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The dynamics of innovation modes: Appropriability Strategy and Innovation Performance

Alejandro Bello-Pintado(*), Carlos Bianchi(†) y Sofía Maio(‡)

Resumen

Este estudio examina cómo los modos de innovación —STI (innovación basada en ciencia y tecnología), DUI (innovación basada en aprender haciendo, aprender usando y aprender interactuando) y su combinación— influyen en el uso que hacen las empresas de los mecanismos formales e informales de protección de la propiedad intelectual (IPPM) y en su desempeño en innovación de productos.

Utilizando datos de panel de la Encuesta de Actividades de Innovación (2010–2021) de Uruguay, los resultados muestran que el modo STI impulsa los mecanismos formales de protección de la propiedad intelectual y aumenta tanto la probabilidad de innovar como el grado de novedad. Por su parte, el modo DUI favorece los mecanismos informales de protección, pero con un impacto limitado sobre los resultados de innovación. Sin embargo, las estrategias combinadas STI-DUI generan tensiones de coordinación que terminan restringiendo el desempeño innovador.

Palabras clave: modos de innovación, estrategias de apropiabilidad del conocimiento, organización de la empresa

Clasificación JEL: O31, O32, O54

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Abstract

This study examines how innovation modes, STI (Science and Technology-based Innovation), DUI (Innovation based on learning-by-Doing, learning-by-Using, learning by-Interacting) and their combination, shape firms' use of formal and informal intellectual property protection mechanisms (IPPM) and influence product innovation performance. Using panel data from the National Innovation Activities Survey (2010 2021) of Uruguay, results show that STI drives formal IPPM and enhances innovation likelihood and novelty, while DUI fosters informal IPPM with limited impact on innovation outcomes. However, combined STI-DUI strategies generate coordination tensions, constraining innovation performance.

Keywords: innovation modes; knowledge appropriability strategies, firm organization

JEL Clasification: O31, O32, O54

1. Introduction

The study of the modes of innovation has been very fruitful in the innovation management literature and maintain intense open debates in the last years (Doloreauz and Shearmaur, 2023; Hervas-Oliver et al., 2021). The seminal paper of Jensen et al. (2007) distinguished between two ideal types of innovation modes, namely STI (*Science and Technology-based Innovation*) and DUI (Innovation based on *learning-by-Doing, learning-by-Using, learning-by-Interacting*). In driving innovation, both modes rely on the creation and transfer of knowledge, yet the DUI mode places greater emphasis on the practical application of tacit knowledge, while the STI mode prioritizes the theoretical understanding and formalization of codified knowledge (Lundvall, 1992; González-Pernía et al., 2015). These contrasting focuses reveal the complementary nature of the two modes to explain performance (Amara et al., 2008; Thomä and Zimmerman, 2020; Piercey et al., 2025). Nevertheless, researchers also argue that combining STI and DUI modes of innovation is not a *panacea*, highlighting controversies related to innovation outputs (Carrillo-Carrillo and Alcalde-Heras, 2020), as well as the challenges arising from the trade-offs between protecting/safeguarding knowledge, which can hinder sharing, and signalling commitment to collaborate and innovate (Alhusen and Bennat, 2021; Telg et al., 2023).

STI modes of knowledge development and transfer rely on formal channels, such as professional networks, patents, and formal training, to codify knowledge. This knowledge is usually created and developed in R&D departments through specific R&D activities conducted by highly trained specialists (Haus-Reve et al., 2023) in collaboration with organizations that produce scientific knowledge, such as universities and research centers (Hervás-Oliver et al. 2011). In contrast, DUI modes depend on more informal channels, such as personal networks, communities of practice, or experiential learning, to generate and share knowledge (Apanasovich et al., 2016). Under this strategy, knowledge transfer is typically unstructured, relying on social interactions and trust between individuals (Thomä, 2017; Haus-Reve et al., 2023).

The distinct nature of these two modes implies different challenges and needs when it comes to managing and protecting knowledge (Grimaldi et al., 2021). While STI may be more naturally aligned with formal protection mechanisms such as patents, the

informal and open character of DUI raises concerns about knowledge leakage and the lack of structured safeguards. These differences highlight the importance of improving the understanding of how firms combine innovation modes with protection strategies and the ability to collaborate and send clear both internal and external signals of commitment, elements that are essential to better support innovation outcomes (Zhu and Xia, 2025). In the background, the effective alignment between innovation modes and knowledge protection strategies becomes essential to ensure that firms can benefit from openness without compromising their competitive position (Zobel et al., 2016; Bogers et al., 2019). This leads to a key question:

To what extent is innovation performance influenced by different modes of innovation through their influence on firms' use of knowledge protection mechanisms (both formal and informal)?

Addressing this question is particularly relevant given the limited knowledge surrounding the appropriability strategy that best support different knowledge types and their contribution to innovation performance. For instance, while the DUI mode is often associated with tacit knowledge and informal contexts, it is not limited to unstructured environments; it may also involve systematic routines and formal training that facilitate more deliberate forms of knowledge sharing and collaboration (Thomä, 2017). Conversely, STI modes, despite their reliance on codified knowledge, may still draw heavily on experiential judgment and other tacit components during scientific discovery and problem-solving processes (Bogers et al., 2019). In this context, the adoption of appropriability mechanisms (formal, informal, hybrid) safeguards knowledge as well as fosters commitment within project teams, key for enhancing collaboration and achieving innovation outcomes. The aim of this paper is to advance the understanding on how innovation modes relate to the use of different intellectual property protection mechanisms (IPPM) to explain innovation performance.

In doing so, this study contributes to the literature regarding STI and DUI modes and innovation performance in two key ways. First, it explores the dynamics of STI and DUI modes and their connection to innovation outcomes, placing particular emphasis on the role played by formal and informal IPPMs in shaping these modes and their interactions. This dimension has received limited attention in the existing literature (Aslesen and Pettersen, 2017), yet we consider it to be essential for advancing the

understanding of the appropriability and commitment strategies behind successful innovation outcomes (Lee et al., 2018). Changes in innovation modes may yield varying degrees of performance depending on how knowledge is protected and transmitted (Zhang and Groen, 2021), and can be decisive in explaining the outcomes of different innovation strategies (Telg et al., 2023). Beyond safeguarding knowledge, protection mechanisms can also serve as signals of commitment to collaboration, encouraging organizations to engage in and sustain cooperative relationships (Hagedoorn and Zobel, 2015; Olaisen and Revang, 2017). Our research approach to this issue from the perspective formalization, which refers to the transition from trust-based and implicit practices to more codified, standardized, or legally binding mechanisms aimed at safeguarding knowledge assets.

Secondly, this study empirically investigates how STI and DUI modes interact in emerging economies, a context that has received limited scholarly attention. While most existing research has focused on developed countries with well-established infrastructures and institutional frameworks (Carrillo-Carrillo and Alcalde-Heras, 2020), the dynamics in less mature innovation systems remain poorly understood (Joseph et al., 2021). This is specifically reflected in the intrinsic relationship between the innovation and appropriability strategies followed by firms in developing countries (Milesi et al., 2013). In emerging economies, informal networks of knowledge and unstructured informational links are at the core of the innovation process, which typically characterizes the DUI mode of innovation (Bartels et al., 2012; Joseph et al., 2021). However, the implementation of innovation and appropriability practices articulated in the national innovation systems has been promoted in the last decade (Suárez and Erbes, 2021; Barros, 2021), reinforcing formal innovation structures through the hiring of qualified employees, the acquisition of new technologies, and access to knowledge from external networks (Lee et al., 2021). The dynamics of these transformations require further attention, particularly because the DUI model remains prevailing and organizations continue to accumulate competences and capabilities through doing, interacting, and learning (Lundvall et al., 2009; Joseph et al., 2021). Investment in R&D are typically lower but informal practices can lead to significant innovations comparable to those in developed countries that invest more in R&D (Edquist, 2010; Parrilli et al., 2020). Therefore, investigating how changes in the size of formal and informal structures affect DUI-STI

interactions over time can shed new light on the debate surrounding NIS performance in developing countries and their effects on innovation performance in such contexts.

