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Agglomeration Externalities in National Systems of Innovation: The Role of Industrial Diversity and Competition on Countries' Innovative Levels

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Abstract

Economic geographers, industrial economists and innovation scholars have long debated the impact of agglomeration externalities on innovation, often with conflicting results. We argue that rather than focusing on which agglomeration externality most influences innovation, we should gain a deeper understanding of how agglomeration externalities influence innovation. Drawing on the concept of national systems of innovation (NSI), we examine the role of industrial diversity and domestic competition as contingency factors that affect the relationship between national innovation inputs and outputs. Using secondary data from 86 countries, we developed interaction models, and our findings indicate that industrial diversity positively influences the relationship between innovation inputs and outputs. Additionally, we found that the relationship between innovation inputs and outputs is strengthened at higher levels of diversity and competition. Also, the positive effects of institutions on innovation outputs increase with high industrial diversity and medium to high domestic competition. Similarly, the positive marginal effect of human capital and research on innovation outputs is strengthened by increasing industrial diversity, although a medium-low level of competition can undermine this effect. This study contributes to the ongoing debate on agglomeration externalities and the NSI literature by highlighting the role of industrial diversity and competition in shaping national innovation outcomes.

Plain language summary

Economic geographers and industrial economists have long been studying the effect of agglomeration externalities (that is, industrial specialisation, diversity and competition) on innovation, albeit with conflicting findings. We argue that rather than asking whether specialising in a given industry, promoting industrial diversity or increasing competition matters most for innovation, we should be answering how they influence innovation. Drawing on national systems of innovation (NSI) literature, we examine the role of industrial diversity and competition on the relationship between national innovation inputs and innovation outputs in 86 countries. Our findings show that the relationship between innovation inputs and outputs is contingent on the level of industrial diversity, with higher levels of industrial diversity leading to a stronger relationship. Moreover, the relationship between innovation inputs and outputs is also contingent on the levels of competition, such that innovation inputs are more effectively converted into innovation outputs in countries with higher industrial diversity and, for most innovation inputs, higher competition. This study contributes to

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reconcile agglomeration externalities discussion with NSI literature, by proposing a previously unexplored role of industrial diversity and competition in countries innovation.

Keywords
agglomeration externalities, competition, industrial diversity, moderation analysis, national systems of innovation

Introduction

The impact of the countries' industrial structure on their capacity to innovate has received considerable attention in economic geography (Bathelt & Storper, 2023; Caragliu et al., 2016), industrial economics (H. L. F. de Groot et al., 2016) and innovation studies (Audretsch & Belitski, 2022; Beaudry & Schiffauerova, 2009). Some countries may be specialized in a given industry (e.g., oil-producing countries), benefiting from specialization of knowledge and intra-industry spillovers that increase innovation potential (Aarstad & Kvitastein, 2020). In contrast, other countries may have more diversified industrial structures, where a cross-sectoral knowledge exchange of ideas between firms in different industries foster innovation. However, the relationship between industrial diversity and the level of innovation is still unclear (Bathelt & Storper, 2023; Beaudry & Schiffauerova, 2009; H. L. F. de Groot et al., 2016).

The influence of industry structure on the countries' innovation capacity has been examined under three types of agglomeration externalities (H. L. F. de Groot et al., 2016). First, Marshall-Arrow-Romer (MAR) externalities suggest that specialization in a single industry promotes innovation by facilitating the intra-industry transmission of knowledge through the restriction of the flow of ideas to other industries so that the innovator can internalize the agglomeration externalities (Glaeser et al., 1992). Second, Jacobs (1969) externalities posit that industry diversity drives innovation by increasing opportunities for knowledge recombination, leading to inter-industry externalities. Glaeser et al. (1992) identified that inter-industry externalities are more likely to occur than intra-industry externalities, highlighting the role of industrial diversity in fostering innovation. Third, Porter (1990) posited that competition favors knowledge transmission, as firms must innovate to survive and be competitive.

The concept of industrial diversity has recently been redefined following the work of Frenken et al. (2007), who proposed that industry diversity should be decomposed in related and unrelated variety. Related variety refers to a diversified industrial structure where industries are closely related, whereas unrelated variety involves a more heterogenous, unrelated industrial structure. Some scholars have argued that related variety fosters innovation by facilitating knowledge spillovers between closely related industries (Tavassoli & Carbonara, 2014). Empirical studies have supported this perspective (Howell et al., 2023; Tavassoli & Carbonara, 2014; Yang et al., 2020). However, unrelated variety has also been shown to promote innovation, particularly radical innovation (Castaldi et al., 2015; Innocenti et al., 2022; Miguelez & Moreno, 2018; Solheim et al., 2020). In contrast, other studies have found that industrial specialization, rather that diversity, has a more beneficial effect on innovation (Castellano et al., 2023; Galliano et al., 2023; Yang & Liu, 2023). These results highlight the debate in the literature regarding the role of industry diversity versus specialization in driving innovation.

Scholars acknowledge, however, that efforts devoted to innovation are more critical for driving innovation than the existing industrial structure (Ejdemo & Örtqvist, 2020; Hervas-Oliver et al., 2022; Mascarini et al., 2023; Solheim et al., 2020). For instance, Hervas-Oliver et al. (2022) found that the internal capabilities of Spanish firms had a more important role in driving radical innovation than industry specialization. Similarly,Mascarini et al. (2023), analyzing an emerging country, found that knowledge spillovers from R&D investments were more likely to lead to breakthrough innovations than related or unrelated variety. These findings have led innovation scholars to consider a possible moderating effect of industry structure on the relationship between innovation inputs and outputs (Ejdemo & Örtqvist, 2020; Solheim et al., 2020). This perspective is in line with the national systems of innovation (NSI) approach, which notes that innovation results from interactions between actors within the innovation system, existing institutions and systems of production (Edquist, 2019; Lundvall, 2007). Nonetheless, the role of competition is often overlooked in these analyses (Kim et al., 2022).

