501	0.0512
	(0.000)	(0.000)	(0.000)	(0.000)
Year F.E	*Yes*	*Yes*	*Yes*	*Yes*
Industry F.E	*Yes*	*Yes*	*Yes*	*Yes*
Technological F.E	*Yes*	*Yes*	*Yes*	*Yes*
Adjusted R2	0.1774	0.1774	0.4244	0.4244
Observations	476,888	476,888	476,888	476,888

Robust standard errors in parentheses

diversity might be a potential enabler for integrating novel technological combinations into new green technologies.[11]

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[11] Figure 5 in Appendix offers a visual representation of the average marginal effects of the recombinant capabilities of the team on the probability of patenting a green technology computed at different levels of the ethnic diversity of the domestic inventor.

Table 2 Robustness check: testing for alternative explanations

	(1)	(2)
Recombinant capabilities	0.0086	0.0049
	(0.000)	(0.000)
Ethnic diversity	0.0255	0.0156
	(0.000)	(0.002)
Interaction term		0.0237
		(0.000)
Ethnic Diversity sq	– 0.0349	– 0.0374
	(0.000)	(0.000)
Alternative explanations		
Geographical dispersion	– 0.0442	– 0.0441
	(0.000)	(0.000)
Network breadth	– 0.0018	– 0.0018
	(0.000)	(0.000)
Geographical bridging	– 0.0045	– 0.0043
	(0.099)	(0.115)
Global team experience	0.0035	0.0034
	(0.010)	(0.013)
Foreign collaborations (%)	– 0.0170	– 0.0169
	(0.002)	(0.002)
Constant	0.0458	0.0475
	(0.000)	(0.000)
Controls	*Yes*	*Yes*
Year F.E	*Yes*	*Yes*
Industry F.E	*Yes*	*Yes*
Technological F.E	*Yes*	*Yes*
Adjusted R2	0.4273	0.4274
Observations	476,888	476,888

Robust standard errors in parentheses

4.2 Robustness checks

4.2.1 Alternative explanations

The literature highlights the existence of mechanisms alternative to ethnicity for facilitating or hindering the recombinant capabilities of the domestic inventors to create complex knowledge—specifically, green technologies –. Thus, we disentangle such confounding factors to tease out the primary driving mechanisms. In detail, in Model 1 and 2 of Table 2, we include proxies for such potential mechanisms.[12] Also in this case, the sign

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[12] Since we aim at controlling for characteristics of the domestic individuals in the R&D team that might act as confounding factors with respect to the ethnic origin of the inventor, we computed all the variables for the domestic inventors only. Global patents – i.e., patents with inventors residing both in the US and in foreign country – account for a small percentage of our main sample (about 3%). Furthermore, estimates are robust when substituting similar measures at the entire team level.

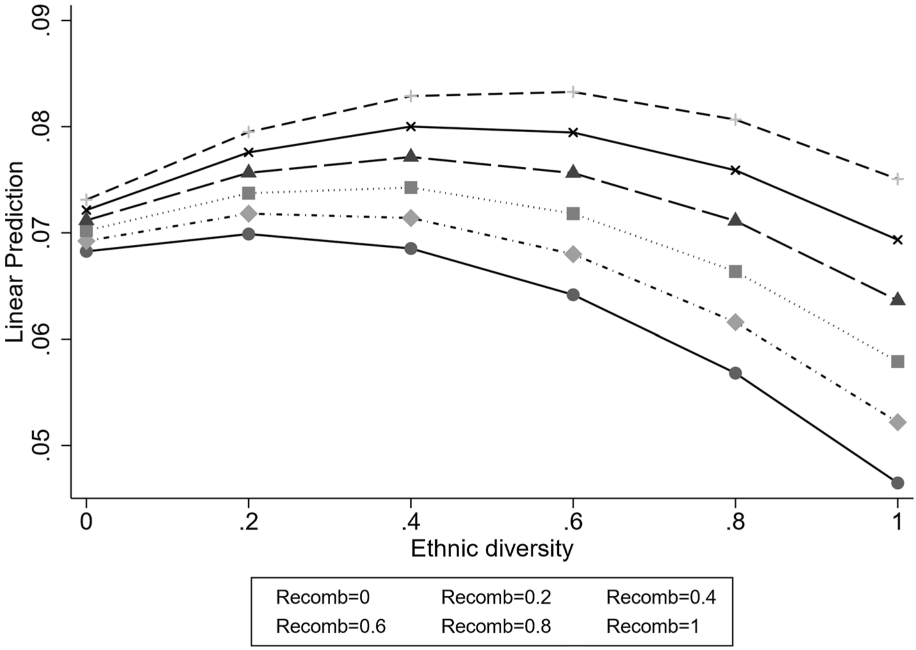

Fig. 1 Sensitivity analysis for the average marginal effects of recombinant capabilities at different values of ethnic diversity. Results from Model 2 in Table 2

and significance of the main explanatory variables are consistent with the baseline model specification, thus confirming the robustness of the complementary role of ethnic diversity and recombinant capabilities of the inventor team in creating novel green technological knowledge. When testing further the robustness of our results to specific patent-level features, the estimates remain consistent (see Table 6 in Appendix).