The paper is organized as follows. The following section develops the theoretical framework presenting a set of hypotheses that address the relationships between innovation modes, protection strategies, and innovation performance. These hypotheses are empirically tested in Section 3, which describes the data, presents the descriptive statistics, and outlines the econometric models employed. The paper finalizes with a discussion of the empirical results and the main conclusions, highlighting their theoretical and managerial implications, and future lines of research.

2. Theoretical Framework

The literature regarding innovation and IPPM suggests that modes of innovation may influence the type of knowledge appropriability mechanisms firms adopt and the performance achieved (Leiponen and Byma, 2009; Ayerbe et al., 2024). This study examines how innovation modes (STI, DUI, and their interaction) influence the use of innovation protection mechanisms and innovation outcomes, both in terms of product innovation and the degree of product novelty. Although innovation modes (STI and DUI) have been primarily studied in direct relation to innovation outcomes (e.g. Apanasovich et al, 2016), our work argues that their impact may be conditioned by the type of appropriability strategy adopted by firms. In other words, innovation modes not only exert a direct influence on innovation, but also an indirect one, by shaping the type of protection employed, thereby affecting the scope and depth of innovation outcomes (Thomä and Bizer, 2013).

2.1 STI- IPP strategy and Innovation Performance

STI mode of innovation promotes the development of formal, structured, and planned capabilities, it is typically grounded in formal R&D activities, collaborations with universities, and codified knowledge generation (Jensen et al., 2007). These collaborations are strong (Alhusen and Bennat, 2020), institutionalized (Johnson & Lundvall,2002), generally planned to generate knowledge and research outcomes that are formal and codified (Nunes and Lopes, 2015).

This type of innovation typically yields outcomes that are more readily documented and appropriated through formal IPPMs, such as patents, utility models, or

industrial designs (Laursen and Salter, 2014). STI based firms tend to use formal IPP mechanisms, as they usually generate outcomes that are codifiable, recordable, and legally appropriable (Li, 2022). In this context, it is reasonable to expect that firms with an STI orientation are more likely to use formal IPPMs, given that their innovation outputs meet the requirements of novelty, industrial applicability, and legal protectability. In addition, by clarifying rights and responsibilities, these mechanisms foster trust and facilitate effective cooperation in innovation projects, particularly in knowledge-intensive sectors (Miozzo et al., 2016). Despite regional institutional architecture matters in determining the specific innovation capacity and outputs (Hervás-Oliver et al., 2021), this result can be observed even in developing countries, albeit with certain institutional limitations (Mathew and Paily, 2021; Santos et al., 2022).

Likewise, under certain circumstances, the combination of formal and informal IPPMs can be useful for safeguarding STI innovations (Suzuki, 2015; Grimaldi et al., 2021). Even more, STI oriented firms typically operate in environments characterized by high competition, rapid technological change, and potential risks of imitation (Arundel and Kabla, 1998; Hall et al., 2014). In this sense, Anton and Yao (2004), and Ottoz and Cugno (2008) develop models in which protection through a combination of patenting and trade secrecy is an optimal strategy depending on the scope of the innovation and the strength of the protection system. As a result, for the STI model, combining formal and informal protection mechanisms serves as safeguards of knowledge but also as a signal of commitment and trust (Zobel, Lokshin, & Hagedoorn, 2017), which are key factors for successful in innovation (Lee et al., 2018). This combined protection strategy is especially critical for firms pursuing radical innovations, where the novelty and complexity of knowledge heighten the risk of misappropriation and require more robust appropriability regimes (Leiponen and Byma, 2009).

In sum, STI oriented firms can adopt formal, yet strategically hybrid protection strategy (Bessen and Meurer, 2008; Nguyen et al, 2023), facilitating the appropriation of returns and to achieve superior innovation outcomes, even in competitive or institutionally weak environments (Grimaldi et al, 2021; Ayerbe et al., 2024).

H1a – The STI mode fosters the use of exclusive formal IPP, as well as the combination of both (formal and informal).

H1b – The above is positively associated with the likelihood of innovating and with innovation novelty.

2.2 DUI- IPP strategy and Innovation Performance

DUI innovation mode relies on practical experience, incremental learning, and interaction with customers or suppliers, fostering more tacit capabilities (Jensen et al., 2007). The exchange of knowledge generally occurs in an unstructured manner, grounded in interpersonal relationships, mutual trust, experience, and trial-and-error (Thomä, 2017; Hause-Reve et al., 2023).

Accordingly, firms operating under the DUI innovation mode tend to rely primarily on informal appropriation mechanisms to protect their innovations. These mechanisms include trade secrecy, speed of implementation, design complexity, and customer loyalty (Arundel, 2001; Leiponen and Byma, 2009). Unlike formal mechanisms, which require registration and legal validation, these informal means do not entail high costs or bureaucratic processes, making them more accessible (Khouilla and Bastidon, 2024). In addition, firms following the DUI innovation mode often lack the capabilities or incentives to implement formal IPPMs (Laursen and Salter, 2014). Moreover, the costs, technical and bureaucratic requirements, and timeframes associated with formal protection can be disproportionate to the expected returns of incremental innovations, leading firms to prioritize more accessible informal IPPMs (Arundel, 2001). This is particularly important in contexts with lower institutional capacity, such as developing countries or industries with limited infrastructure for formal protection (Arundel, 2001), environments where registration costs are high or formal protection is weak (Nguyen et al, 2023).

These informal exchanges, grounded in trust and social capital rather than formal contracts, tend to reduce the likelihood of conflicts and disputes over intellectual property, as relationships are maintained through tacit norms and mutual commitments (Lauritzen and Karafyllia, 2019). This relational flexibility fosters experimentation and co-creation, enabling firms to adapt rapidly to market or technological changes. Informal knowledge sharing through social ties and networks has been shown to enhance innovation capacity

by facilitating the flow of tacit knowledge and minimizing legal disputes that can hinder collaboration (Parente et al., 2022).

Moreover, trust-based informal collaborations create systemic conditions that support innovation, especially in environments characterized by weak institutional frameworks or low formalization (Nooteboom, 2020). In such contexts, the absence of rigid institutional controls allows for more agile and context-sensitive innovation processes contributing to the achievement of innovation outcomes. Empirical evidence suggests that this strategy is effective for generating incremental innovations and improving adaptability in dynamic environments (Vega-Jurado et al., 2019; Orjuela-Ramirez et al., 2023).

In sum, innovations under the DUI mode tend to be incremental or adaptive, focused on continuous improvements and adjustments to local conditions (Laursen and Salter, 2014; Leiponen, 2005), where speed and the ability to maintain exclusivity through informal mechanisms are key to sustaining competitiveness in innovation (Tether, 2002).

H2a – The DUI mode fosters the use of exclusive informal IPP.
H2b – The above is positively associated with the likelihood of innovating, but not with innovation novelty.

2.3 STI-DUI modes, IPP strategy and Innovation Performance

Firms that combine both innovation modes (STI and DUI) are theoretically the most comprehensive or sophisticated (Apanasovich et al., 2016), as they integrate codified and tacit knowledge, structured and experiential learning (Lee et al., 2021). In theory, these firms benefit from the strengths of both modes (Jensen et al., 2007), leading to more robust and potentially radical innovations (Greco et al., 2022). This could justify a greater capacity to use formal protection mechanisms, while also adopting flexible and informal appropriation strategies (Zhou and Wang, 2020).

However, this combination does not always produce positive synergies, especially regarding IPP strategies, as the coexistence of both modes of innovation may not automatically translate into better outcomes (Alhusen and Bennat, 2021). Possible

underlying factors include organizational and coordination conflicts (Santos et al., 2022), strategic ambiguity, weak or bureaucratic institutional frameworks (Friedrich and Kagel, 2025). In the background, the combination of both modes generates a duality that can hinder the coherent selection of an innovation protection strategy, creating organizational ambiguity and reducing clarity on how to capture the value created (Morales et al., 2024). Furthermore, this strategy can also exacerbate uncertainty regarding long-term direction or commitment to a consistently applied innovation strategy (Selivanovskikh et al., 2025).