To bridge these gaps, we analyze how industrial diversity and competition interact with innovation inputs to influence countries' innovation levels. That is, we analyze how the countries' extent of industrial diversity and the level of domestic competition act as contingency factors on their ability to convert innovation inputs into innovation outputs. We argue that countries that have a more diverse industrial structure and a higher level of domestic competition are more effective in converting innovation inputs into innovation outputs. Moreover, we developed an interaction model where industrial diversity shapes the conversion of innovation inputs into outputs and another assuming that the previous is conditional on the level of domestic competition. The hypotheses were tested using multivariate regression and marginal effect analyses for a sample of 86 countries.

This study contributes to the debate on the impact of agglomeration externalities on innovation by providing empirical evidence on the conditional role played by industrial diversity and competition on the relationship between innovation inputs and outputs. Thus, we extend the traditional "direct effect" perspective to help explain the inconsistent results in previous research. We also contribute to reconciling the discussion on agglomeration externalities with the literature on NSI. The evidence showing how conditional factors affect the conversion of innovation inputs into innovation outputs revealed that a country' industrial composition and its levels of domestic competition are key factors in the interaction among the various actors of NSI.

The remainder of this paper is structured as follows. In the next section, we draw on the literature on NSI and agglomeration externalities to develop our hypotheses. Then, we present the methodology, including sample, data and procedures. The fourth section shows the results, which are followed by a broad discussion and the conclusion.

Theoretical Background and Hypotheses

Innovation is defined as "a new or improved product or process (or a combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (OECD/Eurostat, 2018, p. 20). While firms are the primary generators of innovation, they are embedded in their country' NSI, where institutional conditions such as infrastructure and support activities play a crucial role in promoting innovation activities and generating national innovation outputs (Edquist, 2006; Lundvall, 2007). We define national innovation outputs as the immediate outcomes of the NSI, including the creation, diffusion and use of knowledge, technology and creativity.

Empirical research has demonstrated the impacts of innovation inputs on innovation outputs. For instance, studies have shown that the quality of institutions (Peiró-Palomino & Perugini, 2022; Rodríguez-Pose & Zhang, 2020) and countries' infrastructures (Fang et al., 2024) are important determinants of innovation. Other studies, focusing on the creation and diffusion of knowledge, have shown how human capital (Sun et al., 2020) and research (Audretsch & Belitski, 2022) influenced innovation outputs. Similarly, the sophistication of financial markets (Edquist, 2019) and businesses (Gkypali et al., 2018) have also been identified as fundamental for promoting innovation.

These determinants, or innovation inputs, are in close proximity with the determinants of NSI, which are defined as "all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion, and use of innovations" (Edquist, 2006, p. 182). The rationale for how innovation inputs affect innovation outputs is straightforward: a higher investment in these factors is likely to enhance the development, diffusion and application of innovations. Hence, we propose the following hypothesis:

> **Hypothesis 1**: Countries' innovation inputs are positively related to innovation outputs.

Industrial Diversity and Innovation

There is some consensus on the importance of industrial diversity for innovation (H. de Groot et al., 2009; H. L. F. de Groot et al., 2016), but the specific ways in which industrial diversity influences innovation remains debated (Bathelt & Storper, 2023; H. L. F. de Groot et al., 2016). Three theoretical approaches from the literature on economic geography and industrial economics can be taken. First, the Marshall-Arrow-Romer (MAR) approach (Glaeser et al., 1992), which argues that externalities are more relevant for firms within the same industry, emphasizing intra-industry externalities that favor innovation in more specialized economies. Second, based on Jacobs (1969) argument, suggest that diverse economic activities stimulate knowledge recombination by facilitating the exchange of ideas between firms in different lines of activity, highlighting the effects of inter-industry externalities to enhance innovation. The third approach, from Porter (1990) competitive advantage of nations, asserts that competition, rather than monopoly, is the main driver of knowledge externalities, thus spurring innovation.

Although the competition hypothesis for innovation can hold for both specialized and diversified economies, the MAR and Jacobs approaches are mutually exclusive. Empirical evidence has not yet provided a definite answer as to whether industry specialization or diversity is more conducive to innovation. For instance, Castellano et al. (2023) found that industrial specialization plays a more decisive role in innovation than diversification, with the effect being strengthened by the interaction with territorial skill complementarity. Similarly, Galliano et al. (2023) found that industrial specialization had a positive effect on eco-innovation engagement and breadth, while industry variety, particularly unrelated variety, had a negative effect. However, opposing evidence also exists, and

Innocenti et al. (2022) and Miguelez and Moreno (2018) highlighted a positive role of industrial diversity on innovation–specifically that related variety enhances overall innovation, while unrelated variety improved radical or breakthrough innovations.

Albeit the conflicting findings, some scholars argue that prior knowledge and efforts devoted to innovation are more important to innovation outputs than the industrial structure per se (Ejdemo & Örtqvist, 2020; Mascarini et al., 2023). It has been shown that interactions between territorial skills (Castellano et al., 2023) and expenditures on R&D (Mascarini et al., 2023) with industrial structure improves innovation. Following our initial proposition that "investments" in innovation inputs are expected to lead to innovation outputs, the industrial structure of a country is likely to have a moderating role–specifically, that higher industrial diversity is likely to facilitate the transformation of innovation inputs into innovation outputs. The rationale for industrial diversity to moderate this relationship is that countries with a more diverse business ecosystem, or industrial diversity, are better capable of transforming innovation inputs into outputs due a broader pool of different know-how, business models and experiences. Stated differently, since increased industrial diversity can favor inter-industry externalities by enlarging the knowledge pool leading to novel combinations and recombination of ideas, we expect that higher levels of industrial diversity amplify the transformation of innovation inputs into outputs. We propose the following:

> **Hypothesis 2:** A higher industrial diversity will strengthen the positive relation between innovation inputs and innovation outputs.

Competition, Industrial Diversity and Innovation

Competition is relatively less studied than industrial specialization or diversity in the fields of economic geography, industrial economics and innovation studies (H. L. F. de Groot et al., 2016; Kim et al., 2022). Regarding the effects of competition on innovation, a meta-analysis by H. L. F. de Groot et al. (2016) failed to find a consistent evidence of a direct link. However, they also report that unpublished papers were more likely to show a positive effect of competition than published studies, possibly suggesting a potential publication bias. Recent research, however, indicates that increased competition can drive higher investment in R&D (Li & Jian, 2023) and new firm creation (Kim et al., 2022). This effect may arise because strong competition exerts pressure on firms to innovate to enhance their competitive advantages (Combes, 2000; Li & Jian, 2023; Porter, 1990), ultimately contributing to higher levels of national innovation (Furman et al., 2002).