4.2.2 Sensitivity analysis for the degree of ethnic diversity

To deal with further potential sources of heterogeneity in our estimates, we make more thorough considerations about the non-linear relationship between the ethnic diversity of the domestic inventors in the team and the creation of GTs. Specifically, we explore whether the moderator effect of ethnic diversity on the recombinant capabilities for developing technologies for green purposes is sensitive to the degree of ethnic diversity in the inventors' team. Plotting the predictive margins of *EthnDiv* at different values of *Recomb,* Fig. 1 shows that the probability of patenting green technologies increases with the recombinant capabilities of the team—namely, the *Recomb* coefficient is positive and the curve goes up as the *Recomb* variable increases –, but the function assumes an inverse-U shape. Also, the distance between the plotted functions increases with the level of *Recomb*, suggesting that the higher the extent of recombinant capabilities of the R&D team members, the higher the likelihood to develop a green patent, other things being equal. In other words, ethnic diversity in inventors' teams is beneficial to the R&D team's recombinant capabilities up to a certain threshold. Then, diversity might become redundant and create

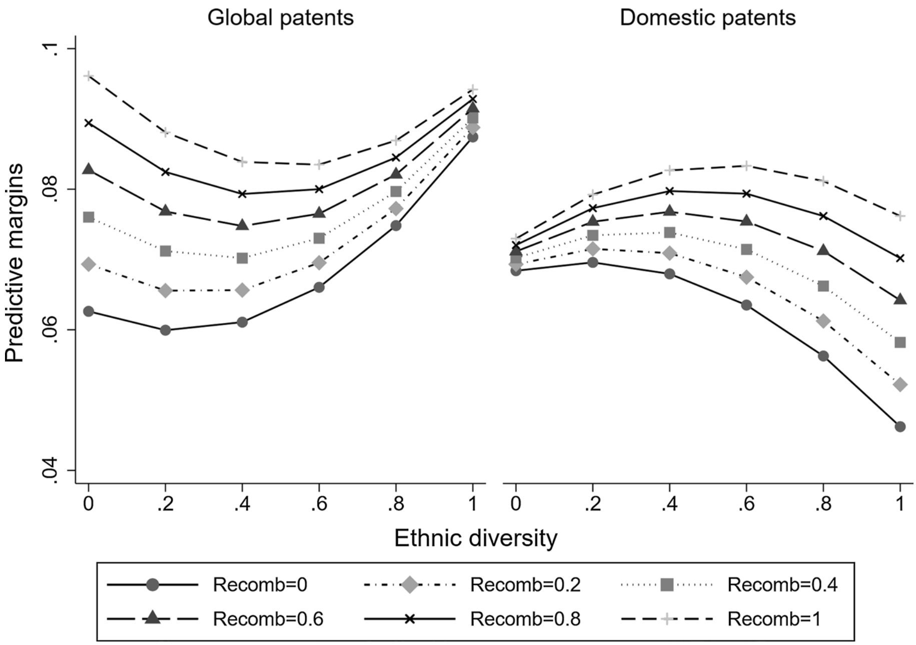

Fig. 2 Global teams patents vs domestic teams: the predictive margins of of recombinant capabilities at different values of ethnic diversity

frictions to the recombination of knowledge for green purposes, in line with the diversity dilemma considered in the theoretical framework.[13]

4.2.3 The geographical distribution of the R&D team

Recent studies on the role of foreign-origin skilled workers in the knowledge creation and integration process of MNEs have shown that ethnic inventors might serve a bridging function among collaborators in the R&D team and geographically dispersed knowledge, especially in the intra-organizational framework (Choudhury, 2016; Choudhury & Kim, 2019; Foley & Kerr, 2013b; Kerr & Kerr, 2018; Marino et al., 2020; Useche et al., 2020). Thus, we explore whether involving ethnic inventors might act as a mechanism alternative to the international composition of the R&D teams to empower individual capabilities to recombine technological-distant technology for green purposes. To this end, we analyze the predictive margins of *Recomb* at different levels of *EthDiv* separately for global and domestic patents. While the function maintains an inverse U-shape for the latter, the relationship "flips" and draws an opposite curve for the global teams (see Fig. 2). In other words, managing both geographically dispersed inventors or culturally diverse R&D teams might embody separate and equally successful knowledge recombination mechanisms to create green technologies, depending on the organization's idiosyncratic characteristics.[14]

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[13] Similar results in Table 6 in the Appendix. Figure 5 reports the average marginal effects of *EthDiv* at different levels of *Recomb*.

[14] Further analysis available in Table 7 and Figure the Appendix.

4.2.4 Environmental policy stringency and the market exploitation of green technologies

In the green innovation field, much research has focused on the role of environmental policy stringency (EPS)[15] and how domestic firms are affected by national policies. However, since MNEs operate in global markets, their decisions in investing in the development and commercialization of GTs might also be influenced by assessments about policies both at home and in the potential host countries, among other factors (D'Agostino, 2015).

