The effect of the firm’s innovation modes DUI and STI on radical innovation and the moderating role of institutional factors in an emerging economy.

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Abstract.

Innovation modes literature explains how firms use and combine scientific and experience-based knowledge to adopt innovation outcomes. Moreover, the association between innovation modes and innovation outcomes differ due to institutional factors. Since innovation modes use and combine heterogeneous knowledge to produce innovation outcomes, institutions can strengthen or weaken knowledge use involve in the innovation process. This paper analyzes how institutional factors, such as ease of imitation, and difficult to access external financing, moderate the effect of the firm’s innovation modes on radical innovations. We use an innovation survey from an emerging economy and apply a multilevel technique. Our main results state that firms adopting a DUI or a DUI-STI mode have a positive association with radical innovation, and this effect is stronger for low levels of imitation, while STI mode is detrimental for adopting radical innovation, but high imitation contributes positively to radical innovation. On the other hand, access to external financing has a negative moderator effect in DUI and STI modes introducing radical innovation.

Keywords:

Doing, using and interacting; DUI innovation mode; science, technology, and innovation; STI innovation mode; radical innovation; formal institutions; informal institutions; imitation; external financing; innovative collaboration; emerging economy; multilevel modeling.

JEL classification:

O30 – O31
1. **INTRODUCTION.**

In a broad sense, innovation modes refer to “...the possibility of synthesizing (in an effective way) highly heterogeneous nature of firms’ innovative behaviors into a manageable and interpretable set of typologies of innovation practices, strategies and performances” (Evangelista and Vezzani, 2010, p. 1257). Innovation modes literature determine two ideal modes through which firms combine knowledge and transform into innovations. The mode based on the use of knowledge from science and technology, the Science-Technology-Innovation mode (STI mode), and the mode based on the use of knowledge from learning by Doing-Using-Interacting (DUI mode) (Jensen, Johnson, Lorenz, and Lundvall, 2007).

The STI innovation mode characterizes by R&D activities, where human scientific capital participates and uses codified knowledge in its innovation process, collaborating with universities, laboratories, and other research centers (Jensen et al., 2007). DUI innovation mode characterizes by involving experience-based learning; employees use tacit knowledge and their professional skills in problem-solving (Jensen et al., 2007). Interactions in the DUI mode are usually with suppliers or customers and based on tacit knowledge.

Besides, firms can adopt skills and resources from both STI and DUI innovation modes¹. In a mixed innovation mode (DUI-STI mode), firms use codified and tacit forms of knowledge for innovating, sourced from collaboration with scientific and supply chain partners, and from personnel with scientific and experience-based knowledge.

Scholars have addressed the influence of firms’ innovation modes on their innovation outcomes. Previous findings assert that combining both innovation modes improves innovation performance (Jensen et al., 2007). Moreover, the STI innovation mode usually relates more with radical and product innovation, while DUI innovation mode usually relates more with incremental and process innovation (Fitjar and Rodríguez-Pose, 2013; Jensen et al., 2007). However, recent literature states that the relationship between innovation modes and innovation outcomes can vary across

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¹ In this research, we refer to DUI-STI mode as a mode using characteristics from both DUI and STI innovation modes.
countries and regions due to firms are embedded in a different social and institutional context (Parrilli and Alcalde, 2016; Parrilli, Fitjar, and Rodríguez-Pose, 2016).

Institutions encourage or discourage firms from innovating (North, 1990). Innovation understood as the result of an interactive learning process, can be influenced by different institutional set-ups (Bengt-Åke Lundvall, 1992). Thereby, a set of institutions, which varies by territory, may shape firms’ relationships with different actors (Lundvall, 2007; Parrilli et al., 2016).

Innovation modes literature state that different innovation modes embedded in a territory may have different effects on innovation outcomes due to “...the potential effect of cultural, institutional and social idiosyncrasies on the geographical reach” (Parrilli and Alcalde, 2016, p. 747). Since innovation modes use and combine heterogeneous knowledge to produce innovation outcomes, institutions can strengthen or weaken knowledge use depending on the type of knowledge. Therefore, formal and informal institutions can moderate the relationship between innovation modes and innovation outcomes differently.

In this paper, we analyze how institutional factors moderate the effect of firms’ innovation modes adopting radical innovations. In the first specific objective, we develop a multilevel model to assess the effect of STI and DUI innovation modes on radical innovations. In the second specific objective, we use a multilevel model to adopt institutional factors as moderators between innovation modes and radical innovation.

Firms with low financial and human resources, accessing external knowledge becomes crucial for innovating; however, institutions may affect knowledge exchange. Being so, this research contributes to explain how ease of imitation, an informal institution, and difficult to access external financing, a formal institution, moderate the relationship between firms’ innovation modes and radical innovation.

To address these objectives, in the next section, we present an overview of the innovation modes literature, and we describe highlights and principal findings. Then, in Section 3, we present the theoretical framework related to innovation modes and institutions. In Section 4, we describe the methodology. Before to show the results, in Section 5, we describe some aspects of science, technology, and innovation (STI) in emerging economies, specifically in Colombia. Then, we present
the results (Section 6) and discussions (Section 7). Finally, we conclude and present future research lines in Section 8.

2. INNOVATION MODES LITERATURE: HIGHLIGHTS AND KEY FINDINGS

Innovation modes describe firms’ innovation strategies linking knowledge to their innovation performance (Jensen et al., 2007; Lundvall and Lorenz, 2007). The literature in innovation modes has addressed two research topics (Apanasovich, 2014): which innovation mode -STI, DUI or DUI-STI- is more effective for adopting innovation outcomes, and the knowledge exchange through the collaboration with diverse partners located on local/global scales. Furthermore, scholars have discussed the role of context for innovation on the second one.

Innovation modes’ approach state that there are forms of knowledge -know-what, know-why, know-how, know-who- predominating in each STI and DUI modes (Jensen et al., 2007). The STI mode refers to know-what and know-why forms of knowledge, which is mostly codified and explicit, while the DUI mode refers to know-how and know-who which is tacit and highly localized (Jensen et al., 2007). The main forms of knowledge in each STI and DUI modes involve different skills, human resources, and partners collaboration.

2.1. Firms’ innovation performance

One of the main purposes across innovation modes literature address the firms’ innovation performance to adopt innovation outcomes. Previous studies in developed countries -Denmark, Norway and Germany- suggest that firms adopting a mix innovation mode (DUI-STI) have a higher association with the product, process, and radical innovations, than firms adopting one innovation mode alone (Jensen et al., 2007; Parrilli and Alcalde, 2016; Thomä, 2017). Similar results are shown in Swedish (Isaksen and Nilsson, 2013) and transition economies (e.g., Belarus) (Apanasovich, Alcalde Heras, and Parrilli, 2016).

These studies highlight the theoretical complementarities between STI and DUI modes for firms. As stated by Jensen et al “Firms that connect more systematically to sources of codified and scientific knowledge are able to find new solutions and develop new products that make them more competitive” (2007, p. 690). The innovation modes’ coexistence rests, in part, on the firms’
capacity to absorb tacit and codified knowledge (Apanasovich et al., 2016; Cohen and Levinthal, 1990) and develop an internal capacity building (Isaksen and Nilsson, 2013). In a low-tech industry, firms characterized by a DUI mode may benefit from external scientific knowledge but may be difficult due to the lack of firms’ absorptive capacity (Isaksen and Nilsson, 2013).