Moreover, in context where formal protection systems are costly or inefficient and many firms operate under resource constraints (e.g. developing countries), companies may find themselves torn between securing formal IPPM for STI generated outputs and trying to maintain secrecy or accelerate the deployment of DUI outcomes. As a result, ineffective hybrid protection strategies can be observed, mainly due to unclear appropriation frameworks (Tether, 2002). In these settings, the ambiguity surrounding protection strategies can compound the challenges firms already face in capturing value from their innovations.

In sum, although a substantial body of research has argued that combining STI and DUI innovation modes can lead to superior innovation outcomes by integrating codified scientific knowledge with experiential, tacit know-how (e.g. Jensen et al., 2007; Fitjar and Rodríguez-Pose, 2013), the effectiveness of this combination may be contingent on the firm's IPP strategy. In practice, when the chosen protection approach is ambiguous, particularly in environments with weak institutional frameworks (with higher costs of formal protection, or limited organizational capabilities), firms may face difficulties aligning STI-related outputs with DUI-derived outcomes, which typically rely on informal means. This misalignment can limit both the likelihood of introducing new products and the novelty degree of such innovations, as competing protection logics create organizational tensions and strategic uncertainty (Santos et al., 2022; Friedrich and Kagel, 2025).

H3 – The combination of STI and DUI may generate tensions in low appropriability environments, constraining the protection strategy, which is negatively associated with both the likelihood and the novelty of innovation.

3. Empirical Analysis.

3.1 The data

The analysis draws on a panel dataset from the Innovation Activities Survey conducted by the National Agency for Research and Innovation (ANII) of Uruguay. The survey, which follows the guide of Oslo Manual (OECD, 2018), comprises eight waves, collected every three years, providing a rich longitudinal perspective on firm-level innovation activities. Although the full panel contains data from the 1998–2000 wave onwards, this study focuses on the period from 2010–2012, when questions regarding a variety of informal IPPMs were first introduced, which are variables central to the models employed in this analysis. We use an unbalanced panel data set which extends to the most recent available wave, 2019–2021, allowing for a contemporary assessment of the interaction between innovation modes, appropriation strategies, and innovation outcomes. This structure enables the examination of temporal dynamics in firms' adoption of both formal and informal intellectual property protection, providing a robust basis for understanding innovation strategies in a developing-country context.

3.2 Variables and Descriptive Statistics

The *dependent variable* is innovation performance, which is measured through product innovation using two complementary indicators that captures if the firm introduces product innovation and the novelty degree of that. Together, these measures allow distinguishing not only the occurrence of product innovation but also its qualitative dimension in terms of novelty.

The descriptive statistics (see Table 2) indicate that product innovation is a relatively frequent outcome among firms that carried out some type of innovation activity (innovative firms), though with some fluctuations over time. On average, approximately 50.8% of firms engaging in innovation activities report product innovation, with a peak of 55% in 2015 and a decline to 45% in 2021**.** This suggests that product innovation constitutes a central component of firms' innovative efforts, but its relative weight may be sensitive to broader economic or technological conditions.

Table 1: Variables

Variable name	Definition	Computing
Dependent variables		

I_Prod	**Product innovation**	Is a binary variable that takes the value of 1 if the firm reports having introduced a product innovation and 0 otherwise.
Novelty	**Novelty of product innovation**	Is a categorical variable capturing the degree of novelty of the product innovation: it equals 1 when the innovation is new to the firm, 2 when it is new to the domestic market, 3 when it is new to the international market, and 0 if no product innovation was introduced
Intermediate variables		
STI	**STI internal** R&D internal	It is a binary variable that takes the value of 1 if the firm reports doing R&D internal activities
	STI external R&D external	It is a binary variable that takes the value of 1 if the firm reports doing R&D external activities
STI index	**(STI internal + STI external) / 2**	The variable equals 0 if the firm does not undertake STI activities, 0.5 if it undertakes them partially, and 1 if it undertakes them fully
DUI	**DUI internal**	This variable equals 1 if the firm reports engaging in at least two of the activities described below and 0 otherwise.
	Training Marketing and Market strategy Organization Design Industrial Engeneering and Desing	These are binary variables that take the value 1 if the firm reports having carried out any innovation activities.
	DUI external	This variable equals 1 if the firm reports engaging in at least two of the activities described below and 0 otherwise.
	Link with other firms	It is a binary variable that takes the value 1 if the firm reports having a link with other firms.
	Establishment of cooperation agreements for:	
	Commercialization The purchase of inputs The purchase of technologies Training activities	These are binary variables that take the value 1 if the firm reports having established any cooperation agreements for these purposes.
DUI index	**(DUI internal + DUI external) / 2**	The variable equals 0 if the firm does not undertake DUI activities, 0.5 if it undertakes them partially, and 1 if it undertakes them fully
Formal IPPM	**Formal index**	According to the number of formal mechanisms used by the firm, we created four levels: 0 = no use, 1 = simple adoption, 2 = extended adoption, and 3 = full adoption. The mechanisms consulted are as follows:
Formal	Invention patents Industrial designs Utility models Trademarks Geographical indications Copyright and related rights	These are binary variables that take the value 1 if the firm reports using any of the formal protection methods.
Informal IPPM	**Informal index**	According to the number of informal mechanisms used by the firm, we created four levels: 0 = no use, 1 = simple adoption, 2 = extended adoption, and 3 = full adoption. The mechanisms consulted are as follows:
Informal	Confidentiality agreements First-to-market strategy Complex design strategy	These are binary variables that take the value 1 if the firm reports using any of the informal protection methods.
Both	(IPPInFormal + IPPFormal)/2 if IPPInFormal >0 & IPPFormal>0	It is a index that represent the number of formal and informal mechanisms used by the firm.
Both IPPM	**Both index**	According to the index created above, we created four levels: 0 = no use, 1 = simple adoption, 2 = extended adoption, and 3 = full adoption.
Control variables		

Size	Firm size.	This variables is measured as the natural logarithm of the number of employees.
Expor	Export intensity	This variables represents the proportion of a firm's total sales that are exported.
FDI	Foreign direct investment	This variable captures the firm's share of capital held by foreign owners.
Age	Firm age	This variable represents the natural logarithm of the number of years since the firm was founded.
Pub_Supp	Public support for innovation	It is a dummy variable that takes the value 1 if the firm has received public support for innovation.
R&D_d)	R&D department.	It is a dummy variable that takes the value 1 if the firm has a formal R&D unit, and 0 otherwise.

Regarding the degree of novelty, most product innovations tend to be incremental rather than radical. On average, 21.2% of innovations are new only to the firm, reflecting internal learning and adaptation processes. A larger share, 24.4%, are new to the domestic market, representing a more ambitious level of innovation with potential for competitive differentiation. By contrast, only 5.3% of innovations are novel at the international level, underlining the challenges firms face in generating breakthroughs with global relevance. These figures highlight the predominance of domestic-market-oriented innovation, with relatively limited international novelty.

Table 2: Innovation Performance: Product Innovation and Novelty. (Innovative firms)

Innovation Performance	**2012**	**2015**	**2018**	**2021**	**Total**
Product Innovation (I_Prod)	48.70%	54.96%	51.65%	44.93%	**50.84%**
Novelty:					
For the firm (Novelty=1)	24.35%	22.28%	17.56%	21.13%	**21.18%**
For the national market (Novelty=2)	21.44%	25.68%	27.82%	20.41%	**24.41%**
For the international market (Novelty=3)	2.91%	7.00%	6.27%	3.33%	**5.25%**

The *independent variables* measure the adoption of different modes of innovation, capturing the different ways firms build and sustain their innovative capabilities. Following the literature, we distinguish between the STI mode, mainly related to the generation and absorption of knowledge through R&D activities, both internal and external, and the DUI mode, which reflects innovation based on experiential learning, organizational practices, and interactions with other actors such as customers, suppliers, and business partners.