MNEs carry out the bulk of their R&D at home (Laurens et al., 2015), and, especially in developing countries, the subsidiaries are more likely to exploit extant knowledge bases rather than having a competence-creating mandate (Athreye et al., 2014; Cantwell & Mudambi, 2005). Thus, it seems reasonable to control for the stringency of environmental regulation in the countries where the MNEs decide to commercialize their innovation and whether it can affect their strategic decisions for green patenting. Our theoretical hypotheses appear confirmed when including a proxy for EPS in exploiting markets, while the policy stringency lacks significance in any specification (for further details, see the Appendix).

5 Conclusions

MNEs innovation processes rely more and more on global knowledge sourcing based on the strategic management of boundary-spanning R&D teams. Literature in international business studies has documented the evolution of MNEs' strategies of R&D internationalization and stressed the importance of blending talents from different geographical locations to ensure successful knowledge generation dynamics and create the conditions for high-impact innovations. Notably, these studies have provided valuable insights for the strategic management of international inventors' teams, emphasizing that effective MNEs' recombinant dynamics rely on the masterly combination of diverse inventors (Asakawa et al., 2018; Papanastassiou et al., 2019; Seo et al., 2020).

In this paper, we have argued that the distinctive competence of MNEs in the strategic management of diversified R&D teams can provide them with a competitive advantage in the global race for rapidly expanding green technologies markets. R&D teams featured by inventors with diverse technical, geographical or ethnic backgrounds are indeed more likely to have easier access to knowledge sources, as well as a better capacity to process, integrate and exploit these diverse inputs. These capabilities are deemed to be crucial for the generation of green technologies, which are described as inherently complex and stemming from the recombination of heterogeneous and loosely related—or cognitively distant—knowledge inputs (Barbieri et al., 2020; Orsatti et al., 2020).

To support this hypothesis, we have investigated the relationship between the impact of the involvement of ethnic inventors' in R&D teams on the generation of green inventions, as well as the moderating role they play in alleviating the challenges for knowledge

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[15] The policy stringency variable (EPS) is proxied by the OECD "Environmental Policy Stringency Index", which is a country-specific and internationally-comparable measure of the degree to which environmental policies attribute a price on environmentally-harmful behaviors.

recombination by acting as a bridge within the diversified knowledge base of the team and contribute to the successful creation of GTs within the organizational boundaries.

By exploiting data drawn from the ethnic patenting database (Kerr & Kerr, 2018) and Harvard Patent Dataverse database (Lai et al., 2011), we recreate information on the probable ethnicity of inventors working for US-based MNEs with global technology development mandate and their career. Consistent with previous literature, we confirm empirical evidence of the positive relations between recombinant-creation capabilities on the generation of GTs: teams composed of individuals with greater experience in original technological combinations between previously unrelated scientific domains also tend to have a higher propensity of developing new green technologies. Moreover, we find that complexity in terms of ethnic origins of US-based inventors correlates with a higher probability of patenting GTs, but the relationship follows a non-linear pattern as it decreases with the level of ethnic diversity. Finally, we find that patents developed by R&D teams involving a higher degree of ethnic diversity among their domestic inventors are more likely to combine technological knowledge in a novel way to develop GTs.

On the latter matter, the moderator effect of ethnic diversity on the recombinant capabilities for developing technologies for green purposes is sensitive to the degree of ethnic diversity in the inventors' team, consistently with previous literature suggesting that increasing diversity might become redundant and create frictions to the recombination of knowledge for green purposes. In particular, these findings reason with established theories on the ambiguous role of cognitive diversity—i.e., in terms of ethnicity, culture, and experience—in fostering innovation (DiTomaso et al., 2007; Ozgen et al., 2014), especially when knowledge is complex and sticky (Dougherty, 1992). Overall, our results suggest that ethnic diversity might act as a valuable individual-level enabling channel to knowledge integration in the MNEs' organizational space, thus providing multinational corporations with additional opportunities to tap new and heterogeneous knowledge sources. Managing both geographically dispersed inventors or culturally diverse R&D teams might embody equally successful knowledge recombination mechanisms to create green technologies, depending on the organization's idiosyncratic characteristics.

Altogether, our paper contributes to the efforts to bridge different literature on the micro-foundations of recombinant capabilities, MNEs' strategies for external knowledge sourcing and strategic management of GTs by analyzing how R&D team ethnic characteristics and organizational factors may interact to affect knowledge flows in the complex multinational organization. However, further exploration is needed to understand better the implications for the firms' strategic management of inventors' teams to grasp the opportunities set by the hybridization of existing knowledge to create innovation in the green field and the potential synergies between multiple diversity dimensions. Also, we share the urge to advance research on the role of ethnic ties between home and host countries in fostering recombinant capabilities, conditional on the type of technological innovation—either as different GTs subfields or the mitigation/adaptation strategies for climate change—and the revealed technological advantages of the countries in which the MNE operates.

All in all, these findings also reason with policymakers and managers and how they can enhance firms' recombinant capabilities in responding to climate change challenges favoring boundary spanning, cross fertilization and radical exploration (Rosenkpof and Nerkar, 2001). On the one hand, the evidence we provide in this paper has implications on the strategic management of firms' technological portfolios. Extant literature has stressed the relevance of ethnic diverse inventors' teams in general. In line with previous evidence, from the perspective of the strategic management of human resources involved in R&D activities, our results confirm that green technological diversification is better achieved by teams involving inventors familiar with recombinant dynamics across broad areas of the knowledge space and with atypical recombinations. Most importantly, ethnic diversity in inventors' teams requires careful management. We actually show that the involvement of ethnic inventors may have a positive impact on the capacity to generate green technologies, and a magnifying impact on the effect of recombinant creation capabilities. Yet excess ethnic diversity can be detrimental, supposedly due to frictions related to the so-called diversity dilemma. Accordingly, a balanced approach to the management of teams' ethnic diversity seems to be the most promising strategy to reap the benefits from the green technology race.