However, in some contexts, complementarities between the DUI and STI innovation modes do not improve innovation performance. In the Basque Country and in emerging economies (e.g., Colombia), it has been shown that the STI innovation mode has a higher association with radical and incremental innovations than the DUI and the DUI-STI modes (Malaver and Vargas, 2013; Parrilli and Elola, 2012). Accordingly to Parrilli and Elola (2012), firms benefit to a greater extent from R&D activities, human capital, and interactions with scientific partners at the national and international scale, while the knowledge exchange from experience does not contribute to innovation. In this context, complementarities between DUI and STI modes leading to higher innovation performance has been addressed from the collaboration perspective.

To measure firms’ innovation performance, the literature on innovation modes has followed the Oslo Manual. Innovation modes distinguish innovation by types -product or process-, technological level -technological and non-technological- and novelty -radical or incremental. The studies have adopted mainly a quantitative approach, and the principal technique used has been logistic regression analysis (Fitjar and Rodríguez-Pose, 2013; Haus-reve, Dahl, and Rodríguez-Pose, 2019; Jensen et al., 2007; Parrilli and Alcalde, 2016; Thomä, 2017). The logistic regression model fits with the kind of research questions addressed by these studies due to the binary nature of the innovation outcomes.

2.2. Collaboration

Firms integrate knowledge from external sources and collaborating with diverse partners facilitates access to new knowledge. Broadly speaking, collaboration with external partners benefits innovation at the firm level. One of the main research objectives has been the influence of the type

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Malaver and Vargas’ results may differ due to a different methodological approach to identify innovation modes and by a sample on a single Colombian region.
of firms’ collaboration -formal or informal-, partners location -local or global- and the type of partners, on firms’ innovation outcomes.

In this respect, the STI mode tend to be related more with scientific partners as research centers and universities, generating codified and explicit knowledge, while the DUI mode is more related with supply-chain partners as clients and suppliers, and with competitors, generating tacit and implicit knowledge. Nevertheless, partners do not influence in the same way the adoption of innovation outcomes. In the DUI mode, interaction with suppliers contributes to product and process innovation -incremental and radical-, interaction with customers contributes only to product innovation -incremental and radical-, while interaction with competitors is detrimental for innovation (Fitjar and Rodríguez-Pose, 2013). The results of Fitjar and Rodríguez-Pose (2013) are not statistically significance for cooperation with research centers and consultancies. Still, cooperation with universities matters for innovation and is easily achieved in industries with an STI mode, due to both STI firms and universities share the same analytical knowledge base (Fitjar and Rodríguez-Pose, 2013; Isaksen and Karlsen, 2010; Trippl, 2011).

Previous studies state that firms seeking knowledge from external sources strengthen their innovation performance, but, at some point, too much interaction can worsen it (Chen, Chen, and Vanhaverbeke, 2011). For the STI mode, the diversity of partners and the intensity of relations improves innovation performance, but interaction with too many partners can be detrimental for innovation (Chen et al., 2011). In the case of DUI mode, there no seems to be a detrimental effect on innovation, related to the scope and depth of relations, as there is a difference in search cost and knowledge leakage between the STI and DUI modes (Chen et al., 2011).

Besides, firms adopting an STI mode benefit from combining scientific with experience-based learning. It does not occur in DUI mode (Chen et al., 2011). These differences in innovation benefits from collaboration may be explained, as we mentioned above, due to the firms’ absorptive capacity. Additionally, firms with limited in-house R&D capabilities for collaborating with external partners have to work on overcoming knowledge and market barriers to innovation (Thomä, 2017).
However, recent studies show that firms collaborating with scientific and supply chain partners at the time do not lead to adopting product innovation compared to firms collaborating with only scientific or supply-chain partners (Haus-reve et al., 2019).

2.3. The role of context in the innovation modes

Innovation modes approach has paid attention to the geographical and contextual aspects for innovating. In a country/region, social, cultural, and institutional idiosyncrasies may influence the innovation modes adopting innovation outcomes (Parrilli and Alcalde, 2016). Thus, the effect of innovation modes on innovation outcomes varies across countries and regions.

In countries that as Norway, firms interacting with non-local partners have a major influence adopting innovations than those firms interacting with local partners (Fitjar and Rodríguez-Pose, 2013). These findings are consistent with studies in the Basque Country in the case of the DUI mode, were regional linkages have a lightly association with innovation outcomes. Too much interaction with local partners contributing with a supply-chain based knowledge may lead to lock-in. Thus, firms need global connections to interact with heterogeneity partners to avoid it (Fitjar and Rodríguez-Pose, 2013; Parrilli and Alcalde, 2016).

For firms adopting an STI mode, non-local scientific collaboration, such as universities, has a lightly association with product and process innovations (Fitjar and Rodríguez-Pose, 2013), but, in the case of the Basque country, the STI mode interacting with local partners has a stronger association with technological and non-technological innovations than the STI mode interacting with non-local partners (Parrilli and Alcalde, 2016).

Nunes and Lopes (2015) highlighted the relevance of considering the territorial context when analyzing the firm's innovative strategies. Favorable territorial conditions such as aspects as the qualifications of the human resources, presence of stakeholders, and the intensity of interactions, allow firms to overcome their scare internal resources (Nunes and Lopes, 2015).
3. THEORETICAL BACKGROUND

3.1. Firms’ innovation modes adopting radical innovation

Firm’s adoption of innovation “...is conceived to encompass the generation, development, and implementation of new ideas or behaviors” (Damanpour, 1991, p. 556). Adoption of innovation creates changes in the firms’ practices as a response to the internal or external environment, or as an action to influence the environment (Damanpour, 1991). These changes vary by the degree of novelty on the innovations through the notion of radicalness, which captures this distribution (Dewar and Dutton, 1986). Therefore, the level of new knowledge in an innovation outcome allows distinguishing between radical and incremental innovation. Thus, radical innovations induce fundamental changes in technology, while incremental innovations produce minor improvements in technology (Damanpour, 1991; Dewar and Dutton, 1986; Ettlie, Bridges, and O’Keefe, 2008).

Dewar and Dutton (1986) understand radical and incremental innovation as two extreme sides from the same theoretical continuum, which several levels of new knowledge embedded in innovation. Regarding the purpose of this research, we focus on radical innovation following the notion of radicalness as the distribution in different levels of new knowledge which are embedded in innovation and characterizes the innovation outcome.

In this way, technology understood in terms of its knowledge component involves both a body of understanding and a body of practice (Jensen et al., 2007). A body of scientific-like understanding is more related to the STI mode which refers to the creation and use of know-what and know-why forms of knowledge, in processes carried out in R&D departments and collaborating with universities and research centers (Jensen et al., 2007; Thomä, 2017). Employees’ skills can understand and transfer scientific knowledge. Firms relying on an STI mode tend to adopt radical innovations with a “higher” degree of novelty compared to experience-based knowledge.

Conversely, a body of practice is more related to the DUI mode, which refers to know-how and know-who forms of knowledge, “learned by employees on the job through trial-and-error when confronted with new problems” (Thomä, 2017, p. 3), and represented in the practical experience and problem-solving methods. This type of experienced-based learning by doing, using, and interacting, involves interaction mainly with suppliers and customers.
Above distinction does not imply that firms only rely on a single innovation mode. A scientific like-understanding body of knowledge requires experienced-based learning for innovation (Thomä, 2017). Know-how and know who forms of knowledge allow building structures and relationships between the scientific and engineering staff to conduct R&D projects (Jensen et al., 2007).