The descriptive analysis of STI mode of firms involved in innovation activities reveal an upward trajectory over the period 2012–2021 (Table 3). Internal R&D consistently represents the main driver, rising from 34.3% in 2012 to 43.3% in 2021, while external R&D also shows a notable increase, from 10.7% to 20.6%. When looking at the aggregate STI index, the share of firms with no STI activity (value 0) decreases steadily from 62.5% in 2012 to 51.3% in 2021. Firms can adopt one of these modes by combining different activities, which allows us to classify their behavior into three levels. Regarding STI mode, both intermediate (0.5) and high (1) categories gain weight. This indicates a gradual but clear strengthening of STI based strategies among firms, particularly through the growing combination of internal and external R&D.

Table 3. Innovation Modes: STI and DUI. (Innovative firms)

	2012	2015	2018	2021	2012-2021
STI internal	**34.30%**	**33.75%**	**39.34%**	**43.26%**	**37.23%**
R&D internal	34.30%	33.75%	39.34%	43.26%	37.23%
STI externo	**10.72%**	**11.48%**	**15.96%**	**20.63%**	**14.31%**
R&D internal	10.72%	11.48%	15.96%	20.63%	14.31%
STI Index					
0	62.48%	62.45%	55.53%	51.25%	**58.40%**
0.5	30.02%	29.86%	33.64%	33.61%	**31.66%**
1	7.50%	7.68%	10.83%	15.14%	**9.94%**
DUI internal	**21.29%**	**22.18%**	**22.58%**	**26.29%**	**22.89%**
Training	42.42%	34.53%	30.22%	29.78%	34.06%
Marketing and Market strategy	11.33%	9.34%	29.42%	33.61%	19.94%
Organization Design	16.39%	32.30%	10.38%	11.98%	19.06%
Industrial Engeneering and Desing	14.70%	9.34%	17.67%	20.97%	14.97%
DUI external	**19.45%**	**16.73%**	**13.34%**	**13.98%**	**15.83%**
Business Links	87.90%	37.06%	42.08%	43.26%	50.14%
Cooperation Agreements in:					
Commercialization	13.48%	13.42%	11.06%	11.48%	12.41%
Training	10.41%	12.45%	9.46%	9.98%	10.73%
Machinery Procurement	9.19%	9.34%	7.07%	7.15%	8.26%
Technology Acquisition	8.88%	8.27%	6.27%	6.16%	7.44%
DUI Index					
0	65.08%	68.19%	71.27%	66.06%	**68.00%**
0.5	29.10%	24.71%	21.55%	27.62%	**25.29%**
1	5.82%	7.10%	7.18%	6.32%	**6.71%**

For DUI mode, the picture is more heterogeneous. Internal DUI practices evolve unevenly: training shows a decline (42.4% to 29.8%), while marketing and market strategy expand sharply (from 11.3% to 33.6%). Organizational design peaks in 2015 (32.3%) but later stabilizes around 12%, whereas industrial engineering and design gradually increase to over 20% by 2021. External DUI practices show a different pattern: business links were extremely prevalent in 2012 (87.9%) but drop sharply afterward, stabilizing near 43% in 2021. Other cooperation dimensions such as commercialization, training, machinery procurement, and technology acquisition, remain comparatively modest, between 6% and 13% throughout the period. DUI index suggests relative stability, with around two-thirds of firms reporting no DUI activity (value 0) across the years, and only about 6–7% reaching the maximum level (1).

We use the use of IPPM as *intermediate variables.* Regarding IPPM, we distinguish between firms that use formal (exclusive), informal (exclusive) or both. Firms can implement formal or informal IPPM by combining different tools, as measured through the three level ordered variable IPPM index (Table 4).

The descriptive statistics reveal a relatively stable but differentiated pattern in the adoption of formal IPPM over the 2012–2021 period. Trademarks consistently dominate formal protection, with usage rates around 28–30%, while patents remain marginal and even decline sharply to only 2.66% in 2021. Other formal mechanisms, such as copyrights, industrial designs, and geographical indications, play a comparatively minor role, each below 6%.

Table 4. Formal and Informal IPPMs. (Innovative firms)

	2012	2015	2018	2021	2012-2021
Formal IPPM					
Trademarks	30.02%	27.63%	29.30%	28.45%	28.74%
Patents	7.81%	5.84%	6.16%	2.66%	5.73%
Copyright and related rights	4.29%	5.35%	5.25%	5.82%	5.19%
Industrial designs	3.06%	3.40%	2.28%	2.16%	2.79%
Utility models	2.60%	1.46%	1.82%	2.50%	1.99%
Geographical indications	1.84%	1.75%	1.60%	1.83%	1.74%
Informal IPPM					
Trade Secrecy	28.48%	32.30%	34.44%	42.43%	34.03%
First-to-market strategy	31.70%	25.19%	28.16%	28.62%	28.02%
Complex design strategy	15.62%	13.91%	12.54%	14.48%	13.99%

Formal IPPM exclusive	9.65%	10.12%	9.69%	6.31%	**9.18%**
Informal IPPM exclusive	22.05%	23.83%	25.20%	29.45%	**24.91%**
IPPM Both (formal-informal)	26.03%	22.96%	23.83%	27.12%	**24.63%**
No IPPM	42.27%	43.09%	41.28%	37.10%	**41.28%**

By contrast, the use of informal IPPM shows greater dynamism, particularly in the case of secrecy. Secrecy rises markedly from 28.5% in 2012 to over 42% in 2021, consolidating its position as the most prevalent informal mechanism. "First to the market" and "design complexity" remain important but less dominant strategies, with relatively stable adoption rates near 28% and 14%, respectively. The trend underscores that informal protection methods are pervasive and, in the case of secrecy, increasingly valued as alternatives or complements to formal instruments.

The joint distribution of formal and informal IPPM highlights the coexistence and potential interaction between formal and informal mechanisms. Firms relying exclusively on informal IPPMs represent about one-quarter of the sample, and their share increases steadily, reaching nearly 30% in 2021. Exclusive reliance on formal IPPMs is much less common and declines over time, from 9.7% to just 6.3%. The most notable finding, however, is the persistent presence of firms combining both types of mechanisms, around 25% on average.

In addition to the main variables of interest, the analyses include several control variables that according with previous literature explain innovation performance (See table 1).

3.3. Econometric strategy

As the variables of interest, both the dependent variables (innovative performance) and the explanatory variables (modes of innovation) and the intermediate variables (IPPM), are only surveyed for 'innovative firms' – i.e. firms that have carried out some innovation activity – the estimates on the effects of innovation modes on firms' innovative performance can only be made for those firms.

The econometric strategy is based on a sequential two-stage estimation model, applying estimation techniques for dummy and ordered dependent variables, as widely employed in the literature of innovation management and economics (Uzzi and Gillespie,

2002; McCann et al., 2016). Following Hall and Sena (2017) we adapt this technique by adding a two-stage specification, which allows us to examine the impact of innovation modes on the use of IPPMs and subsequent product innovation outcomes.

Ordered logit models estimates he probability that a unit change in the independent variables changes the magnitude of dependent variables, by considering a linear function which captures the distribution of the independent variables according the cut points as defined in the variable construction.

Equations (1) represents the general expression of the ordered logit estimation.

$$P(Dep\_Variable_{j1}) = \mathrm{P}(k_{i-1} < \beta_1 x_{ij} + \cdots + \beta_k x_{kj} + \mu_j \leq k_i) (1)$$

Where: β are the coefficients to estimate for each cut point *k.* μ *is the error term assumed to be logistically distributed*

Equations (2) and (3) represent the specification used in each stages respectively.

$$log\left(\frac{P_1+\cdots P_k}{1-P_1-\ldots P_k}\right) = \beta + \beta_1 STI + \beta_2 DUI + \beta_3 (STI * DUI) + \beta_4 X + \delta_t + \mu_{it} \ (2)$$

Where *P* represents the probability to use a type of IPPM – formal, informal or both – ordered as shown in Table 1. Explicative variables STI and DUI as defined in Table 1. *X* is a vector of control variables a defined in Table 1, δ are time fixed effects and μ is the error term.