On the other hand, this research also bears important policy implications. In general, our evidence is coherent with the wide body of literature stressing the importance of environmental policy stringency in triggering the generation of GTs via demand pull dynamics. However, our analysis also implies that environmental policy needs to be coordinated with other policy domains, and especially with science and technology policy. These latter not only should promote public and private investments in boundary spanning research, but also should provide incentives to make inventors' teams more and more international, increasing the involvement of ethnic inventors. Accordingly, Innovation policies promoting technological and ethnic diversifity can create the conditions, on the one hand, for the composition of heterogeneous inventor teams and, on the other hand, for the access to a sufficiently broad knowledge pool providing inputs for recombinant creation dynamics (Orsatti et al., 2020). Moreover, such policy mix should be designed to enhance the capacity to engage in green recombinant knowledge by means of learning-by-interacting dynamics (Junginger et al., 2010).

Our results also provide a fertile ground for future research. While we mainly focused on the invention generation phase of the innovation process, it is also important to discern the adoption and exploitation of green technologies at the organizational level. Even though the analysis of the dynamics of global market exploitation of green technologies within the MNEs' network is beyond the scope of the present work, we have contributed to scrape the surface of the multifaceted mechanisms of intra-organization diffusion of green innovations. Further research could explore whether MNEs exploit green knowledge developed at home for building competitive advantages within the internal network of subsidiaries located in different countries in conjunction with host-country specific advantages (Cantwell, 2005; Dunning 1993; (Rugman & Verbeke, 1992) or how environmental regulations in home and host countries affect the MNEs global exploitation strategy.

6 Appendix

See Fig. 3 and (Tables 3, 4, 5 and 6).

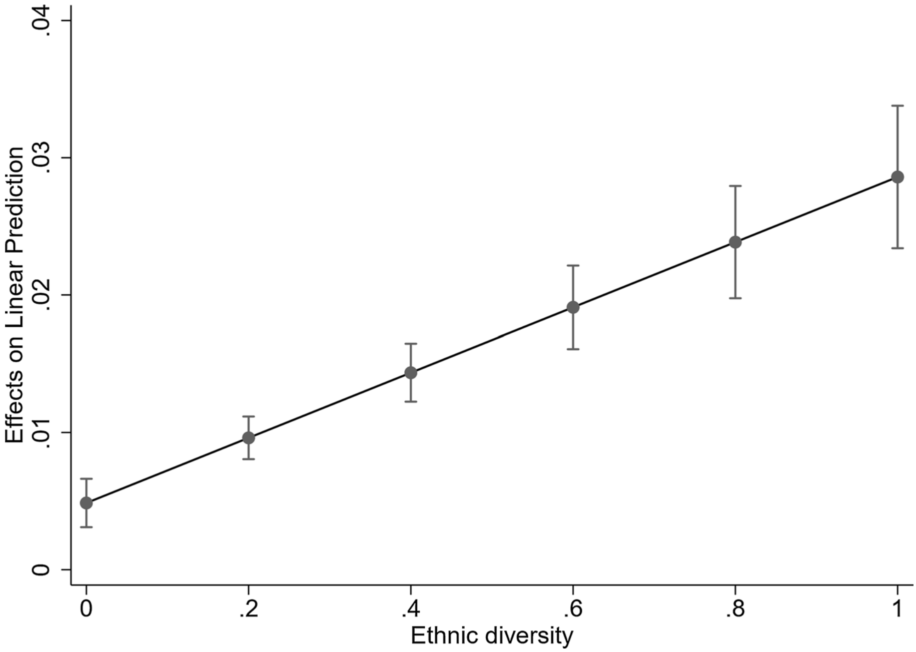

Fig. 3 The average marginal effects of ethnic diversity at different values of recombinant capabilities. Confidence intervals at 95% reported

6.1 Heterogeneity in diversity

To further understand the empirical mechanism behind the “heterogeneity in diversity” phenomenon, we built a set of dummy variables equal to one if the value of ethnic diversity in the inventors’ team is higher than a certain threshold of the variable’s sample distribution (Table 7).[16] We also present the average marginal effects of Recombinant capabilities at the different distribution cut-offs for the specification with controls at the firm- and team-level while in Fig. 3. As the cut-off increases, the differences in the average marginal effects for observations below and above the threshold first decreases and then increases again. Thus, this graphical representation seems to point in the same direction as the interpretation of the sensitivity analysis presented in the main text.

6.2 Heterogeneity in geographical distribution

First, we perform a subsample analysis splitting our observations between global and domestic patents (see Table 8). The estimates are robust with our theoretical hypotheses only in the domestic patents group (Models 2 and 4), suggesting that involving ethnic inventors might act as an alternative mechanism to source external knowledge and

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[16] We considered the following distribution thresholds: the 60, 70, 75, 90, 95, 99th percentiles and the average value of the variable Ethnic Diversity.