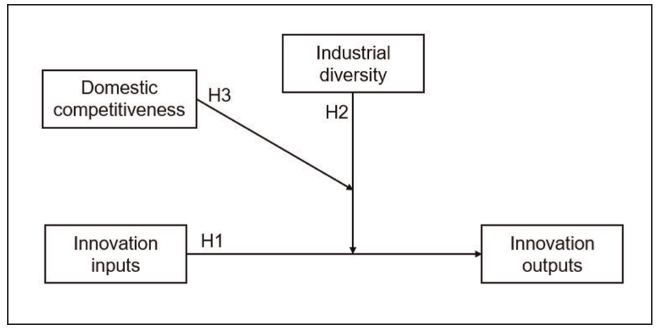

Figure 1. Hypotheses.

Firms in highly specialized countries may experience the negative effects from increased competition, such as price wars, which can undermine entire industries competing for the same customer base (Audretsch & Belitski, 2022). In contrast, firms in highly diversified countries may benefit from increased competition, as firms compete for different customer segments, leading to improvements in their products and processes. Thus, we argue that countries with higher industrial diversity and strong domestic competition have a greater incentive to invest in innovation inputs, which in turn leads to higher innovation outputs. That is, we suggest that the moderating role of industrial diversity on the relationship between innovation inputs and outputs is contingent on the level of domestic competition. This implies a three-way interaction between innovation inputs, industrial diversity and competition in explaining variation in the level of national innovation outputs. Our hypothesis thus proposes:

> **Hypothesis 3**: The higher the domestic competition, the stronger the amplifying effect of industrial diversity will be on the relationship between innovation inputs and outputs.

Figure 1 shows how the concepts relate and graphically depict our hypotheses.

Method

The national systems of innovation (NSI) approach suggests that innovation results from a complex interaction among various actors and institutions within national borders. However, the complexity and multidimensionality associated with the NSI have sustained significant challenges to scholars, making empirical operationalization difficult (Edquist, 2006, 2019). Cirillo et al. (2019) noted two main reasons for the challenge. First, capturing a detailed and quantified perspective of the countries' institutional setting is difficult. Albeit some characteristics and dimensions of NSIs—for example, R&D expenditure, education levels and so forth—can be reasonably quantified, others, such as policies or institutional linkages, cultural phenomena and so forth, are less amenable to quantification. Second, measuring innovation processes is difficult, and relying on the usual indicators, such as patents or R&D expenditures, provide only a partial view of the innovation system (Smith, 2006). To overcome these challenges, scholars in the NSI literature have relied on composite indicators to empirically examine and compare national systems of innovation, developing various analytical frameworks, such as the ArCo indicator (Archibugi & Coco, 2004) or the national innovative capacity indicator (Furman et al., 2002).

Data and Sample

To test the hypotheses, we have collected the most recently available country-level data from multiple secondary sources: Global Innovation Index (GII) 2021 (WIPO, 2021), International Labor Organization (ILO) statistics on the population and labor force and the Global Competitiveness Report (GCR; Schwab, 2019).

A total of 86 countries were included in the analyses, which resulted from the intersection of all databases, representing about 56% of the world's population and 71% of the world's GDP (World Bank). Regarding reference years, both the ILO labor force statistics and the GCR refer to 2019 values. The reference years of the GII's indicators were more diverse, ranging from 2017 to 2020. Nevertheless, most indicators refer to 2019 (37 out of 81 indicators). The countries in the sample were: Albania, Argentina, Armenia, Australia, Austria, Azerbaijan, Belgium, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Chile, Costa Rica, Cote d'Ivoire, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, Estonia, Finland, France, Georgia, Germany, Greece, Guatemala, Honduras, Hungary, Iceland, India, Iran, Ireland, Italy, Jamaica, Japan, Jordan, Kenya, Kyrgyzstan, Latvia, Lebanon, Lithuania, Luxembourg, Malaysia, Malta, Mauritius, Mexico, Moldova, Mongolia, Netherlands, Nigeria, North Macedonia, Norway, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Qatar, Republic of Korea, Romania, Russian Federation, Rwanda, Senegal, Singapore, Slovakia, Slovenia, Spain, Sri Lanka, Sweden, Switzerland, Thailand, Trinidad and Tobago, Turkey, United Arab Emirates, UK, USA, Uruguay, Vietnam, Zambia, and Zimbabwe.

Variables

Our dependent variable is innovation outputs, which represents the overall level of innovation outputs of a country. Data was collected from the GII's innovation outputs sub-index and reflects the average of two innovation output pillars: knowledge and technology outputs and creative outputs. The innovation output sub-index scores ranged from 0 to 100 where higher scores mean higher innovation outputs (WIPO, 2021).

Various indices and scoreboards measuring innovation could have been used, but the GII has several advantages. First, it includes a larger number of countries (close to 130 in every yearly report). Second, its structure allows for the differentiation between innovation inputs and outputs. Third, in addition to hard data and composite indicators, it includes questionnaire items from the Executive Opinion Survey (World Economic Forum). Fourth, its input structure is in close proximity to the elements that define NSI (Alcorta & Peres, 1998).

Our independent variable is innovation inputs, referring to the enablers of innovation in a country, which we measured using the GII's innovation input sub-index. Scores ranged from 0 to 100, where a higher value means a better achievement. To deepen our analyses, we disaggregate the inputs sub-index into its five pillars (WIPO, 2021): the institutions pillar captures countries' institutional settings, including political, regulatory and business environments; the human capital and research pillar reflects countries' investment in education and research and development; the infrastructure pillar captures national investments in general infrastructure, information and communication technologies and ecologically sustainable development; the market sophistication pillar gauges countries' level of market development, measuring credit, investment and market scale; and the business sophistication pillar captures the readiness of businesses to innovate, including innovation linkages, knowledge workers and knowledge absorption.