The predicted value of the probability of use different IPPMs is used as regressor in the second stage to estimate the probability and novelty of product innovation, distinguishing again between formal, informal, and combined IPPMs.

$$log\left(\frac{P_1+\cdots P_k}{1-P_1-\ldots P_k}\right) = \beta + \beta_1 p\_IPPM \quad + \beta_2 STI + \beta_3 DUI + \beta_4 (STI * DUI) + \beta_5 X + \delta_t + \mu_{it} \ (3)$$

Where *p_IPPM* represents the predicted probability to use a type of IPPM estimated through equation (1). Explicative variables STI and DUI as defined in Table 1. *X* is a vector of control variables a defined in Table 1, δ are time fixed effects and μ is the error term.

4. Results.

4.1 Innovation Modes, Formal IPPM and Innovation Performance

The estimation results regarding firms that rely exclusively on formal IPPM (Table 5, model 5.1.2) reveals that only the DUI mode is a significant driver of adoption (1.206, $p<0.01$). This effect is corroborated by the estimation of marginal effects, which shows the significant effect of DUI mode, negative for the no adoption of formal IPPMs and positive for simple or extended adoption (Table A1, appendix).

Moreover, structural and institutional resources clearly matter. The existence of a formal R&D department strongly increases the likelihood of adopting formal protection (1.174, $p<0.01$), as do firm age (0.488, $p<0.01$) and public support (0.892, $p<0.01$). This suggests that the adoption of formal IPPM is driven by DUI mode and embedded in firms' organizational capacity and policy environment.

In addition, formal IPPMs have a significant effect on innovation outcomes (Table 6, models 6.2.1 and 6.2.2, marginal effects in Table A2 Appendix). The predicted use of formal mechanisms increases both the probability of introducing product innovations (0.268, $p<0.05$) and the degree of novelty (0.348, $p<0.01$). At the same time, STI mode exerts a positive influence on product innovation (2.061, $p<0.001$) and on the novelty of innovation (2.087, $p<0.001$), confirming its role as the key driver of knowledge-based innovation outcomes.

DUI mode also shows a significant and positive effect on innovation outcomes, 1.069 ($p<0.001$) and 1.012 ($p<0.001$), for product innovation and novelty respectively. This result is in line with previous works signaling the relevance of learning and interacting innovation process as a source critical knowledge resources in developing countries (Lorenz and Kramer-Mbula, 2019; Mathew and Paily, 2021).

Finally, the interaction between STI and DUI seems showing tensions when both modes of innovation are simultaneously adopted, since the effect are negative and significant, -1.122 ($p<0.001$) for product innovation and -1.540 ($p<0.001$) for novelty. In sum, the results confirm H1a and H1b, supporting that formal mechanisms are positively influenced by STI modes, and that, through them, the effect of STI on innovation performance is reinforced.

4.2 Innovation Modes, Informal IPPM and Innovation Performance

The analysis shows that firms adopting exclusively Informal IPPM display a different pattern compared to those relying on formal protection (Table 5, model 5.2.2). Both, STI and DUI modes appears as significant predictors of IPPMs adoption, (1.492, $p<0.001$), and (1.897, $p<0.001$), respectively. This confirms that informal mechanisms are inherently linked to experience-based learning processes, but also shows the relevance of science-based process. The estimation of marginal effects confirms the significant and

Table 5: Estimation results first stage. Innovation Modes and IPPM adoption

	Formal IPPM		Informal IPPM		Both IPPM	
	5.1.1	**5.1.2**	**5.2.1**	**5.2.2**	**5.3.1**	**5.3.2**
STI		-0.414		1.492***		2.287***
		(0.436)		(1.25e-09)		(0)
DUI		1.206**		1.897***		2.647***
		(0.0322)		(0)		(0)
STI#DUI		0.475		-0.521		-1.726***
		(0.702)		(0.318)		(0.00300)
R&D_d	1.141***	1.174***	1.142***	0.433**	1.781***	0.739***
	(0.000306)	(0.00133)	(0)	(0.0108)	(0)	(7.44e-05)
Age	0.470***	0.488***	-0.141*	-0.121	0.0233	-0.00222
	(0.00163)	(0.00147)	(0.0685)	(0.102)	(0.801)	(0.980)
Size	0.106	0.084	0.168***	0.0709*	0.179***	0.0833
	(0.198)	(0.319)	(0.000118)	(0.0910)	(0.000967)	(0.116)
Expor	0.00494	0.005	0.00389*	0.00315	0.00547**	0.00499**
	(0.228)	(0.195)	(0.0764)	(0.131)	(0.0307)	(0.0430)
FDI	-0.175	-0.175	0.0986	0.188	0.454**	0.464**
	(0.603)	(0.611)	(0.568)	(0.256)	(0.0169)	(0.0127)
Pub_Supp	0.958***	0.892***	0.457***	0.337**	1.188***	0.908***
	(0.000381)	(0.00128)	(0.00367)	(0.0279)	(0)	(1.10e-07)
2015.year	0.110	0.131	-0.0103	-0.00977	-0.116	-0.160
	(0.680)	(0.631)	(0.948)	(0.949)	(0.491)	(0.338)
2018.year	0.118	0.168	0.190	0.0934	0.241	0.0367
	(0.680)	(0.566)	(0.246)	(0.562)	(0.182)	(0.839)
2021.year	-0.515	-0.520	0.405**	0.237	0.194	0.0801
	(0.139)	(0.148)	(0.0255)	(0.180)	(0.339)	(0.689)
cut1	4.789***	4.942***	1.365***	1.429***	2.446***	2.500***
	(0)	(0)	(1.53e-06)	(2.18e-07)	(0)	(0)
cut2	10.53***	10.79***	3.138***	3.238***	3.939***	4.052***
	(0)	(0)	(0)	(0)	(0)	(0)
cut3			5.288***	5.441***	6.826***	7.048***
			(0)	(0)	(0)	(0)
sigma2_u	4.598***	4.941***	1.737***	1.278***	3.191***	2.677***
	(0.000801)	(0.000905)	(9.55e-05)	(0.000927)	(2.55e-07)	(1.60e-06)
Observations	1,594	1,594	2,091	2,091	2,082	2,082
Firms	1,280	1,280	1,599	1,599	1,591	1,591
Log likelihood	-723.24141	-718.33565	-1958.8856	-1878.1513	-1895.5365	-1803.5689
χ^2	43.58	46.98	91.65	187.93	179.11	248.04

Marginal effects in the appendix

negative effect of both modes (DUI and STI) on the probability to no adoption of informal IPPMs and the positive effects on the probability that firm adoption of simple, extended or full IPPMs (Table A3, appendix). Organizational resources again matter. The presence of a formal R&D department increases the probability of informal protection (0.433, $p<0.01$), as does public support (0.337, $p<0.05$).

When moving to innovation outcomes, second stage, however, the mediating role of informal mechanisms weakens (Table 6, models 6.3.1 and 6.3.2). The predicted adoption of informal mechanisms has a positive and significant effects on the likelihood of achieving product innovation (0.709, p<0. 05) as well as for the novelty of innovation (0.920, p<0. 01). Instead, the results show that, when considering the predicted effects of IPPM, STI and DUI does not exert significant direct effects on innovation outcomes (Marginal effects, Table A4, Appendix). In sum, the results for the case of informal mechanisms of protection are relevant insofar as the effects are mainly observed in the relationship between innovation modes and the exclusive use of these protection mechanisms. Even more interestingly, in these cases, the effects of innovation modes are significant only through these mechanisms of protection and not directly. This finding validates H2a and partially validates H2b, as informal mechanisms increase the probability of innovating and, contrary to expectations, also the degree of novelty.

4.3 Innovation Modes, Formal-Informal IPPM and Innovation Performance

Finally, the simultaneous use of formal and informal protection mechanisms reveals a distinct pattern compared to their exclusive adoption (Table 5, model 5.3.2). On the one hand, while both DUI and STI are significant drivers of the simultaneous use of formal and informal IPPMs (2.287, p<0.01 and 2.647, p<0.01, respectively. Marginal effects Table A5, Appendix), the STI–DUI interaction does not remains irrelevant and shows a negative and significant effect (1.726, p<0.01). This result suggest that the joint presence of innovation modes generate tensions rather than complementarities. This could be the result of coordination costs, conflicting signals to partners, or trade-offs between openness and secrecy (Bello-Pintado et al., 2022). Adopting hybrid protection strategies appears to be effective only up to a certain threshold; when firms intensively combine STI and DUI modes, the resulting frictions outweigh the potential synergistic benefits.