Table 3 List and description of the control variables

Variable	Description	Type
Team characteristics		
Team size	# Inventors listed in the patent	Patent level
Tenure	# Years since inventors’ first patent	Team average
Patent stock	Inventors’ patent stock at t computed with a depreciation rate of 15%	Team weighted average
Triadic patents (%)	Share of inventors’ triadic patents	Team weighted average
Green inventions	Log of # green technologies in the patent portfolio until t	Team weighted average
Firm characteristics		
Firm age	# years since firm’s first patent	Firm level
Productivity	log of # patents until t	Firm level
Green experience	Dummy equals to 1 if the firm has patented at least one green technology until t	Firm level
Alternative explanations		
Geographic dispersion	Dispersion index based on the inventors’ residing countries as reported in patent	Patent level
Network breadth	# Unique collaborators with whom the domestic inventors’ have been working until t	Team average (domestic inventors)
Geographical bridging	# Unique countries where the domestic inventors have been residing until year t	Team average (domestic inventors)
Global team experience	# Patents with at least one domestic and one foreign inventor in which the domestic inventors have been involved until t	Team average (domestic inventors)
Foreign collaborations	Share of foreign collaborators with whom the domestic inventors have been working until t	Team average (domestic inventors)
Patent characteristics		
Technological scope	# unique IPC subclasses listed in patent	Patent level
Backward citations	# Backward citations reported in the patent	Patent level
Forward citations	# Citations received by the patent after 5 years	Patent level
Claims	# Claims reported	Patent level

Table 4 Descriptive statistics for the general sample

	Obs	Mean	Std. Dev	Min	Max
Green technology	476,888	0.07	0.26	0.00	1.00
Ethnic diversity	476,888	0.21	0.25	0.00	0.86
Recombinant capabilities	476,888	0.47	0.41	0.00	1.00
Team size	476,888	2.42	1.69	1.00	60.00
Tenure	476,888	6.76	5.12	1.00	34.00
Patent stock	476,888	6.07	13.95	1.00	486.57
Triadic patents (%)	476,888	0.33	0.37	0.00	1.00
Green inventions	476,888	0.25	0.56	0.00	4.96
Firm age	476,888	18.31	7.24	1.00	34.00
Firm productivity	476,888	7.12	1.89	0.00	10.91
Green experience	476,888	0.92	0.27	0.00	1.00
Geographical dispersion	476,888	0.02	0.08	0.00	0.80
Network breadth	476,888	8.40	11.49	0.00	427.00
Geographical bridging	476,888	0.98	0.23	0.00	6.00
Global team experience	476,888	0.08	0.30	0.00	8.00
Foreign collaborations (%)	476,888	0.02	0.07	0.00	1.00
Technological scope	476,888	1.55	0.96	1.00	38.00
Backward citations	476,888	4.88	8.79	0.00	360.00
Forward citations	476,888	12.46	21.15	0.00	844.00
Claims	476,888	16.51	13.01	0.00	517.00
Technological scope	476,162	1.79	1.14	1.00	44.00
Forward citations at 5 yrs	476,162	8.54	23.28	0.00	1575.00
Backward citations	476,162	14.40	17.33	0.00	237.00
Claims	476,888	16.49	13.01	0.00	517.00

Table 5 Descriptive statistics by green and non– green patents

	Obs	Mean	Std. Dev	Min	Max
Non-green technologies					
Ethnic diversity	442,448	0.21	0.25	0.00	0.86
Recombinant capabilities	442,448	0.46	0.41	0.00	1.00
Team size	442,448	2.42	1.69	1.00	60.00
Tenure	442,448	6.76	5.14	1.00	34.00
Patent stock	442,448	5.97	13.48	1.00	486.57
Triadic patents (%)	442,448	0.33	0.37	0.00	1.00
Green inventions	442,448	0.16	0.43	0.00	4.96
Firm age	442,448	18.32	7.21	1.00	34.00
Firm productivity	442,448	7.12	1.90	0.00	10.91
Green experience	442,448	0.92	0.28	0.00	1.00
Geographical dispersion	442,448	0.02	0.08	0.00	0.80
Network breadth	442,448	8.40	11.50	0.00	427.00
Geographical bridging	442,448	0.98	0.23	0.00	6.00

Table 5 (continued)