Thereby, the STI mode which incorporates a body of scientific-like understanding is more associated with fundamental changes in products and processes, therefore, most novelty outcomes; while the DUI mode which incorporates a body of practice is more associated with fewer novelty outcomes in existing products and processes. However, firms combining both DUI and STI modes -and diverse forms of knowledge- tend to be more associated with radical innovations than the single DUI and STI modes. Hence, our hypotheses are:

**Hypothesis 1a.** Firms adopting a DUI-STI mode are more likely to adopt radical innovation than those firms adopting a DUI or an STI innovation mode alone.

**Hypothesis 1b.** Firms adopting an STI mode are more likely to adopt radical innovation than those firms adopting a DUI mode alone.

3.2. **Institutions and innovation modes**

Institutions play a crucial role in firms’ learning and innovation process. “Institutions are sets of habits, routines, rules, norms, and laws, which regulate the relations between people and shape human interaction” (Johnson, 1992, p. 26). They represent formal and informal rules of the game to reduce uncertainties and provides stability (North, 1990). Due to institutions, firms systematize activities for saving time, which allows to concentrate efforts in their innovation process, free resources, and use it in creative activities aiming to adopt innovations (Johnson, 1992).

Given that institutions in a region influence firms’ innovation process (Barasa, Knoben, Vermeulen, Kimuyu, and Kinyanjui, 2017; Laursen, Masciarelli, and Prencipe, 2012), institutional factors may affect the effectiveness of firms’ innovation modes adopting innovation outcomes.

Literature has highlighted the importance of institutions such as imitation and access to financing which are associated with ways of knowledge protection and use of external resources,
respectively, which affect the innovation process (Ritala and Hurmelinna-Laukkanen, 2013; Wu, Harrigan, Ang, and Wu, 2019).

3.2.1. Imitation

Imitation literature suggests that, when a firm adopts an imitation strategy, it follows lead firms to adopt innovations (Lee and Zhou, 2012; Levitt, 1960). Still, firms’ imitation success may depend on information access and imitation barriers. To address the role of imitation in the relationship between firms’ innovation modes and innovation outcomes, we rely on two approaches: information-based and causally ambiguity.

Information based-theories state that, under uncertain environment, there are risks concerning if innovative actions will produce innovation outcomes. Therefore, firms can be more receptive to information implicit in other firms’ actions than in their information (Lieberman and Asaba, 2006). The leader firm acts based on its information, and at the same time, it reveals this information to other firms. Follower firms rely on this information and potentially can imitate the leader firm actions (Lieberman and Asaba, 2006). Indeed, follow others provides information that can reduce risks and uncertainty, decrease costs of firms’ new technology development and, therefore, increase the possibility of introducing innovations (Wu et al., 2019).

On the other hand, the appropriability scheme in a region can discourage firms from innovating. An appropriability scheme can be developed through both intellectual property rights or firms’ appropriability mechanisms (Ritala and Hurmelinna-Laukkanen, 2013). In the latter, firms’ connections between actions and outcomes can be challenging to understand and, therefore, to imitate (Lippman and Rumelt, 1982). Characteristics as tacit knowledge, complexity, and specificity produce ambiguity in the innovation process, and it creates imitation barriers (Reed and Defillippi, 1990).

In this way, firms develop complex activities which result from skills’ combine, and these skills can be based on tacit knowledge acquired mostly on learning by doing from experience (Reed and Defillippi, 1990). Complex activities and routines, as well as the use of tacit knowledge in the innovation process, make it difficult to copy it by other firms (Wu et al., 2019). Thus, both
approaches -information-based and causally ambiguity- are complementary to explain the moderating role of imitation on innovation modes introducing radical innovation.

Given that firms are embedded in an emerging economy such Colombia, characterized by an uncertain environment (Wu et al., 2019), accordingly to the information-based approach, firms with a DUI, STI and DUI-STI innovation mode are encouraged in adopt an imitation strategy for reducing risk and uncertainty associated to adopting radical innovations.

However, the difference in the moderating effect of ease of imitation lies in the forms of knowledge corresponding to the DUI, STI, and DUI-STI modes. DUI mode uses implicit and tacit knowledge, which is learned by employees on the job through trial and error while they are doing using and interacting (Thomä, 2017). The forms of knowledge predominately in the DUI mode are more difficult to codify and transfer, whereby, when a firm with a DUI mode adopts an imitation strategy to innovate, it reduces firm’s capacity to replicate technology introduced by other firms (Wu et al., 2019).

Firms with an STI mode predominately use explicit and codified knowledge which refers to scientific knowledge based on principles and laws easy to transfer, share and is widely accessible by other firms with similar knowledge bases (Asheim, Isaksen, Moodysson, and Sotarauta, 2011; Jensen et al., 2007; Thomä, 2017). The properties of codified knowledge in the STI mode facilitate firms to replicate the technology of other firms.

Given that firms adopting a DUI-STI innovation mode use diverse forms of knowledge from science and experience-based learning, ease of imitation weakens the introduction of radical innovation. The DUI-STI mode combine diverse forms of knowledge; firms with such strategy are more associated with tacit knowledge in an emerging economy. As we mentioned before, the moderating role of imitation will be higher for firms with STI innovation modes than firms with a DUI or a DUI-STI innovation mode. Therefore, our hypotheses are:

**Hypothesis 2a.** In the presence of ease of imitation, the relationship between DUI-STI mode and radical innovation is weaker than the relationship between DUI or STI mode with radical innovation.
Hypothesis 2b. In the presence of ease of imitation, the relationship between STI mode and radical innovation is stronger than the relationship between DUI mode and radical innovation.

3.2.2. Access to external financing

The use of external financing is related to the extent of a firm’s innovation, mainly, for bank financing in emerging economies (Ayyagari, Demirgüç-Kunt, and Maksimovic, 2011; Beck, Demirguckunt, and Maksimovic, 2008). However, access to financing is considered a key institution-based barrier to innovation in emerging economies (Zhu, Wittmann, and Peng, 2012). Small firms have less access to external financing in regions with less developed capital markets (Beck et al., 2008). For example, emerging economies, such as China, is a challenging for small and medium firms obtaining external financing (Hadjimanolitis, 1999; Zhu et al., 2012). Therefore, firms’ adoption of innovation may be less effective for firms depending on external financing for innovation.

The role of accessing external financing on the relation between innovation modes and radical innovation varies depending on the grade of scientific knowledge in innovative activities. For firms with a DUI mode, whose innovation activities are mainly non-R&D activities, adopting an innovation do not require high financial resources. Interaction with customers and suppliers tend to be of the informal type and do not involve monetary exchange (Tripl, 2011).

Conversely, firms adopting an STI mode base their innovation activities on formal R&D, using and producing scientific knowledge. The knowledge exchange of formal linkages -with universities and research centers- is based on contracts and often involves monetary compensations (Tripl, 2011). R&D activities tend to be long-term and financing these activities can be difficult.

In the STI mode, the level of novelty in the innovation outcome tend to be higher than for DUI mode, the “high” level of novelty is generated with scientific knowledge which is more dependent on external financing. In this sense, for firms with an STI mode, the adoption of radical innovations tends to be less effective in the presence of access to external financing than for firms with a DUI mode.