For innovation performance measures, (Table 6, models 6.4.1 and 6.4.2) results show that the mediating role of simultaneous protection becomes more apparent. For product innovation, the predicted adoption of hybrid mechanisms has a positive and significant effect (0.263, p<0.05). Similarly, for the novelty of innovation, the effect is also positive (0.341, p<0.01) (Marginal effects, Table A6 Appendix).

Table 6: Second stage Innovation Modes, IPPM and Innovation Performance

	Baseline models		Formal IPPM		Informal IPPM		Both IPPM	
	I_Prod	Novelty	I_Prod	Novelty	I_Prod	Novelty	I_Prod	Novelty
	6.1.1	6.1.1	6.2.1	6.2.2	6.3.1	6.3.2	6.4.1	6.4.2
STI			2.061***	2.087***	0.892	0.570	1.348***	1.162***
			(0)	(0)	(0.114)	(0.240)	(0.000213)	(0.000194)
DUI			1.069***	1.012***	0.0474	-0.315	0.696*	0.527
			(0.000157)	(4.07e-05)	(0.947)	(0.608)	(0.0971)	(0.147)
c.STI#c.DUI			-1.122**	-1.540***	-0.625	-0.895**	-0.540	-0.785**
			(0.0120)	(1.63e-05)	(0.190)	(0.0198)	(0.274)	(0.0495)
Formal IPPM Predict			0.268**	0.348***				
			(0.0425)	(0.00230)				
Informal IPPM Predict					0.709**	0.920***		
					(0.0425)	(0.00230)		
Both IPPM Predict							0.263**	0.341***
							(0.0425)	(0.00230)
R&D_d	1.473***	1.264***	0.334	0.0866	0.342	0.0963	0.454***	0.242*
	(0)	(0)	(0.117)	(0.629)	(0.105)	(0.586)	(0.00869)	(0.0899)
Age	0.0199	-0.000932	-0.111	-0.173**	0.106	0.108*	0.0207	-0.00287
	(0.732)	(0.986)	(0.216)	(0.0269)	(0.131)	(0.0815)	(0.723)	(0.956)
Size	-0.0101	0.00295	-0.112***	-0.101***	-0.140***	-0.137***	-0.112***	-0.0997***
	(0.762)	(0.924)	(0.00199)	(0.00193)	(0.00114)	(0.000332)	(0.00205)	(0.00206)
Expor	-2.36e-05	0.00463***	-0.00273	0.00171	-0.00351*	0.000703	-0.00259	0.00190
	(0.989)	(0.00271)	(0.139)	(0.301)	(0.0857)	(0.697)	(0.155)	(0.243)
FDI	0.173	0.179	0.253*	0.259**	0.0729	0.0252	0.0841	0.0398
	(0.179)	(0.125)	(0.0566)	(0.0274)	(0.610)	(0.842)	(0.550)	(0.749)
2015.year	0.336***	0.465***	0.303**	0.416***	0.345***	0.470***	0.380***	0.516***
	(0.00442)	(1.16e-05)	(0.0124)	(9.55e-05)	(0.00408)	(8.66e-06)	(0.00183)	(1.53e-06)
2018.year	0.215*	0.422***	0.0847	0.289***	0.0636	0.261**	0.120	0.335***
	(0.0798)	(0.000154)	(0.500)	(0.00953)	(0.616)	(0.0199)	(0.339)	(0.00270)
2021.year	-0.236*	-0.164	-0.230	-0.108	-0.537***	-0.508***	-0.390***	-0.316**
	(0.0860)	(0.194)	(0.153)	(0.448)	(0.000727)	(0.000319)	(0.00557)	(0.0120)
/lnsig2u	-0.130	0.879***	-0.307		-0.307		-0.307	
	(0.622)	(1.30e-06)	(0.301)		(0.301)		(0.301)	
Constant	-0.399*		-0.564***		-0.564***		-0.564***	
	(0.0594)		(0.00868)		(0.00868)		(0.00868)	
cut1		0.537***		0.715***		0.715***		0.715***
		(0.00531)		(0.000177)		(0.000177)		(0.000177)
cut2		1.653***		1.874***		1.874***		1.874***
		(0)		(0)		(0)		(0)
cut3		4.025***		4.296***		4.296***		4.296***
		(0)		(0)		(0)		(0)
sigma2_u				0.671***		0.671***		0.671***
				(4.29e-05)		(4.29e-05)		(4.29e-05)
Observations	3,159	3,159	3,159	3,159	3,159	3,159	3,159	3,159
Firms	2,121	2,121	2,121	2,121	2,121	2,121	2,121	2,121
Log likelihood	-2075.9163	-3572.6225	-1966.0845	-3445.6674	-1966.0845	-3445.6674	-1966.0845	-3445.6674
χ^2	146.24	202.43	266.45	386.63	266.45	386.63	266.45	386.63

Marginal effects in the appendix

Importantly, the direct effect of STI on innovation outcomes is positive while the interaction between STI and DUI exerts a negative and significant effect on innovation novelty (–0.785, $p<0.05$) revealing to potential tensions or inefficiencies when both

modes are simultaneously activated. By contrast, R&D departments continue to play a positive and significant role in driving product innovation (0.454, $p<0.01$).

In sum, the joint use of formal and informal IPPM enhances innovation outcomes, but when the combination of STI and DUI are the innovation strategy of the firm, there are frictions that undermine potential complementarities. In this context, while hybrid protection mediates positively for product innovation and novelty, the STI–DUI interaction remains negative, reflecting coordination costs and inefficiencies.

5. Discussion

This study provides new evidence into how innovation modes affect the use of different appropriability strategies and, in turn, how these strategies condition product innovation performance. While prior research has mostly examined the direct link between STI/DUI and innovation performance (e.g. Apanasovich et al., 2016; Mathew and Paily, 2021), our findings highlight that the relationship is more complex and no universal, as the appropriability strategy followed by firms plays a mediation role in this process. Across four waves of data, covering a ten years period, the evidence reveals that the appropriability strategy is unevenly distributed according to the innovation modes and that their effectiveness varies depending on whether the firm relies predominantly on STI, DUI, or a combination of both.

Regarding H1a and H1b**,** our results do not support the claim that the STI mode fosters the use of formal IPP mechanisms but, the adoption of hybrid protection combining formal and informal strategies. The observed fact that DUI rather than STI drives the exclusive adoption of formal IPPMs points that these mechanisms plays a dual role as both protection tools and commitment signals. Firms engaging in DUI activities rely heavily on external collaboration, user interaction, and tacit knowledge exchanges, which are highly vulnerable to opportunism. In this context, formal mechanisms serve not only to safeguard knowledge but also to signal credibility and commitment to partners, thereby reducing uncertainty and fostering trust (Miozzo et al., 2016; Teng et al., 2023). This signalling role explains why DUI mode drives formal IPPMs despite their less codified knowledge base. Importantly, in our setting, STI significantly enhances innovation performance, with high and significant effects in novelty and the likelihood of

introducing product innovations. Furthermore, once in place, formal and combined IPPMs mediate the relationship between innovation modes and outcomes.

This means that by protecting and legitimizing knowledge exchanges, formal IPPMs reinforce the positive effect of STI activities on product innovation and novelty (Hagedoorn and Zobel, 2015). In other words, while STI provides the scientific and technological foundations for innovation, the adoption of formal mechanisms ensures that knowledge is both secured and perceived as trustworthy, thus amplifying the innovation payoff (Laursen and Salter, 2014). The presence of R&D departments and access to public support enhance the STI based strategy with the use of combined IPPMs, indicating that organizational and institutional scaffolding play a critical role even under weaker appropriability regimes.