	Obs	Mean	Std. Dev	Min	Max
Global team experience	442,448	0.08	0.30	0.00	8.00
Foreign collaborations (%)	442,448	0.02	0.07	0.00	1.00
Technological scope	442,448	1.51	0.90	1.00	38.00
Backward citations	442,448	4.99	8.96	0.00	360.00
Forward citations	442,448	12.64	21.57	0.00	844.00
Claims	442,448	16.55	13.05	0.00	517.00
Technological scope	441,794	1.77	1.12	1.00	44.00
Forward citations at 5 yrs	441,794	8.71	23.72	0.00	1575.00
Backward citations	441,794	14.57	17.51	0.00	237.00
Claims	442,448	16.53	13.05	0.00	517.00
Green Technologies					
Ethnic diversity	34,440	0.21	0.25	0.00	0.84
Recombinant capabilities	34,440	0.56	0.38	0.00	1.00
Team size	34,440	2.44	1.70	1.00	27.00
Tenure	34,440	6.80	4.96	1.00	34.00
Patent stock	34,440	7.32	18.89	1.00	486.57
Triadic patents (%)	34,440	0.34	0.37	0.00	1.00
Green inventions	34,440	1.36	0.77	0.69	4.93
Firm age	34,440	18.16	7.50	1.00	34.00
Firm productivity	34,440	7.19	1.70	0.00	10.91
Green experience	34,440	0.98	0.13	0.00	1.00
Geographical dispersion	34,440	0.02	0.09	0.00	0.72
Network breadth	34,440	8.48	11.43	0.00	224.50
Geographical bridging	34,440	0.98	0.24	0.00	3.00
Global team experience	34,440	0.09	0.31	0.00	6.00
Foreign collaborations (%)	34,440	0.02	0.07	0.00	1.00
Technological scope	34,440	2.12	1.42	1.00	35.00
Backward citations	34,440	3.58	5.99	0.00	154.00
Forwardcitations	34,440	10.23	14.50	0.00	685.00
Claims	34,440	15.91	12.41	0.00	237.00
Technological scope	34,368	2.00	1.31	1.00	14.00
Forward citations at 5 yrs	34,368	6.40	16.50	0.00	1377.00
Backward citations	34,368	12.32	14.63	0.00	217.00
Claims	34,440	15.88	12.42	0.00	237.00

empower the individual capabilities to recombine technological-distant technology for green purposes.

The graphical representation of this specification clearly depicts the potential underlying mechanism (Fig. 5): while the average marginal effect of recombinant capabilities is boosted by the degree of ethnic diversity in the R&D team entirely composed of US inventors (dashed plot), the relationship decreases with the ethnic diversity of the domestic inventors in the team for global patents.

Table 6 Robustness check: alternative explanations and patent quality

	(1)	(2)
Recombinant capabilities	0.0086	0.0049
	(0.000)	(0.000)
Ethnic diversity	0.0257	0.0158
	(0.000)	(0.001)
Interaction term		0.0236
		(0.000)
Ethnic Diversity sq	– 0.0356	– 0.0381
	(0.000)	(0.000)
Alternative explanations		
Geographical dispersion	– 0.0430	– 0.0430
	(0.000)	(0.000)
Network breadth	– 0.0017	– 0.0017
	(0.000)	(0.000)
Geographical bridging	– 0.0045	– 0.0043
	(0.096)	(0.111)
Global team experience	0.0035	0.0034
	(0.010)	(0.012)
Foreign collaborations (%)	– 0.0168	– 0.0168
	(0.002)	(0.002)
Controls		
Team size	0.0046	0.0046
	(0.000)	(0.000)
Tenure	– 0.0041	– 0.0040
	(0.000)	(0.000)
Patent stock	– 0.0039	– 0.0039
	(0.000)	(0.000)
Triadic patents (%)	0.0043	0.0044
	(0.000)	(0.000)
Green inventions	0.2927	0.2928
	(0.000)	(0.000)
Firm age	– 0.0001	– 0.0001
	(0.311)	(0.274)
Firm productivity	0.0006	0.0006
	(0.008)	(0.008)
Green experience	0.0020	0.0020
	(0.028)	(0.025)
Patent– level controls		
Technological scope	0.0007	0.0007
	(0.019)	(0.035)
Forward citations at 5 yrs	– 0.0000	– 0.0000
	(0.000)	(0.000)
Backward citations	0.0000	0.0000
	(0.039)	(0.049)
Claims	– 0.0001	– 0.0001
	(0.010)	(0.011)

Table 6 (continued)

	(1)	(2)
Constant	0.0467	0.0484
	(0.000)	(0.000)
Year F.E	*Yes*	*Yes*
Industry F.E	*Yes*	*Yes*
Technological F.E	*Yes*	*Yes*
Adjusted R2	0.4285	0.4286
Observations	476,162	476,162