We measured industrial diversity at the national level as the shares of employees in each industry in a country. To assess this variable, we drew from Frenken et al. (2007) notion of unrelated variety at the national level using the two-digit ISIC codes and computed industrial diversity using Shannon's diversity index with International Standard Industrial Classification (ISIC) Rev.4 codes at the national level. We define industrial diversity according to Equation 1.

$$Diversity = \sum_{k=1}^{n} P_{kc} log_2 \left(\frac{1}{P_{kc}} \right) \quad (1)$$

Where Pkc is the share of employees in class k (two-digit ISIC code) in country c. This implies that, for instance, a country where all employees work in the same industry will have a diversity value of 0, while a country with an equal number of employees across all industries will have a diversity value of ≈ 4.5. This measure

Table 1. Variables and Data Sources.

Dependent variable	Description	Source of data
Innovation outputs	Measures knowledge and technology outputs (including knowledge creation, impact and diffusion) and creative outputs (including countries' intangible assets, creative goods and services and online creativity). Range: 0 to 100.	GII 2021
Independent variables		
Innovation inputs	Aggregate index of the five input pillars (*institutions*, *human capital and research*, *infrastructure*, *market sophistication* and *business sophistication*). Range: 0 to 100.	GII 2021
Institutions	Captures countries' institutional settings, including political, regulatory and business environments. Range: 0 to 100.	GII 2021
Human capital and research	Reflects countries' investment in education and research and development. Range: 0 to 100.	GII 2021
Infrastructure	Captures national investments in general infrastructure, information and communication technologies and ecologically sustainable development. Range: 0 to 100.	GII 2021
Market sophistication	Gauges countries' level of market development, measuring credit, investment and market scale. Range: 0 to 100.	GII 2021
Business sophistication	Captures the readiness of businesses to innovate, including innovation linkages, knowledge workers and knowledge absorption. Range: 0 to 100.	GII 2021
Industrial diversity	Entropy measure of the shares of employees in all two-digit industries (ISIC Rev.4, values for 2019). Range: 0 to 4.459.	ILOSTAT
Domestic competition	Measures the extent to which competition is distorted. Range: 0 to 100.	(Schwab (2019)

captures two features of diversity, richness and evenness, in such a manner that the larger the number of industries in a country and the more evenly distributed the employment across those industries, the higher the country's industrial diversity (see Simonen et al., 2015).

Domestic competition was measured using the domestic competition index from the GCR 2019. This construct reflects the extent to which domestic competition is distorted (Sala-i-Martin et al., 2011). The domestic competition index ranges from 0 to 100 and its items, which are based on the World Economic Forum's Executive Opinion Survey, include: (i) distortive effects of taxes and subsidies on competition, (ii) extent of market dominance and (iii) competition in services. In essence, higher scores reflect a higher domestic competition.

Table 1 includes a description of the variables.

Estimation Method

Estimations were obtained through ordinary least squares with heteroskedasticity-corrected standard errors (White, 1980), and independent and moderating variables were standardized to avoid excess multicollinearity. The main effects were estimated with Equation 2.

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{2}$$

Where Y is innovation outputs, X is the independent variable and ε is the error term. Independent variables used in each model were the innovation input sub-index and each of the five GII's input pillars.

Interactions with industrial diversity were estimated using the regression model of Equation 3.

$$Y = \beta_0 + \beta_1 X + \beta_2 Z + \beta_3 XZ + \varepsilon \tag{3}$$

Where Z is the moderating variable (i.e., industrial diversity) and the marginal effect of X on Y was calculated with Equation 4.

$$\frac{\partial Y}{\partial X} = \beta_1 + \beta_3 Z \tag{4}$$

To calculate Johnson and Neyman (1936) plots of marginal effects with 95% confidence intervals, we also calculated the variance of its estimation as in Equation 5.

$$\hat{\sigma}^2_{\frac{\partial Y}{\partial X}} = \text{var}(\hat{\beta}_1) + Z^2 var(\hat{\beta}_3) + 2Zcov(\hat{\beta}_1\hat{\beta}_3) \tag{5}$$

Lastly, the three-way interaction with industrial diversity and competition was estimated with the regression model of Equation 6.

$$Y = \beta_0 + \beta_1 X + \beta_2 Z + \beta_3 W + \beta_4 XZ + \beta_5 XW + \beta_6 ZW + \beta_7 XZW + \varepsilon \tag{6}$$

Where W is the variable competition, and marginal effects were calculated using Equation 7.

$$\frac{\partial Y}{\partial X} = \beta_1 + \beta_4 Z + \beta_5 W + \beta_7 ZW \tag{7}$$

Table 2. Descriptives and Correlation Matrix.

Variables	Mean	S.D.	Min	Max	VIF	1	2	3	4
1. Innovation outputs	28.94	13.03	9.25	62.05					
2. Innovation inputs	46.84	11.60	29.98	70.04	3.22	0.92			
3. Industrial diversity	3.53	0.37	2.25	3.96	1.78	0.59	0.64		
4. Domestic competition	55.31	8.99	38.16	73.75	2.15	0.68	0.71	0.34	

Note. N = 86. All correlations have a *p*-value below .05.

Table 3. OLS Results for Main Effects and Interaction.

	Model 1			Model 2			Model 3		
	Coeff	S.E.	p	Coeff	S.E.	p	Coeff	S.E.	p
Constant	28.943	0.563	.000	28.058	0.782	.000	28.175	1.139	.000
Innovation inputs	11.979	0.578	.000	11.251	0.727	.000	10.867	1.239	.000
Ind. diversity				1.317	0.968	.177	0.601	1.444	.678
Competition							0.256	1.037	.806
Innovation inputs × Ind. diversity				1.401	0.762	.070	1.244	1.467	.399
Innovation inputs × Competition							−0.298	0.973	.760
Ind. diversity × Competition							0.483	1.494	.284
Innovation inputs × Ind. diversity × Competition							0.985	0.960	.308
n	86			86			86		
Adj. R^2	0.843			0.846			0.843		
F-stat	429.578			163.340			65.807		

Note. Dependent variable: Innovation outputs.