The DUI-STI mode combine and use both scientific and experience-based learning knowledge, whereby the moderating role of access to external financing to adopt radical innovation has a
minor effect in comparison with the STI mode, but a significant effect in comparison with the DUI mode. Therefore, our hypotheses are as follow:

**Hypothesis 3a.** In the presence of difficult to access external financing, the relationship between DUI-STI mode and radical innovation is stronger than the relationship between STI mode and radical innovation but weaker than the relationship between DUI mode and radical innovation.

**Hypothesis 3b.** In the presence of difficult to access external financing, the relationship between DUI mode and radical innovation is stronger than the relationship between STI mode and radical innovation.

Figure 1 summarizes the hypotheses testing. The first group of hypotheses (H1) test which innovation modes have a major effect on radical innovation. The second and third group of hypotheses (H2 and H3) introduce ease of imitation and external financing as institutional moderators for innovation modes adopting radical innovation. Also, we differentiate between the group of hypotheses A (H1a, H2a, and H3a) which tests the relations between the three innovation modes and the group of hypotheses B (H1b, H2b, and H3b) which tests for DUI and STI modes only.

![Figure 1. Model of innovation modes and institutional factors.](image)
4. METHODOLOGY

4.1. Data description

In this research, data related to innovation modes, radical innovation and institutions are retrieved from the Development and Technological Innovation Survey (Encuesta de Desarrollo e Innovación Tecnológica – EDIT). Latin America countries have the most active innovation surveys data production in the developing world (Castellacci and Natera, 2012), and Colombian innovation survey has increased their use by the research community -e.g., Gallego et al., (2015); Gomez et al., (2014); Julia-rossi et al., (2019).

Colombian statistical agency (Departamento Administrativo Nacional de Estadística - DANE) conducts EDIT’s survey every two years and seeks to characterize innovation dynamics in Colombian manufacture firms (DANE, 2017). EDIT’s design takes methodological orientations from both Oslo and Bogotá Manuals by the Organization for Economic Cooperation and Development (OECD) and the Network for Science and Technology Indicators of Ibero-American (in Spanish, RICYT), respectively.

Firm-level observation units are those firms with more than ten employees or those with a higher reference production for a reference year (DANE, 2017). Small, medium and large firms are classifying in 55 industrial activities based on the International Standard Industrial Classification (Clasificación Internacional Industrial Uniforme - CIIU). DANE captures the data at the national level (census) and asks for information carried out for firms in the previous two years.

For this research, we used data from EDIT VII and VIII, corresponding to the years 2014 and 2016, respectively. The data was collected via a web page and identified firms’ activities carried out in 2013-2014 (EDIT VII) for introducing radical innovation in 2015-2016 (EDIT VIII). EDIT VIII survey has information for 7947 firms, but only 1044 firms have complete information related to collaboration, innovation outcomes, and institutions. After removing outliers from the dependent and the independent variables, we obtain 908 firms.
4.2. Description of variables

4.2.1. Dependent variable

The dependent variable represents the firm’s adoption of radical innovation. We can identify the degree of radicalness in an innovation outcome by the level of new knowledge, but it depends on individuals perceptions on firms -the unit of adoption- (Dewar and Dutton, 1986). Thus, we identified radical innovation from a market perspective as fundamental changes in firms’ products and processes concerning industry competitors (Crossan and Apaydin, 1991; Forés and Camisón, 2016).

In the same way, literature on innovation modes identify firms’ radical innovation comparing the level of new knowledge in the innovation outcome with respect to the firm’s market (Lettl, Herstatt, and Gemuenden, 2006), as those innovations that are new to the firms’ market (Fitjar and Rodríguez-Pose, 2013; Jensen et al., 2007; Parrilli and Alcalde, 2016). In this research, we identify firms’ radical innovation if the firm has introduced new or significantly improved goods or services, new to the national or international firm’s market (Fitjar and Rodríguez-Pose, 2013; Parrilli and Alcalde, 2016). Thus, firms’ radical innovation is represented as a binary variable, where takes the value of 1 if the firm has introduced new or significantly improved goods or services, new to the national or international firm’s market, in the last two years and 0 if otherwise. Table 2 shows some descriptive statistics.

4.2.2. Independent variables at the firm scale: innovation modes

At the firm level, previous studies identify innovation modes in two ways: factorial analysis (Jensen et al., 2007; Thomä, 2017) and defining features for each innovation mode following literature (Chen et al., 2011; Fitjar and Rodríguez-Pose, 2013; Parrilli and Alcalde, 2016). In this research, we identified STI and DUI innovation modes following Fitjar (2013) and Parrilli (2016) studies by grouping firms based on their interaction with external agents.

Independent variables, at the firm level, represent innovation modes adopted by firms, and we distinguish between STI, DUI, and the combination of both innovation modes through interaction with external agents (Chen et al., 2011; Fitjar and Rodríguez-Pose, 2013; Jensen et al., 2007; Parrilli and Alcalde, 2016). Literature relates different forms of collaboration to STI and DUI innovation
modes. STI innovation mode relates most to collaborate with universities, research centers, or consultants. On the other hand, DUI innovation mode is related with collaboration with customers or suppliers (Apanasovich et al., 2016; Fitjar and Rodríguez-Pose, 2013; Jensen et al., 2007; Parrilli and Alcalde, 2016).

We use EDIT’s questions concerning the firm’s collaboration or interacting with agents. We consider both formal and informal interactions due to the importance of firms’ informal interaction in developing countries. DUI mode represents firms’ collaboration with clients and suppliers only. STI mode represents firms’ collaboration with universities, consultancies, research centers or technology development centers only, and DUI-STI mode represents firms’ collaboration with, one DUI partner and one STI partner at the time.

DUI innovation mode takes the value of 1 if the firm collaborates exclusively with clients or suppliers and 0 otherwise. STI innovation mode takes the value of 1 if the firm collaborates exclusively with universities, research centers or technology development centers, and 0 otherwise. DUI-STI innovation mode the value of 1 if the firm collaborates with one DUI partner and one STI partner at the time, and 0 otherwise.

4.2.3. **Independent variables at the regional scale: institutional factors**

Considering innovation as a multilevel phenomenon (Gupta, Tesluk, and Taylor, 2007), firms’ innovation modes adopting radical innovation occurs at the firm level, and this relationship is moderated by informal and formal institutions from a higher level: ease of imitation and difficult to access external financing.

This multilevel linkage is understood from a bottom-up perspective. Both institutional factors emerge from firm-level perceptions and are aggregated at the regional scale. Ease of imitation represents the firms’ perceptions in a region concerning to the importance of the ease of imitation to adopt innovations, and difficult to access external financing represents the firms’ perceptions in a region about the difficult to access external financing to adopt innovations.

We use for both ease of imitation and difficult to access external financing a variation of the Likert scale, with three-point categories -1 to 3- which represents a null, medium and a high level of
importance for the firm, respectively. Then, from the firm’s scale perceptions, we design a regional measure like the mean of the scores for each region.

In this respect, there are two moderations: one is the product term between each innovation mode and ease of imitation, and the other one is the product term between each innovation mode and difficulty to access external financing. Innovation modes were measured as binary variables, while ease of imitation and difficulty to access external financing were measured with a three-point Likert scale.