Robust standard errors in parentheses

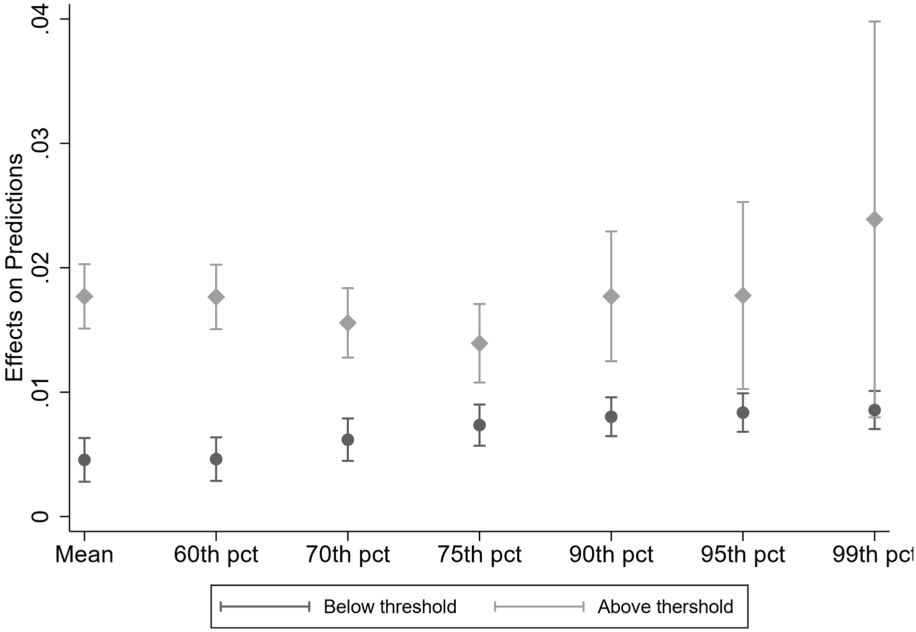

Fig. 4 Sensitivity analysis for the average marginal effects of recombinant capabilities at different cut-offs of the distribution of ethnic diversity. Model with alternative explanation controls. Confidence intervals at 95% reported

6.3 Environmental policy stringency and the market exploitation of green technologies

The reason to introduce this robustness check in our work is twofold. The first motivation derives from methodological reasons: our sample is representative of a specific niche of firms, that is multinational companies based in the US that have experienced, at some point of their activity, global technology development. Since we already control for general temporal shocks via fixed effects, and there is not a prominent policy shift in the US during the time of analysis, we believe it would appear redundant to add home country measures of stringency in environmental regulation. Secondly,

Table 7 Robustness check: Sensitivity analysis for ethnic diversity measure

	(1) Mean	(2) 60th	(3) 70th	(4) 75th	(5) 90th	(6) 95th	(7) 99th
Recombinant capabilities	0.0032	0.0032	0.0045	0.0054	0.0056	0.0057	0.0057
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Ethnic diversity	– 0.0020	– 0.0019	– 0.0015	– 0.0016	– 0.0057	– 0.0057	– 0.0129
	(0.018)	(0.022)	(0.082)	(0.086)	(0.000)	(0.004)	(0.002)
Interaction term	0.0081	0.0080	0.0046	0.0019	0.0023	0.0013	0.0056
	(0.000)	(0.000)	(0.004)	(0.284)	(0.389)	(0.744)	(0.490)
Constant	0.0518	0.0517	0.0511	0.0508	0.0503	0.0504	0.0504
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Controls	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year F.E	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Industry F.E	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Technological F.E	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Adjusted R2	0.4244	0.4244	0.4244	0.4243	0.4244	0.4244	0.4244
Observations	476,888	476,888	476,888	476,888	476,888	476,888	476,888

Robust standard errors in parentheses

Table 8 Robustness check: Testing for heterogeneity in the geographical distribution of R&D teams

	(1) Global patents	(2) Domestic patents	(3) Global patents	(4) Domestic patents
Recombinant capabilities	0.0338	0.0031	0.0335	0.0046
	(0.000)	(0.001)	(0.000)	(0.000)
Ethnic diversity	– 0.0207	0.0224	– 0.0230	0.0129
	(0.341)	(0.000)	(0.291)	(0.011)
Interaction term	– 0.0265	0.0142	– 0.0267	0.0254
	(0.091)	(0.000)	(0.089)	(0.000)
Ethnic diversity sq	0.0474	– 0.0491	0.0478	– 0.0351
	(0.200)	(0.000)	(0.196)	(0.000)
Constant	0.0565	0.0513	0.0833	0.0549
	(0.000)	(0.000)	(0.000)	(0.000)
Controls	*Yes*	*Yes*	*Yes*	*Yes*
Alternative explanations	*No*	*No*	*Yes*	*Yes*
Year F.E	Yes	Yes	Yes	Yes
Industry F.E	Yes	Yes	Yes	Yes
Technological F.E	Yes	Yes	Yes	Yes
Adjusted R2	0.5202	0.4224	0.5205	0.4258
Observations	18,152	458,736	18,152	458,736