And variance was calculated using Equation 8.

$$\hat{\sigma}^2_{\frac{\partial Y}{\partial X}} = \mathrm{var}(\hat{\beta}_1) + Z^2 var(\hat{\beta}_4) + W^2 var(\hat{\beta}_5) + Z^2W^2 var(\hat{\beta}_7) + 2Zcov(\hat{\beta}_1\hat{\beta}_4) + 2Wcov(\hat{\beta}_1\hat{\beta}_5) + 2ZWcov(\hat{\beta}_1\hat{\beta}_7) + 2ZWcov(\hat{\beta}_4\hat{\beta}_5) + 2WZ^2cov(\hat{\beta}_4\hat{\beta}_7) + 2ZW^2cov(\hat{\beta}_5\hat{\beta}_7) \quad (8)$$

This allowed us to plot the marginal effects of predictor variables along the range of values of the moderator instead of relying exclusively on the significance of the interaction term (Kingsley et al., 2017). Thus, moderation claims are made only if marginal effects are significant for any value of the moderator.

Concerns of endogeneity could arise regarding the competition variable, W in Equation 6. We assessed it for its potential to be an endogenous regressor using Wooldridge (2016) procedure. Namely, we regressed competition on all independent regressors, plus income per capita and trade openness, and saved the residuals. We then included the saved variable in Equation 6 and tested for its significance with a t-test using heteroskedasticity-corrected standard errors. Since it did not attain statistical significance ($p = .487$), we conclude that competition is not correlated with ε and is not a problematic endogenous regressor (Wooldridge, 2016).

Results

Table 2 shows the descriptive statistics and correlation matrix, and reveals that variance inflation factors (VIF) were below the threshold of 10 (Aiken & West, 1991).

Table 3 shows the regressions' results of the innovation input-output relationship, and the moderating effects of industrial diversity and domestic competition. In the table, we observe that the *F*-test for all models is statistically significant and that the adjusted R^2 were higher than .8 in all models, revealing a good explanatory power of the predictor variables. Model 1 tests the main effects, revealing a positive and statistically significant relationship between innovation inputs and outputs ($\beta = 11.979$, $p < .001$). That is, we found support for Hypothesis 1, and the positive relationship between innovation inputs and outputs.

Model 2 introduces the interaction between innovation inputs with industrial diversity. The coefficient is positive as predicted but does not reach statistical significance ($p = .07$). To better understand this effect, and avoid underestimating the moderating effect of industrial diversity on the relationship between innovation inputs and outputs (Kingsley et al., 2017), we analyzed the marginal effects using Jonhson and Neyman (JN) plots. Figure 2 shows the marginal effects of innovation inputs

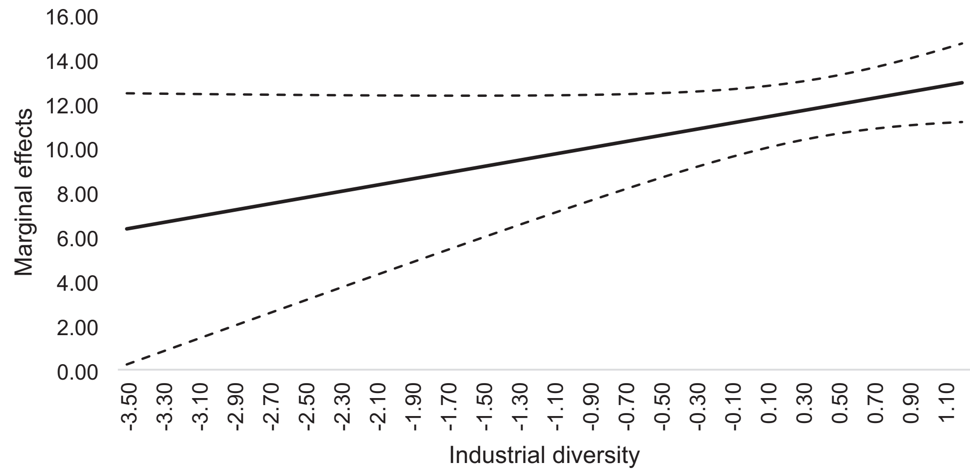

Figure 2. Marginal effects of innovation inputs on outputs, moderated by diversity.

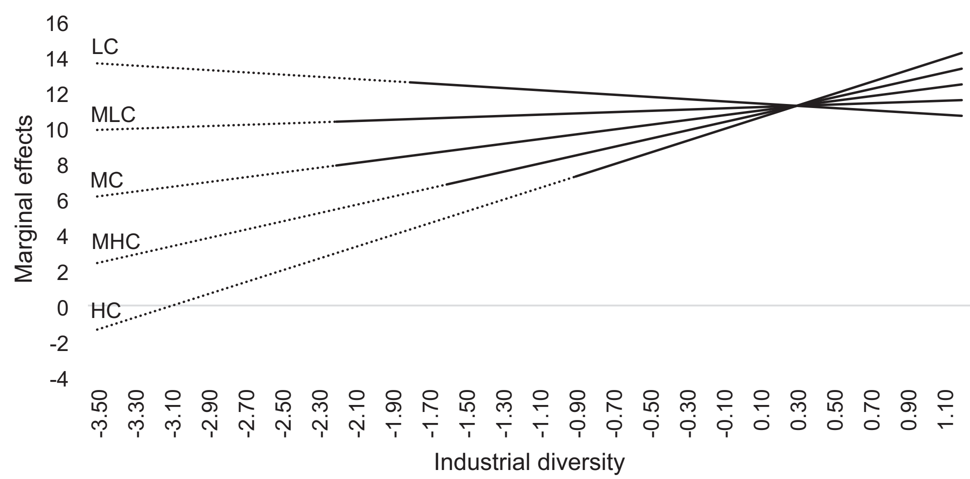

Figure 3. Marginal effects of innovation inputs on outputs, moderated by diversity and competition.
Note. Full segments indicate significance at 0.05 level. LC = low competition; MLC = medium-low competition; MC = medium competition; MHC = medium-high competition; HC = high competition.

on innovation outputs across the range of diversity values in the sample. The results show that the marginal effects are positive and statistically significant at the 95% confidence level for all levels of industrial diversity, and they increase as industrial diversity increases. Hence, we find support for Hypothesis 2.