We follow Dawson’ suggestions (2013) for creating a moderation term, the continuous independent variables should be standardized, as it facilitates the interpretation of moderation. Therefore, variables of ease of imitation and difficulty to access external financing were standardized and multiplied by each innovation modes, and we obtain moderations which are continuous variables.

4.2.4. Control variables

We control firm size (Size), measured as the log of the number of employees for 2016; research and development (R&D), measured as the log of internal and external R&D expenditure reported by the firm in the last two years (Fitjar and Rodríguez-Pose, 2013; Jensen et al., 2007; Parrilli and Alcalde, 2016). As regional control, we use the log of regional gross domestic product for 2016. Controls as a share of exports, and personnel in the region with a doctorate or master’s degree were used, but there were no significant. Besides, we introduce controls for the firm sector as a set of dummy variables corresponding to two-digits of the CIIU codes -Clasificación Internacional Industrial Uniforme-, but there was no significance.

4.3. Estimation technique

Multilevel modeling is an appropriate technique due to the hierarchical structure of firms embedded in regions. Firms (first level) are nested within regions (second level), and each region has measures of different institutional factors. Firms sharing institutional factors will often have a similar innovations outcome. Seven regions were considered for the empirical study in Colombia, and they are in Appendix B. The model developed was:
\[ y_{ij} = \beta_0 + \beta_1 DUI_{ij} + \beta_2 STI_{ij} + \beta_3 DUI \cdot STI_{ij} + \beta_4 IM_j + \beta_5 Fin_j + \beta_6 DUI \cdot IM_{ij} + \beta_7 DUI \cdot Fin_{ij} + \beta_8 STI \cdot IM_{ij} + \beta_9 STI \cdot Fin_{ij} + \beta_{10} DUI \cdot STI \cdot IM_{ij} + \beta_{11} DUI \cdot STI \cdot Fin_{ij} + \beta_{12} IM_j + \beta_{13} R\&D_{ij} + \beta_{14} GDP_j + \mu_j + \epsilon_i \]

Were:

\( y_{ij} \): is a binary variable for firm \( i \) in the region \( j \).

\( DUI_{ij} \): is a binary variable which indicates DUI innovation mode for firm \( i \) in the region \( j \).

\( STI_{ij} \): is a binary variable which indicates STI innovation mode for firm \( i \) in the region \( j \).

\( DUI \cdot STI_{ij} \): is a binary variable which indicates DUI and STI innovation modes combine for firm \( i \) in the region \( j \).

\( IM_j \): is an ordinal variable and indicates the ease of imitation for firm \( i \) in the region \( j \).

\( Fin_j \): is an ordinal variable and indicates difficult to access external financing for firm \( i \) in the region \( j \).

\( DUI_{ij} \cdot IM_j \): represents the interaction between DUI innovation mode and ease of imitation for firm \( i \) in the region \( j \).

\( DUI_{ij} \cdot Fin_j \): represents the interaction between DUI innovation mode and difficult to access external financing for firm \( i \) in the region \( j \).

\( STI_{ij} \cdot IM_j \): represents the interaction of STI innovation mode with imitation for firm \( i \) in the region \( j \).

\( STI \cdot Fin_j \): represents the interaction of DUI innovation mode with difficult to access external financing for firm \( i \) in the region \( j \).

\( DUI \cdot STI_{ij} \cdot IM_j \): represents the interaction between DUI and STI innovation modes combine and ease of imitation for firm \( i \) in the region \( j \).

\( DUI \cdot STI_{ij} \cdot Fin_j \): represents the interaction between DUI and STI innovation modes combine and difficult to access external financing for firm \( i \) in the region \( j \).

\( Size_{ij} \): represents the control for the firm’s size for firm \( i \) in the region \( j \).
$R&D_{ij}$: represents the control for the firm’s research and development for firm $i$ in the region $j$.

$GDP_j$: represents a regional control for the gross domestic product for the region $j$.

$\mu_j$: represents the error term for region $j$.

$e_i$: represents the error term for firm $i$.

5. SCIENCE, TECHNOLOGY, AND INNOVATION IN EMERGING ECONOMIES AND COLOMBIA

As we mentioned above, innovation modes literature has been addressed in developed and transition economies, and, to a lesser extent, in emerging economies. In this section, we show an overview of the science, technology, and innovation (STI) in emerging economies such Latin America and the Caribbean (LAC) countries as for Colombia as the empirical study of this research.

Several features represent the STI in emerging economies$^3$: low R&D investment and expenditure, low human resources for STI activities, and differences -with developed countries- in the type of innovation outcomes.

In general terms, LAC region characterizes by low levels of R&D investment, low levels of R&D expenditure, and high dependence of public funding sources. In comparison with countries of the Organization for Economic Co-operation and Development -OECD-, the investments in R&D in the LAC countries (except for Brazil and Chile) are less than 0.5% of GDP (in OECD countries is 2.2%) (IDB, 2010). The R&D expenditure in LAC is ten times lower than in the United States -USA- (Anlló and Suárez, 2009). Besides, the public sector’s R&D financing represents around 60% (in European countries is 45%, and in the USA, it is 36%) (Anlló and Suárez, 2009).

Moreover, human resources for STI activities in LAC firms are comparatively lower than European firms. Also, there is a preference in the LAC region for the acquisition of machinery and equipment over R&D investment. Therefore, firms in LAC tend to incorporate technology through the acquisition of capital goods instead of R&D activities (Anlló and Suárez, 2009).

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$^3$ We describe three of them which we consider important for contextualizing this research.
Given the low level of resources—financial and human—in LAC firms for innovating, interaction with external actors becomes crucial. Interaction with actors, in a broad sense—formal or informal—is similar in LAC and European firms, both rely mostly on supply-chain actors—suppliers, clients, and competitors—than in scientific organizations as sources of ideas for innovation (IDB, 2010). Also, the share of formal collaboration in firms from LAC countries is similar to French and German firms (IDB, 2010).

At the firm’s level, the picture is quite similar from above. The firms’ innovation outcomes and innovation activities (OECD and Eurostat, 2005) in emerging economies are different from firms in developed countries. In LAC region, technological innovation—product and processes—are mainly on the adaptative and incremental type; firms tend to adopt more process innovation than product innovation, and by novelty, most innovations are new to the firm than to the market or to the world (IDB, 2010). Firms’ innovation activities are mainly oriented to the acquisition of foreign technology and to adopt it in the production processes; also, the STI activities that firms conduct are around 40% of the R&D expenditure (in OECD countries is 70%) (IDB, 2010).

In Colombia, approximately the fifth part of manufacturing firms adopt innovation outcomes (21.7% in 2016). Nonetheless, this proportion has not changed significantly over time; the mean of the innovation outcomes has increased slightly (Table 1). Colombian firms—as LAC firms—tend to adopt significantly improved goods and services to a greater extent than new goods and services, and by novelty regarding firms’ market, innovations new to the firms’ national and international markets are less frequent.

Table 1. Innovation outcomes in firms by novelty regarding firms’ market.