Robust standard errors in parentheses

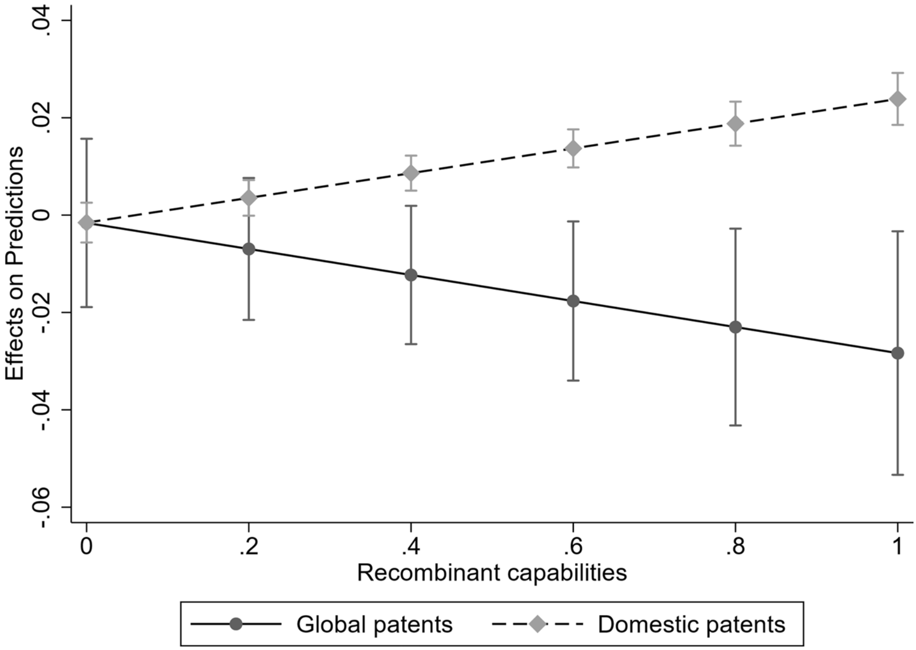

Fig. 5 The average marginal effects of ethnic diversity at different levels of recombinant capabilities among global or domestic patents. Model with alternative explanation controls. Confidence intervals at 95% reported

MNEs carry out the bulk of their R&D at home (Laurens et al., 2015) and, especially in developing countries, the subsidiaries are more likely to exploit extant knowledge bases rather than having a competence-creating mandate (Athreye et al., 2014; Cantwell & Mudambi, 2005). Thus, it seems reasonable to control for the stringency of environmental regulation in the countries where the MNEs decide to commercialize their innovation and whether it can affect the strategic decisions of the multinationals in terms of the development of green technologies.

In order to reduce biases deriving from strategic patenting motivations and in an attempt to disentangle mainly market exploitation reasons, we focus on granted patents in the first three countries—different from the US—where the MNE extended protection for the invention.[17] The policy stringency variable (EPS) is proxied by the OECD "Environmental Policy Stringency Index", which is a country-specific and internationally-comparable measure of the degree to which environmental policies attribute a *price* on environmentally-harmful behaviors.[18] The EPS variable is a dummy that equals one if the average EPS

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[17] The information about market exploitation is recollected through data about the patent family to which each focal patent belongs using the ORBIT database by QUESTEL. According to the ORBIT FamPat collection, a family groups together all the patent documents from different national patent offices that refer to the same single invention.

[18] The EPS is based on the degree of stringency of 14 environmental policy instruments, both market-specific (e.g., taxes, trading schemes, and feed-in tariffs) and non-market-specific (e.g., standards and R&D subsidies). The EPS takes values ranging from 0 (not stringent) to 6 (stringent) and it covers 28 OECD and 6 non-OECD countries since 1990.

Table 9 Robustness check: Environmental Policy Stringency in the market of exploitation

	(1)	(2)	(3)	(4)	(5)	(6)
Recomb	0.0075***	0.0045**	0.0097***	0.0075***	0.0066***	0.0055*
	(0.0015)	(0.0018)	(0.0023)	(0.0015)	(0.0025)	(0.0028)
EthnDiv	0.0354***	0.0284***	0.0354***	0.0383***	0.0312***	0.0284***
	(0.0085)	(0.0086)	(0.0085)	(0.0090)	(0.0091)	(0.0094)
EPS	0.0001	0.0001	0.0019	0.0012	0.0029	0.0020
	(0.0011)	(0.0011)	(0.0015)	(0.0015)	(0.0018)	(0.0020)
EPS*Recomb			– 0.0036		– 0.0035	– 0.0016
			(0.0028)		(0.0028)	(0.0035)
EPS*EthDiv				– 0.0045	– 0.0041	0.0007
				(0.0043)	(0.0043)	(0.0061)
EPS*Recomb*EthDiv						– 0.0094
						(0.0114)
Recomb*EthDiv		0.0154***			0.0153***	0.0209**
		(0.0056)			(0.0056)	(0.0090)
EthDiv squared	– 0.0561***	– 0.0575***	– 0.0561***	– 0.0565***	– 0.0580***	– 0.0581***
	(0.0143)	(0.0143)	(0.0143)	(0.0143)	(0.0143)	(0.0143)
Constant	0.0484***	0.0498***	0.0473***	0.0477***	0.0482***	0.0487***
	(0.0039)	(0.0039)	(0.0040)	(0.0040)	(0.0040)	(0.0041)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E	Yes	Yes	Yes	Yes	Yes	Yes
Industry F.E	Yes	Yes	Yes	Yes	Yes	Yes
Technological F.E	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.4154	0.4154	0.4154	0.4154	0.4154	0.4154
Adjusted R2	0.4150	0.4150	0.4150	0.4150	0.4150	0.4150
Adjusted within– R2	0.3024	0.3025	0.3024	0.3024	0.3025	0.3025
Observations	124,487	124,487	124,487	124,487	124,487	124,487

Robust standard errors. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

value at t-1 in the exploitation countries is above the sample mean in that year, and zero otherwise. Table 9 reports different model specifications including the EPS measure as well as the interaction with our main explanatory variables.

Acknowledgements We acknowledge the very useful suggestions from Fabrizio Cesaroni and Larissa Rabbiosi. Previous versions of this paper were presented at the Academy of Management Conference, the European Academy of Management and the Sinergie Conference. We are grateful to the participants for their comments.

Funding Open access funding provided by Università degli Studi di Torino within the CRUI-CARE Agreement.

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