In Model 3, we tested Hypothesis 3, proposing a three-way interaction between innovation inputs, industrial diversity and competition, that predicts that this interaction is positive—that is, the positive relationship between innovation inputs and outputs is strengthened when industrial diversity and competition increase. The coefficient for the interaction was positive, albeit not significant. To further explore this effect, we plotted the marginal effects across the range of industrial diversity values and five equidistant competition points within the range of the sample (i.e., low, medium-low, medium, medium-high and high competition; Figure 3). The results show that the marginal effects of innovation inputs on outputs were significant for some values of industrial diversity across all five levels of competition. Furthermore, the marginal effects were significant for a range of industrial diversity values and become more positive with increasing competition, supporting Hypothesis 3. Interestingly, although we found a positive marginal effect, we also noted that at low levels of

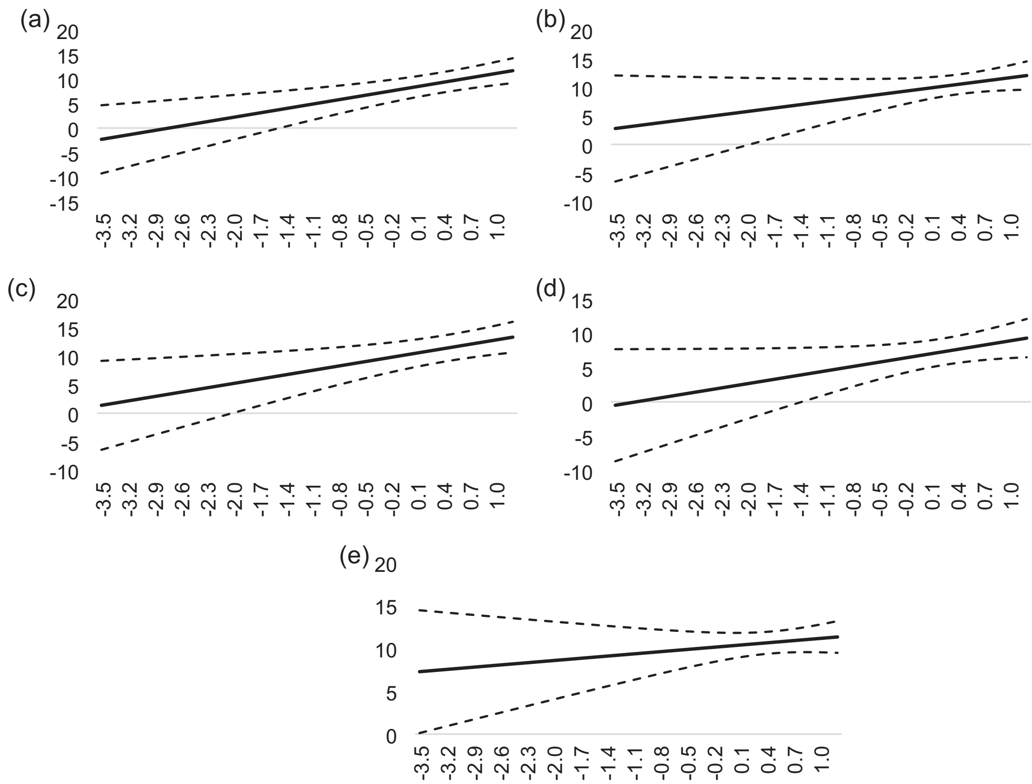

Figure 4. Marginal effects of innovation input pillars on outputs, moderated by diversity: (a) institutions, (b) human capital and research, (c) infrastructure, (d) market sophistication, and (e) business sophistication

Note. The Y axis is the magnitude of marginal effects. The X axis is the values of Industrial diversity. Industrial diversity values reflect the standardization procedure

competition, industrial diversity dampens the relationship between innovation inputs and innovation outputs. Examples may be observed for such countries as Bolivia and Mongolia, that have the lowest domestic competition. These results seem to support a non-linear role of competition in innovation, which is consistent with previous studies by Aghion et al. (2005) and Arvanitis et al. (2020), which proposed an inverted-U relationship. This inverted U shape signifies that medium levels of competition are the most beneficial to innovation. Nonetheless, our results indicate that higher levels of competition increase the effect of industrial diversity on the conversion of innovation inputs into outputs, particularly in medium to high levels of industrial diversity.

Post Hoc Analyses

We further our analyses by decomposing innovation inputs into its five input pillars. Tables A.1 to A.5, in the Appendix, show the regressions' results for each input pillar. Model 1 in each table refers to Equation 2. The main effects indicate a positive and statistically significant relationship ($p < .001$) between each innovation input pillar and innovation outputs. Model 2 in the tables refers to Equation 3 and only the interaction of institutions and infrastructure with industrial diversity showed a statistically significant relationship. Nonetheless, Figure 4 shows that the marginal effects of each of the innovation input pillars increase when diversity increases, being significant at medium to high levels of industrial diversity, except for business sophistication where the positive moderating effect is significant for the complete range of industrial diversity values. Hence, results provide further evidence of the Jacobs externalities hypothesis, which argues that higher diversity favors innovation. This could, however, be easily overlooked if we only paid attention to the coefficients of the interaction terms.

Nevertheless, we realized that the moderation effect only exists when relatively high levels of industrial diversity are present. That is, less diversified economies do not benefit from the contribution of Jacobs' externalities to transform innovation inputs into actual outputs, which is more evident in the case of institutions, human capital and research, infrastructure and market sophistication. These findings further support Hypothesis 1, yet, those related to human capital and research (Figure 4—panel b) partially contradict the results of Solheim et al. (2020), who found that interactions between unrelated variety and firms' R&D investment to predict innovation were only significant at low to moderate levels of variety when firms did not engage in R&D.