<table>
<thead>
<tr>
<th>Year</th>
<th>New to the firm</th>
<th>New to the firm’s natl. market</th>
<th>New to the firm’s intl. market</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obs.</td>
<td>mean</td>
<td>Sd.</td>
</tr>
<tr>
<td>2010</td>
<td>1392</td>
<td>0.16</td>
<td>0.67</td>
</tr>
<tr>
<td>2012</td>
<td>853</td>
<td>1.53</td>
<td>0.74</td>
</tr>
<tr>
<td>2014</td>
<td>909</td>
<td>1.87</td>
<td>1.30</td>
</tr>
<tr>
<td>2016</td>
<td>977</td>
<td>1.87</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Significantly improved goods and services

<table>
<thead>
<tr>
<th>New to the firm</th>
<th>New to the firm’s natl. market</th>
<th>New to the firm’s intl. market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs.</td>
<td>mean</td>
<td>Sd.</td>
</tr>
<tr>
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</tr>
<tr>
<td>2014</td>
<td>909</td>
<td>1.87</td>
</tr>
<tr>
<td>2016</td>
<td>977</td>
<td>1.87</td>
</tr>
</tbody>
</table>
### RESULTS

6.1. Firms’ innovation modes and innovation outcomes

Concerning the innovation modes (Table 2), descriptive statistics show DUI-STI mode is the most frequent mode adopted by firms (33.3%). Firms tend to collaborate with both scientific and supply chain partners than with one type of partner alone. DUI is the second most frequent mode adopted by firms (31.1%). There is a low share of firms (5.9%) collaborating with scientific partners alone (STI mode), and the third part of firms do not collaborate with any scientific or supply chain partners. Table 3 shows the correlation matrix for the independent variables. The relationships between the three innovation modes are negative and statistically significant.

Table 2. Descriptive statistics.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Firms</th>
<th>Mean</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Novelty</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radical innovation</td>
<td>908</td>
<td>0.098</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Innovation modes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUI</td>
<td>908</td>
<td>0.311</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>STI</td>
<td>908</td>
<td>0.059</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>DUI_STI</td>
<td>908</td>
<td>0.324</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Institutions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imitation</td>
<td>908</td>
<td>0.101</td>
<td>-0.916</td>
<td>1.553</td>
</tr>
</tbody>
</table>
External financing 908 -0.106 -1.229 1.330

Controls
Firm size (log) 908 2.032 0.778 3.644
R&D expenditure (log) 908 2.208 0.00 8.363
GDP (log) 908 7.306 7.127 7.418

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  DUI</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2  STI</td>
<td>-0.23</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3  DUI_STI</td>
<td>-0.75*</td>
<td>-0.28</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4  Imitation</td>
<td>-0.03</td>
<td>-0.22</td>
<td>-0.28</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5  External financing</td>
<td>0.01</td>
<td>-0.24</td>
<td>-0.28</td>
<td>0.93*</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6  Firm size (log)</td>
<td>-0.34</td>
<td>-0.08</td>
<td>0.53</td>
<td>-0.69</td>
<td>-0.68</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7  R&amp;D expenditure (log)</td>
<td>-0.30</td>
<td>-0.27</td>
<td>0.61</td>
<td>-0.55</td>
<td>-0.56</td>
<td>0.75*</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>8  GDP (log)</td>
<td>0.04</td>
<td>-0.21</td>
<td>-0.32</td>
<td>0.97*</td>
<td>0.85*</td>
<td>-0.69</td>
<td>-0.55</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Note: statistical significance: *p<0.05.

Related to radical innovations, firms adopting a DUI mode show a major association with radical innovation than firms adopting an STI mode. There are a low number of firms adopting an STI mode; this corresponds to countries with low R&D investments, like Colombia.

We estimated the relationship between DUI, STI, and DUI-STI innovation modes and radical innovation. Table 4 presents the results for radical innovation as the dependent variable. Models were estimated with robust standard errors. Model 1 includes control variables; Model 2 includes control and independent variables, and Model 3 includes control, independent, and interaction terms.

Besides, in Table 4, we reported pseudo-R2 for fixed effects and VIF. In the case of pseudo-R2, this indicator must be interpreted carefully for generalized linear mixed models. A generalized mixed model produces a variance for fixed and random factors, and residual variance and pseudo-R2 omits the variance associated with the random factors. In this sense, pseudo-R2 is lower as more
predictors are included in the model. In the case of VIF, controls variables are the one which shows higher VIF values comparing with the independent and moderate variables (Appendix C).

Table 4. Multilevel regression coefficients with robust standard errors.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sizing (log)</td>
<td>-0.618***</td>
<td>3.939***</td>
<td>1.639***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>R&amp;D (log)</td>
<td>0.699***</td>
<td>1.159***</td>
<td>0.838***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>GDP (log)</td>
<td>-0.489***</td>
<td>-4.080***</td>
<td>-3.100***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td><strong>Independent modes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUI</td>
<td>-9.189***</td>
<td>4.384***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>STI</td>
<td>1.577***</td>
<td>-42.367***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>DUI_STI</td>
<td>0.007***</td>
<td>7.996***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>Imitation</td>
<td>-2.882***</td>
<td>10.373***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>External financing</td>
<td>7.362***</td>
<td>-0.132***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td><strong>Interaction terms</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUI-Imitation</td>
<td>-17.848***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STI-Imitation</td>
<td>47.685***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUI_STI-Imitation</td>
<td>-9.902***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUI-financing</td>
<td>-0.032***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STI-financing</td>
<td>-73.948***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUI_STI-financing</td>
<td>2.364***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-10.126***</td>
<td>2.524***</td>
<td>-4.384***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>ICC</td>
<td>0.002</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>908</td>
<td>908</td>
<td>908</td>
</tr>
<tr>
<td>Log Likelihood</td>
<td>-138.707</td>
<td>-161.488</td>
<td>-155.928</td>
</tr>
<tr>
<td>VIF</td>
<td>2.99</td>
<td>7.98</td>
<td>13.52</td>
</tr>
</tbody>
</table>
Model 3 shows that DUI-STI mode has the strongest relationship with radical innovation (7.99) in compare with DUI (4.38) and STI (-42.36) modes. These results support hypothesis H1a which reinforce previous literature results (Jensen et al., 2007; Parrilli and Alcalde, 2016). In the case of hypothesis H1b, we state that firms adopting an STI mode are more likely to introduce radical innovation than those firms adopting a DUI mode alone and the results do not support our hypothesis, as the DUI mode has a positive and stronger association with radical innovation than the STI mode. This null effect of firms adopting an STI mode on radical innovation does not follow previous literature results, and It seems to indicate a low impact of collaboration with universities, research centers or consultants for introducing radical innovation.

6.2. The moderating role of ease of imitation and access external financing

We examine informal and formal institutions as moderators of the relationship between innovation modes and radical innovation, supporting in the ratio of possibilities for each variable (Figure 2). To extend the interpretation of the results, Figure 3 shows the moderating role of ease of imitation -column 1- and difficult to access external financing -column 2- for each innovation mode at low and high levels of the moderator variables. Solid lines represent high levels of the moderator variables, while dashed lines represent low levels. We choose extreme values to represent high and low levels to be able to visualize the differences (Dawson, 2014).

We state that ease of imitation moderate the relationship between innovation modes and radical innovation, such that the relationship between DUI-STI mode and radical innovation is weaker than the relationship between DUI or STI mode and radical innovation (H2a), and the relationship between STI mode and radical innovation is stronger than the relationship between DUI mode or radical innovation (H2b).