Turning to H2a and H2b, our analysis strongly corroborates the relevance of DUI mode on the appropriability strategy followed by the Uruguayan firms. In confirms that DUI fosters the adoption of informal IPPM, aligning with prior evidence that relational learning, trust, and experiential know-how are better safeguarded through secrecy, speed, and customer loyalty (Arundel, 2001; Leiponen and Byma, 2009). However, DUI mode also foster the adoption of formal and hybrid appropriability. This is an interesting finding in the light of the wide previous accumulation form the fields of innovation economics and development, which have emphasized that experiential know-how and unstructured interaction have usually been the main knowledge source in firms acting in developing countries (Lorenz and Kramer-Mbula, 2019). Adding to previous knowledge, this finding show the relevance and extension of DUI practice associated with appropriability strategies based on formal, informal or hybrid IPPM.

On another hand, exclusive use of informal protection aligns with the dual logic of science-based codified knowledge and experience-based tacit learning. In DUI oriented firms, informal mechanisms are particularly effective because they allow firms to safeguard sensitive knowledge while maintaining the flexibility and openness required for collaborative learning. In addition, the results suggest that in STI oriented firms, these mechanisms complement codified outputs by protecting intermediate, non-patentable results, enabling ongoing scientific problem-solving. Importantly, informal mechanisms also operate as relational signals. The dual protective and signaling function explains why the direct effects of STI and DUI modes on innovation performance vanish once informal

IPPMs are accounted for. Instead, their influence is transmitted through informal mechanisms, which significantly enhance both the likelihood of product innovation and its novelty. Thus, informal IPPMs emerge as key mediators, validating H2a and partially H2b, since they not only increase the probability of innovating but also contrary to expectations, raise the degree of novelty by fostering trust-based exchanges and knowledge recombination.

This asymmetry corroborates the critical importance of DUI innovation mode in developing countries. However, it also reflects a key limitation of DUI strategies, while relational and incremental learning is crucial for adoption of IPPM, such strategy alone do not secure innovation payoffs. The results suggest that IPPM is necessary to sustain DUI-driven knowledge flows but not fully efficient to generate competitive product innovations.

Regarding H3, estimations confirms that the simultaneous adoption of formal and informal protection mechanisms reveals a distinct dynamic that differs from their exclusive use. Both STI and DUI modes significantly drive the adoption of hybrid IPPMs, yet their interaction produces a negative and significant effect, suggesting that combining science-based and experience-based learning under hybrid protection may generate tensions rather than complementarities. These frictions can reflect coordination costs, ambiguous signals to partners, or inherent trade-offs between openness and secrecy (Bello-Pintado et al., 2022). Innovation intensity increases, but the probability of product innovation is not enhanced, and the interaction term between STI and DUI becomes negative. While hybrid strategies are effective in mediating innovation performance, positively influencing both product innovation and novelty, they appear beneficial only up to a certain threshold. Beyond that point, in a context of low appropriability, the coexistence of STI and DUI modes under hybrid protection dilute the clarity of commitment signals, affecting collaboration and reducing efficiency. These patterns align with recent studies on institutional and organizational frictions in innovation systems (Santos et al., 2022; Friedrich and Kagel, 2025), emphasizing the conclusion that complementarities between modes are contingent rather than universal (Chaminade et al., 2009; Carrillo-Carrillo, and Alcalde-Heras, 2020).

All in all, the results of this study shows that the effectiveness of innovation modes is contingent on the appropriability strategies adopted and, partially, on the organizational

and institutional context in which they operate. The results reveal that the relationship between innovation modes and appropriability strategies is more complex than anticipated. DUI, rather than STI, drives the adoption of formal mechanisms. Informal mechanisms, in turn, act as key mediators, protecting knowledge while signaling trust and reciprocity, allowing both STI and DUI effects on innovation to materialize indirectly, even increasing novelty. Hybrid strategies appear beneficial by mediating positive outcomes for both product innovation and novelty, yet only up to a threshold. These findings confirm that appropriability strategies are not merely safeguards but relational tools that push the effectiveness of innovation modes, and that their benefits are conditioned by institutional and organizational contexts.

Furthermore, the results highlight the particularly contingent nature of innovation outcomes in developing economies, where institutional weaknesses, resource constraints, and organizational heterogeneity can alter expected complementarities between innovation modes and appropriability strategies. This context is critical to interpret some unexpected findings, for instance that DUI, rather than STI, drives the adoption of formal protection mechanisms; that informal IPPMs not only mediate innovation outcomes but also increase the degree of novelty; or that the joint use of STI and DUI under hybrid strategies generates frictions instead of complementarities. These results must be considered within the functioning of incomplete innovation system, that operate in a different manner that those described for developed countries, and foster new avenues for future research. In this regard, it is necessary new evidence to shed light whether the observed patterns are context-specific or if they hold across a broader range of institutional and economic settings, potentially providing insights into the universality or contingency of innovation strategies.

6. Concluding Remarks

This study provides new evidence on the differentiated roles of innovation modes (STI and DUI) and their interaction with IPPMs as determinants of product innovation performance. In addition to corroborating several relevant aspects found in previous literature, this study arrives at significant and unexpected results that contribute to the current debate on firms' innovation and appropriation strategies, emphasising the importance of analysing both together and their interactions.

The STI mode of innovation strongly fosters the adoption of informal IPPM and, under certain conditions, a combined formal-informal strategy, while DUI rather unexpectedly, explains the adoption of formal mechanisms. In contexts of intensive collaboration and tacit knowledge exchange, where opportunism is more likely, formal IPPMs serve not only to safeguard knowledge but also to signal credibility and commitment to partners. While STI mode directly affect innovation performance which is further reinforced when formal or hybrid IPPMs are in place, even in contexts characterized by weak institutional frameworks, such as developing countries. At the same time, STI exerts a strong direct effect on innovation performance, which is further reinforced when formal or hybrid IPPMs are in place.

In contrast, we observed that DUI oriented firms adopt formal, informal and hybrid IPPM, yet the effect of this mode on innovation outcomes only appears associated with formal IPPMs. It corroborates the relevance of experiential and interactive learning in the innovation process, but, also, highlight the necessary articulation with formal mechanisms to achieve successful innovation performance. DUI provide the basis for credible protection, while STI delivers the technological foundation for innovation, even under weak appropriability regimes.

Another relevant finding shows that when STI and DUI are combined in a more sophisticated strategy, the joint adoption of both innovation modes does not automatically enhances innovation outcomes. While both modes individually foster the use of hybrid protection strategies, their interaction produces negative effects, suggesting that combining science-based and experience-based learning under hybrid protection can generate tensions rather than complementarities. Instead, coordination challenges ambiguous signals to partners, or trade-offs between openness and secrecy, which is particularly important in low appropriability environments. As a result, although hybrid strategies can effectively mediate innovation performance and increase novelty, their benefits appear limited beyond a certain threshold, where the coexistence of STI and DUI dilutes the clarity of commitment signals and reduces collaborative efficiency.

From an academic perspective, these findings highlight the importance of integrating innovation modes with knowledge appropriability strategies in studies of innovation performance. This approach moves beyond linear models linking innovation modes directly to performance, highlighting the mediating role of protection strategies in

shaping both incremental and radical innovations. Moreover, complementarities between STI and DUI are contingent, as their interaction under hybrid protection can generate coordination challenges and strategic ambiguity, especially in low appropriability contexts. These insights highlight that the effectiveness of innovation strategies depends on the interaction between mode, protection, and organizational or institutional context, offering a clearer framework for understanding how firms maximize innovation outcomes. From a theoretical perspective, this study demonstrates that understanding innovation processes requires examining different theoretical perspectives. Innovation is inherently complex, involving the management of resources, leadership decisions, and organizational and institutional contexts. By linking innovation modes (STI and DUI) with knowledge appropriability strategies, our approach bridges the literature on organizational learning and innovation with theories of knowledge protection and capture. This integrative perspective highlights that the effectiveness of innovation strategies cannot be fully understood through isolated frameworks, as performance outcomes emerge from the interplay between learning modes, protection mechanisms, and the broader organizational environment.