Moreover, almost all countries are able to fully appropriate Jacobs' externalities in converting business sophistication into innovation outputs, regardless of diversity levels (Figure 4—panel e). This suggests that a country's business sophistication is a core driver of innovation, a finding in line with Hervas-Oliver et al. (2022), who concluded that firms' capabilities were more important for innovation than any agglomeration effects. Two possible explanations could be made for this finding. On the one hand, since firms are the main innovators within an economy, a sophisticated business environment is likely to be conducive to the development of innovations, regardless of the existing agglomeration type. On the other hand, given the importance of business sophistication to improve innovation (Hervas-Oliver et al., 2022), firms in relatively different contexts of more or less diversified industries are able to fully appropriate these externalities.

Model 3 in the tables refers to Equation 6 and test the three-way interactions between industrial diversity and domestic competition with each innovation input pillar, where none of the interaction terms achieved statistical significance. However, by plotting the marginal effects, we observe some interesting results (Figure 5). While our previous analysis revealed positive moderation effects of industrial diversity, this is not always the case when the level of domestic competition is considered. In Figure 5, panel (a) we observe that the marginal effects of institutions are not significant at moderately low to low levels of competition, while industrial diversity in countries with higher levels of competition positively moderates the relationship between institutions and innovation outputs. This suggests that only countries with relatively high levels of diversity and competition are able to fully appropriate the benefits from the knowledge externalities generated by both types of agglomeration to effectively use the institutional context in developing innovation outputs. Our results are aligned to those by Miocevic et al. (2022), who found that the regulatory quality interacted with competition (informal competitors), having a positive effect on product innovation.

Panel (b) reveals similar results. However, for countries with medium-low competition more industrial diversity reduces human capital and research marginal effects on innovation outputs. This suggests a detrimental effect of medium-high levels of industrial diversity in specific contexts of relatively low competition. Perhaps this is showing evidence of the U-shaped relationship found by Li and Jian (2023), where medium levels of agglomeration did not generate knowledge externalities, nor an intensive competitive environment that would lead to higher R&D investments.

Similar to the two previous panels, panel (c) shows a positive moderation effect of both industrial diversity and competition on the relationship between infrastructure and innovation outputs, which is, nonetheless, an insignificant effect when competition is low. Panels (d) and (e) reveal a quite different picture. Even though the marginal effects of market sophistication and business sophistication increase with increasing industrial diversity, their strength diminishes when competition increases. This negative effect of competition could be linked to the inverse-U effect hypothesis of competition (Aghion et al., 2005; Arvanitis et al., 2020), where extremely high and low levels of competition dampen innovation.

Overall, our results suggest the presence of an interaction between industrial diversity and competition that, in most cases, strengthens the relationships between innovation inputs and innovation outputs.

Discussion and Concluding Remarks

This study contributes to the ongoing debate on the importance of specialization, industrial diversity and competition for promoting innovation (Castellano et al., 2023; H. L. F. de Groot et al., 2016; Hervas-Oliver et al., 2022; Li & Jian, 2023; Solheim et al., 2020). While various perspectives have been studied, there lacks a consensus on which type of agglomeration externality most favors innovation (Castellano et al., 2023; H. L. F. de Groot et al., 2016; Innocenti et al., 2022). We enter this debate integrating the literature on NSI and arguing that the countries' degree of industrial diversification and the level of domestic competition are more likely to influence national innovation processes than the innovation output directly, hence assuming a role of contingency factors that shape how innovation inputs are translated into outputs. As expected, our results show a positive relationship between innovation inputs and outputs, which is consistent with previous research (Audretsch & Belitski, 2022; Fagerberg & Srholec, 2008; Rodríguez-Pose & Zhang, 2020; Sun et al., 2020). Moreover, our results in this regard corroborate the central tenet in NSI theory that higher levels of innovation are driven by well-developed systemic elements within a country (Edquist, 2019; Niosi et al., 1993; Yu & Huarng, 2023).

A diversified economy includes a diverse base of know-how, business models and experiences, where the exchange of complementary knowledge across firms and