Model 3 allows us to state that the association between innovation modes and radical innovation differs according to imitation as coefficients were all statistically significant. The negative
coefficient of the moderator variables DUI-Imitation and DUI-STI-Imitation suggest that for both DUI and DUI-STI innovation modes the predicted value to adopt radical innovation increases as ease of imitation decreases, while for STI mode the predicted value to adopt radical innovation increases as ease of imitation increases (Model 3 in Table 4). The odds-ratios in Figure 2 show that in the presence of ease of imitation, the DUI mode has the weakest association to adopt radical innovation, followed by the DUI-STI mode, while the STI mode has the strongest association with radical innovation. It allows us to support our hypothesis H2a partially. Besides, for the DUI and STI modes, in the presence of ease of imitation, the latter has a stronger relationship with radical innovation than the DUI mode, and it completely supports our hypothesis H2b.

![Figure 2. The standardized odds ratio for Model 3.](image)

The Y-axis represents the independent variables, and the X-axis represents the possibilities (odds ratios) for each independent variable to adopt radical innovation. Odds ratios’ values are between 0 and infinite, and the vertical white line has the value one. Odds ratios greater than 1 indicate the possibilities to adopt radical innovation. ims mean ease of imitation, and dfins means difficult to access external financing.

Colombian firms characterizing by a DUI-STI innovation mode has the greatest possibilities -in terms of odds-ratios- to adopt radical innovation than firms with a DUI or STI mode alone. When introducing ease of imitation, it reduces the odds-ratio in DUI-STI and DUI innovation modes while increasing the odds-ratio for the STI mode (Figure 2). Indeed, at low levels of ease of imitation, DUI and DUI-STI modes have a stronger effect of adopting radical innovation, while high levels of ease
of imitation have a strong effect on STI mode to adopt radical innovation. The above indicates that ease of imitation, as an informal institution, encourages adoption of radical innovation mostly for firms using exclusively scientific kind of knowledge, derived from collaborating with universities, research centers, or consultants.

Our third group of hypotheses tested for the moderating role of difficult to access external financing. We state that, in the presence of difficult to access external financing, the relationship between DUI-STI mode and radical innovation will be stronger than in place of STI mode and radical innovation, but weaker than DUI mode and radical innovation (H3a). Also, we state that in the presence of difficult to access external financing, the relationship between DUI mode and radical innovation is stronger than the relationship between STI mode and radical innovation (H3b).

Table 4 shows that the coefficients of the moderator variables of innovation modes and difficult to access external financing were all statistically significant. Based on the results, we state that, in the presence of difficult to access external financing, DUI-STI has a stronger association with radical innovation than DUI or STI modes (Figure 2). These results support partially our hypothesis H3a. Besides, for the DUI and STI modes, in the presence of access to external financing, DUI mode has a stronger association with radical innovation than the STI mode, and it supports our hypothesis H3b.

The effect of DUI and STI mode on radical innovation is greater at low levels of difficult to access external financing, while in the case of DUI-STI mode the effect is stronger at high levels. Firms using DUI or STI innovation modes alone needs financial resources for innovating, but to some extent, the difficult to access to external resources is not detrimental for innovating by combining both innovation modes.
Figure 3. Moderating effect of ease of imitation (right column) and difficult to access external financing (left column) on the innovation modes-radical innovation relationship (two-way binary logistic interaction with continuous moderators).

7. DISCUSSION

The present study analyzes how ease of imitation and external financing moderate the association of firms’ innovation modes adopting radical innovations. We have developed a multilevel model to assess the effect of STI and DUI innovation modes on radical innovations, and we have included institutional factors as moderators between innovation modes and radical innovation. We highlight two main aspects: the association of innovation modes and radical innovation and the moderating role of ease of imitation and difficult to access external financing.
Here we showed that innovation modes relate to radical innovation and that institutions as ease of imitation and difficult to access external financing moderate these relations. In particular, both DUI-STI and DUI modes affect the adoption of radical innovation positively, while STI mode is detrimental to adopt radical innovation (Table 4). One possible explanation could be that the kind of knowledge in STI firms derived from collaboration with universities, research centers, or consultants in Colombia is not suitable for radical innovation. Collaboration in STI firms is related to non-scientific activities such as technical assistant, technology transfer, or training.

Besides, we showed that the DUI-STI mode improves firms’ adoption of radical innovation to a greater extent than firms using DUI or STI modes alone. Suggesting that the kind of knowledge from scientific partners, derived from collaboration with universities, research centers, or consultants; combined with the kind of knowledge from learning by doing, using and interacting, derived mainly from collaborating with clients or suppliers has a greater effect in innovating than firms using scientific or experienced kind of knowledge only.

Regarding moderations, ease of imitation decreases the association between radical innovation and innovation modes for firms with a DUI or a DUI-STI mode, while it increases for firms with an STI mode (Figure 2). Due to implicit and tacit knowledge is not often codified and it makes difficult to transfer, and whereby to imitate by other firms, using a DUI mode and combining with an imitation strategy reduces firm’s capacity to replicate technology introduced by other firms. It indicates that the DUI or DUI-STI innovation modes are not compatible with an imitation strategy to adopt radical innovation. Firms with an STI mode use mostly explicit and codified knowledge, and this kind of knowledge is easy to transfer and to be absorbed by other firms -with similar skills. Therefore, firms using an STI mode are able to adopt radical innovation due to they are combining it with an imitation strategy.

In the case of difficult to access external financing, it decreases the association between radical innovation and firms with DUI, STI, and DUI-STI innovation modes (Figure 3). This indicates that firms based on both scientific or experienced-based knowledge or a mixed-mode are able to adopt in a lesser extent, radical innovation as difficult to access external financing increases. However, firms using scientific knowledge for adopting radical innovation are more dependent on external
financial capital than firms using knowledge from learning by using, doing, and interacting (Figure 2).

Our study’s results confirm previous studies stating the major effect of DUI-STI mode on radical innovation (Fitjar and Rodríguez-Pose, 2013; Jensen et al., 2007; Parrilli and Alcalde, 2016). However, part of our study’s result differs from the current state of knowledge when pointing a negative relationship between firms with STI innovation modes and radical innovation. As we mentioned above, the reason for such differences lies in that the results are contingent on an emerging economy due to low capacities of scientific partners in R&D.

Previous studies highlight that innovation modes’ effect on innovation outcomes vary between countries and regions due to differences in social, cultural, and institutional factors (Parrilli and Alcalde, 2016). Our study extends this statement by adding informal and formal institutions as moderators and specifying the effects of forms of knowledge in firms. In this sense, part of our results concerning the moderating role of ease of imitation is consistent with previous studies, which indicate that an appropriability regime in firms has a positive effect on the adoption of radical innovation, due to firms are more willing to engage in radical innovation (Ritala and Hurmelinna-Laukkanen, 2013). However, for firms with an STI innovation mode, the ease of imitation is considered important for introducing radical innovations.

Additionally, our study has implications for policymakers and managers. The results provide information for policy design related to appropriability scheme and external financing. We highlight that, in the case of emerging economies, the effect of imitation and access to financing for the introduction of radical innovations differ according to the firms’ strategy.

STI firms take advantage of adopting radical innovation when they imitate others, due to the ease of transferring scientific type knowledge. In this sense, policy instruments that encourage the introduction of radical innovations through imitation should be aimed at stimulating the production of knowledge in firms and their partners -mainly universities and research centers- so that scientific knowledge can be used by several firms. Nevertheless, policymakers must consider the share of the firm regarding each innovation mode. In Colombia, STI firms represent a low share of firms, and promoting imitation schemes increase firms’ possibilities with an STI mode to adopt
radical innovation but decrease firms’ possibilities for DUI and DUI-STI modes. One way to solve this is by applying sectoral policies with incentives in STI sectors.