For policymakers and practitioners, the results suggest that supporting formal protection mechanisms alone may be insufficient in contexts with prevalent DUI capabilities and weak institutions. Policies promoting R&D development, knowledge codification, and coordination capacities can enhance firms' ability to appropriate value from innovations. For managers, the study emphasizes the strategic importance of aligning innovation modes with appropriate protection strategies, integrating both formal and informal IPPMs. Moreover, effective leadership in collaborative innovation projects is critical, as managers must balance the pursuit of openness and knowledge sharing with the careful selection of protection mechanisms. Strong leadership can help the superation of coordination challenges, reduce strategic ambiguity, and ensure that appropriation strategies reinforce rather than hinder innovation outcomes. Future research could explore how these dynamics evolve across different industries, institutional contexts, and stages of firm maturity. Specifically, examining sectoral variations in the effectiveness of hybrid protection strategies, or the role of networked collaborations in mitigating the coordination challenges of combining STI and DUI, could yield deeper insights. Moreover, longitudinal studies in developing countries could investigate how improvements in institutional frameworks or firm capabilities alter the relationship

between innovation modes, IPP strategies, and innovation outcomes, addressing the limitations of cross-sectional or single-country analyses. Future studies could also investigate the role of managerial and project-level leadership in guiding the adoption of formal and informal protection mechanisms, exploring how leadership decisions interact with organizational learning processes. Additionally, research could examine the micro-foundations of complementarities and tensions between STI and DUI, such as how team composition, knowledge codification practices, and coordination mechanisms influence the effectiveness of hybrid strategies across different stages of the innovation process.

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Appendix

Table A1 –Model 5.1.2 - Marginal effects.

Formal IPPM Index	Explicative variables	dy/dx	std. err.	z	P>z
0	STI	0.032	0.041	0.770	0.442
	DUI	-0.112	0.040	-2.800	0.005***
1	STI	-0.031	0.040	-0.770	0.443
	DUI	0.110	0.039	2.800	0.005***
2	STI	-0.001	0.001	-0.730	0.467
	DUI	0.002	0.001	1.700	0.089*

Table A2 – Marginal effects.

	Explicative variables	dy/dx	std. err.	z	P>z
Model 6.2.1					
I_Prod = 1	STI	1.844	0.178	10.370	0.000***
	DUI	0.780	0.252	3.090	0.002***
	FormalIPPM_Predict	0.268	0.132	2.030	0.043**
Model 6.2.2					
Novelty = 0	STI	-0.389	0.032	-12.270	0.000***
	DUI	-0.134	0.047	-2.840	0.005***
	FormalIPPM_Predict	-0.076	0.025	-3.050	0.002***
Novelty = 1	STI	0.065	0.008	7.910	0.000***
	DUI	0.022	0.008	2.740	0.006***
	FormalIPPM_Predict	0.013	0.004	2.960	0.003***
Novelty = 2	STI	0.257	0.022	11.580	0.000***
	DUI	0.088	0.031	2.830	0.005***
	FormalIPPM_Predict	0.050	0.016	3.030	0.002***
Novelty = 3	STI	0.067	0.007	9.260	0.000***
	DUI	0.023	0.008	2.780	0.006***
	FormalIPPM_Predict	0.013	0.004	2.970	0.003***

Table A3. Model 5.2.2 - Marginal effects.

Informal IPPM Index	Explicative variables	dy/dx	std. err.	z	P>z
0	STI	-0.263	0.038	-6.910	0.000***
	DUI	-0.334	0.041	-8.070	0.000***
1	STI	0.138	0.021	6.470	0.000***
	DUI	0.174	0.024	7.360	0.000***
2	STI	0.103	0.016	6.560	0.000***
	DUI	0.131	0.017	7.510	0.000***
3	STI	0.022	0.004	4.980	0.000***
	DUI	0.028	0.005	5.490	0.000***

Table A4 - Marginal effects.

	Explicative variables	dy/dx	std. err.	z	P>z
Model 6.3.1					
I_Prod = 1	STI	0.771	0.520	1.480	0.138
	DUI	-0.114	0.649	-0.170	0.861
	InFormalIPPM_Predict	0.709	0.349	2.030	0.043**
Model 6.3.2					
Novelty = 0	STI	-0.086	0.097	-0.890	0.375
	DUI	0.119	0.122	0.970	0.331
	InFormalIPPM_Predict	-0.200	0.066	-3.040	0.002***
Novelty = 1	STI	0.015	0.017	0.890	0.373
	DUI	-0.021	0.022	-0.960	0.338
	InFormalIPPM_Predict	0.035	0.012	2.850	0.004***
Novelty = 2	STI	0.057	0.064	0.890	0.376
	DUI	-0.078	0.080	-0.970	0.331
	InFormalIPPM_Predict	0.131	0.043	3.040	0.002***
Novelty = 3	STI	0.015	0.017	0.880	0.379
	DUI	-0.020	0.021	-0.980	0.329
	InFormalIPPM_Predict	0.034	0.011	3.030	0.002***

Table A5. Model 5.3.2 – Marginal effects.

Both IPPM Index	Explicative variables	dy/dx	std. err.	z	P>z
0	STI	-0.315	0.037	-8.480	0.000***
	DUI	-0.355	0.039	-9.010	0.000***
1	STI	0.117	0.016	7.460	0.000***
	DUI	0.132	0.017	7.810	0.000***
2	STI	0.171	0.021	8.090	0.000***
	DUI	0.192	0.023	8.480	0.000***
3	STI	0.028	0.005	5.600	0.000***
	DUI	0.031	0.005	5.870	0.000***

Table A6 – Marginal effects.

	Explicative variables	dy/dx	std. err.	z	P>z
Model 6.4.1					
I_Prod = 1	STI	1.244	0.310	4.010	0.000***
	DUI	0.557	0.342	1.630	0.103
	BothIPPM_Predict	0.263	0.130	2.030	0.043**
Model 6.4.2					
Novelty = 0	STI	-0.220	0.058	-3.820	0.000***
	DUI	-0.071	0.064	-1.100	0.270
	BothIPPM_Predict	-0.074	0.024	-3.040	0.002***
Novelty = 1	STI	0.039	0.010	3.730	0.000***
	DUI	0.012	0.011	1.110	0.266
	BothIPPM_Predict	0.013	0.005	2.830	0.005***
Novelty = 2	STI	0.144	0.038	3.780	0.000***
	DUI	0.046	0.042	1.100	0.271
	BothIPPM_Predict	0.049	0.016	3.050	0.002***
Novelty = 3	STI	0.037	0.010	3.610	0.000***
	DUI	0.012	0.011	1.090	0.275
	BothIPPM_Predict	0.013	0.004	3.040	0.002***

Table A7: Descriptive statistics and correlations matrix.

	I_Prod	Novelty	STI	DUI	Formal IPPM index	Informal IPPM index	Both IPMM index	R&D_d)	Size	Expor	FDI	Age	Year	Pub_Supp
I_Prod	1.000													
Novelty	0.881	1.000												
STI	0.335	0.355	1.000											
DUI	0.258	0.290	0.374	1.000										
Formal IPPM index	0.352	0.416	0.336	0.332	1.000									
Informal IPPM index	0.381	0.471	0.400	0.355	0.826	1.000								
Both IPMM index	0.388	0.470	0.390	0.369	0.897	0.969	1.000							
R&D_d)	0.277	0.299	0.525	0.318	0.306	0.335	0.329	1.000						
Size	0.067	0.085	0.191	0.176	0.147	0.149	0.151	0.150	1.000					
Expor	0.056	0.127	0.134	0.076	0.143	0.144	0.144	0.211	0.113	1.000				
FDI	0.042	0.077	0.071	0.025	0.125	0.116	0.120	0.070	0.198	0.313	1.000			
Age	0.049	0.050	0.090	0.063	0.060	0.051	0.050	0.073	0.281	-0.045	-0.043	1.000		
Year	-0.041	-0.029	0.083	-0.029	0.034	0.015	0.012	0.018	-0.002	0.027	-0.006	0.124	1.000	
Pub_Supp	0.128	0.145	0.159	0.178	0.179	0.218	0.209	0.156	0.116	0.069	0.024	0.080	-0.111	1.000