There are industries such as chemicals and drugs were “formal” appropriability schemes -e.g., patents- could be effective; in the case of industries where imitation encourage firms to innovate, the suggestion would be to promote sharing information between actors. Besides, policy instruments must ensure that firms can appropriate economic returns from innovation through superior sales or service efforts (Harabi, 1995).

Given the detrimental role of difficult to access external financing for firms with an STI and DUI innovation mode, policy instruments should focalize on facilitating access to financial resources according to the innovation projects which may differ in firms with different innovation modes.

In this respect, managers in STI firm must consider taking advantage of an imitation strategy by implementing ways to acquire information as technological surveillance, while is not recommended for managers in DUI firms invest resources on copy other firms. Additionally, managers must consider combining collaboration with different actors as a way to compensate difficult to access external financing.

8. CONCLUSIONS

This research aimed to analyze how easy of imitation and difficult to access external financing moderate the effect of firm’s innovation modes on radical innovation, using an innovation survey from an emerging economy, and applying a multilevel technique for firms embedded in regions. Results contribute to the innovation modes literature with empirical evidence in the relations set up by the approach and by building evidence that institutional factors affect innovation modes adopting radical innovation.

We support empirical evidence indicating that firms with a DUI-STI innovation have a greater significant effect on adopting radical innovations than firms with one mode alone. Moreover, the relation of the STI innovation mode with radical innovation is not as predicted by literature. The kind of scientific knowledge resulted from collaborating with universities, consultants, and research centers do not contribute to adopting radical innovation. Indicating that the type of
knowledge exchanged in the interaction is important in innovation more than the collaboration itself.

Firms adopting a DUI or a DUI-STI mode has a positive association with radical innovation, and this effect is stronger for low levels of imitation, while STI mode is detrimental for adopting radical innovation, but high imitation contributes positively to radical innovation. On the other hand, access to external financing has a negative moderator effect in DUI and STI modes introducing radical innovation.

Future studies should explore a multilevel approach in other innovation outcomes, particularly to assessing the effect of STI innovation modes. Besides, studies also can explore imitation and access to external financing by economic sectors. Formal and informal institutions can act as imitation barriers and explore other institutional factors -information access or demand uncertainty- can contribute to understanding how, through policy, improve firms’ innovation performance introducing innovation outcomes.

Finally, this research has limitations related to the number of observations of firms adopting radical innovation, which tends to be low in emerging economies. Additionally, as firms’ internal capabilities are important to developing innovation modes, considering it in defining innovation modes identified from firms’ external relationships. Multilevel modeling technique is sensitive to the number of regions, which affects results in their significance.

**APPENDIX**

Appendix A. Questions used to identify innovation modes.

<table>
<thead>
<tr>
<th>Agent</th>
<th>Variable</th>
<th>Question</th>
<th>Variable coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers</td>
<td>Cooperation with customers.</td>
<td>Did your company cooperate with any of the following types of partners to carry out scientific, technological, and innovation activities during 2015-2016?</td>
<td>1 if firm cooperates with customers, 0 if otherwise.</td>
</tr>
<tr>
<td></td>
<td>Interaction with customers.</td>
<td>Indicate whether customers were important or not as the origin of ideas to develop or implement new good services or significantly improved, new processes significantly improved, new organizational</td>
<td>1 if firm interacts with customers, 0 if otherwise.</td>
</tr>
<tr>
<td>Suppliers</td>
<td>Cooperation with suppliers.</td>
<td>Did your company cooperate with any of the following types of partners to carry out scientific, technological, and innovation activities during 2015-2016?</td>
<td>1 if firm cooperates with suppliers, 0 if otherwise.</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Interaction with suppliers.</td>
<td>Indicate whether suppliers were important or not as the origin of ideas to develop or implement new good services or significantly improved, new processes significantly improved, new organizational methods, or new marketing techniques, during the period 2015-2016 in your firm</td>
<td>1 if firm interacts with suppliers, 0 if otherwise.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consultants</th>
<th>Cooperation with consultants.</th>
<th>Did your company cooperate with any of the following types of partners to carry out scientific, technological, and innovation activities during 2015-2016?</th>
<th>1 if firm cooperates with consultants, 0 if otherwise.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interaction with consultants.</td>
<td>Indicate whether consultants were important or not as the origin of ideas to develop or implement new good services or significantly improved, new processes significantly improved, new organizational methods, or new marketing techniques, during the period 2015-2016 in your firm</td>
<td>1 if firm interacts with consultants, 0 if otherwise.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Universities</th>
<th>Cooperation with universities.</th>
<th>Did your company cooperate with any of the following types of partners to carry out scientific, technological, and innovation activities during 2015-2016?</th>
<th>1 if firm cooperates with universities, 0 if otherwise.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interaction with universities.</td>
<td>Indicate whether universities were important or not as the origin of ideas to develop or implement new good services or significantly improved, new processes significantly improved, new organizational methods, or new marketing techniques.</td>
<td>1 if firm interacts with universities, 0 if otherwise.</td>
</tr>
</tbody>
</table>
methods, or new marketing techniques, during the period 2015-2016 in your firm

Interaction with universities. Indicated if, during 2015-2016, the firm had a relationship with universities, such as support for the realization of scientific, technological, and innovation activities, search for new services that are significantly improved, significantly new processes, new organizational methods, or new marketing techniques.

1 if firm interacts with universities, 0 if otherwise.

Source: authors own elaboration based on the EDIT’s survey.

Appendix B. Regions in the study.

<table>
<thead>
<tr>
<th>Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antioquia</td>
</tr>
<tr>
<td>Risaralda</td>
</tr>
<tr>
<td>Atlántico</td>
</tr>
<tr>
<td>Santander</td>
</tr>
<tr>
<td>Bogotá</td>
</tr>
<tr>
<td>Valle del Cauca</td>
</tr>
<tr>
<td>Cundinamarca</td>
</tr>
</tbody>
</table>

Appendix C. Variance Inflation Factor to each variable and total.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VIF</td>
<td>1/VIF</td>
<td>VIF</td>
</tr>
<tr>
<td>Sizing (log)</td>
<td>1.000</td>
<td>1.000</td>
<td>1.004</td>
</tr>
<tr>
<td>R&amp;D (log)</td>
<td>1.000</td>
<td>1.000</td>
<td>1.001</td>
</tr>
<tr>
<td>GDP (log)</td>
<td>1.000</td>
<td>1.000</td>
<td>1.004</td>
</tr>
<tr>
<td>DUI</td>
<td>1.003</td>
<td>0.997</td>
<td>1.000</td>
</tr>
<tr>
<td>STI</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>DUI_STI</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Imitation</td>
<td>1.001</td>
<td>0.999</td>
<td>1.005</td>
</tr>
<tr>
<td>External financing</td>
<td>1.001</td>
<td>0.999</td>
<td>1.059</td>
</tr>
<tr>
<td>DUI-Imitation</td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>STI-Imitation</td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>
DUI_STI-Imitation  1.000  1.000  
DUI-financing  1.000  1.000  
STI-financing  1.000  1.000  
DUI_STI-financing  1.000  1.000  

**TOTAL VIF**  2.999  7.986  13.522

**REFERENCES**