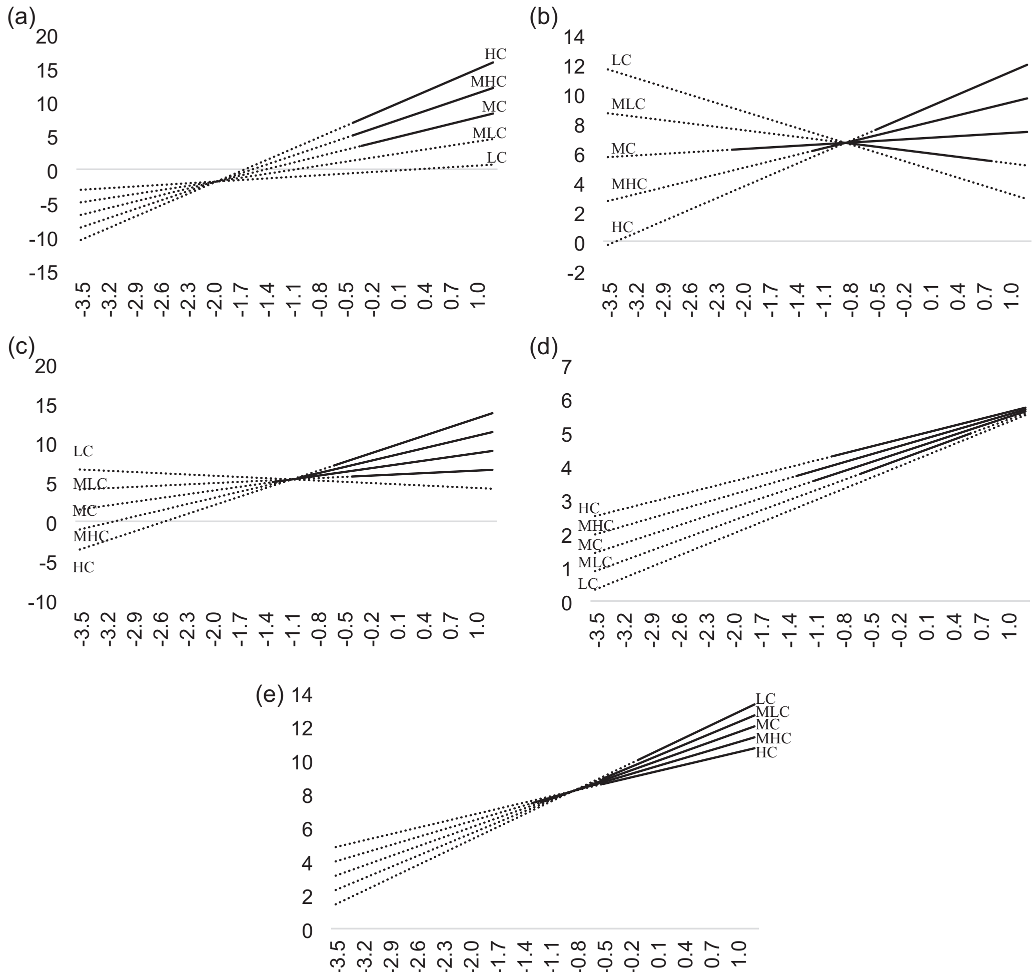

Figure 5. Marginal effects of innovation input pillars on outputs, moderated by diversity and competition: (a) institutions, (b) human capital and research, (c) infrastructure, (d) market sophistication, and (e) business sophistication

Note. Full segments indicate significance at 0.05 level. The Y axis is the magnitude of marginal effects. The X axis is the values of Industrial diversity. Industrial diversity values reflect the standardization procedure. LC = low competition; MLC = medium-low competition; MC = medium competition; MHC = medium-high competition; HC = high competition.

industries facilitates search and experimentation, thus enhancing innovation (Wang et al., 2017). Our results highlight the relevance of industrial diversity as a relevant factor for countries NSI. We observed that higher levels of industrial diversity are beneficial for countries' innovation processes, leading to greater innovation outputs. The five countries exhibiting the highest levels of industrial diversity (Switzerland, USA, Netherlands, South Korea, and UK) are also ranked on the top 10 most innovative countries (WIPO, 2021). Nonetheless, detailed analyses revealed that for some innovation inputs (such as institutions, human capital and research, infrastructure and market sophistication) lower levels of industrial diversity do not significantly contribute for achieving greater innovation outputs. This finding contrasts with the MAR hypothesis and studies that support it (Castellano et al., 2023; Galliano et al., 2023). While previous studies have explored whether specialization or diversity better support innovation (Castellano et al., 2023; H. L. F. de Groot et al., 2016; Hervas-Oliver et al., 2022; Li & Jian, 2023; Solheim et al., 2020), our results establish industrial diversity as a contingency factor influencing countries' innovation processes.

In addition to industrial structure, market conditions also shape countries' innovation levels (Arvanitis et al., 2020; Porter, 1990). Our results reveal an interaction between industrial diversity and competition that influences national innovation processes. This is aligned with Jacobs' externalities, which suggests that a larger number of firms operating across different industries increase competition for new ideas and, ultimately, improves innovation. Extant empirical evidence also confirms the positive effects of both diversity and competition on innovation (Kim et al., 2022; Miguelez & Moreno, 2018). Although our findings show a reinforcing effect of industrial diversity and competition on innovation outputs, this is not the case for all innovation inputs. The positive effect of both market sophistication and business sophistication on innovation outputs is enhanced by increasing industrial diversity but the effect is less pronounced when competition is high. A possible explanation for this effect is the inverted-U hypothesis relationship for the effect of competition on innovation (Aghion et al., 2005; Arvanitis et al., 2020), which posits that the effect of competition on innovation is not monotonic, but rather follows an inversed-U shape: innovation levels are higher somewhere in the middle of the competition continuum (i.e., at moderate levels of competition) and lower on the extremes (for low and high levels of competition). In unreported models (available from the authors upon request), we tested the moderating effect of competition on the relationship between business sophistication and innovation outputs—the models report positive marginal effects of business sophistication but a negative moderating effect of competition. This suggests that greater industrial diversification mitigates the negative effect of high competition and, thus, marginal effects of business sophistication on innovation outputs remain positive.

This study contributes to reconciling the literature on agglomeration externalities with the literature on national systems of innovation. A country's industrial structure and market conditions play a role in the achievement of innovation outputs that is distinct from what previous literature attributed them (Castellano et al., 2023; H. L. F. de Groot et al., 2016; Hervas-Oliver et al., 2022; Li & Jian, 2023; Solheim et al., 2020). Specifically, we have shown that industrial diversity and competition are crucial factors influencing how countries use innovation inputs to generate innovation outputs.

This study also responds to H. L. F. de Groot et al. (2016) call for considering a macro-level perspective when investigating the impact of agglomeration externalities. While much of prior studies have focused mainly on regional or city-level approaches (e.g., Audretsch & Belitski, 2022; Mascarini et al., 2023), we extend the examination to the national level.

Furthermore, our analysis of the interactions between industrial diversity and competition also informs policymakers on how to strengthen a country' NSI. While higher industrial diversity seems to ease the conversion of innovation inputs into innovation outputs, policies aimed at influencing competition need to be adapted to the specific innovation input they seek to influence.

Limitations and Future Research Perspectives

This study has some limitations worth noting. First, we employ a cross-sectional design, which limits our ability to make causality inferences, as we cannot guarantee that the antecedent precedes the outcome. Moreover, a relatively small number of countries in the sample, albeit highly substantial, needs cautious interpretation. Future studies, using longitudinal data, may analyze the interactions between industrial diversity and competition to attain a more robust understanding of the effects we have found in this study.

Second, competition may follow an inverted-U relationship with innovation, as suggested by Aghion et al. (2005), although this possibility was not addressed in this study. Nonetheless, our results revealed a negative moderating effect of competition on some innovation inputs, which may be indicative of such an inverted-U relationship. Future studies may analyze a possible quadratic effect of competition as a moderator of the relationship between innovation inputs and innovation outputs. Such modeling of competition could identify threshold levels, informing policymakers of the optimal level of competition that promotes innovation.

Third, this study focused exclusively on two moderators of the innovation inputs-outputs relationship. However, other factors are likely to influence the innovation processes of countries. This is also an area in which more future research is needed to extend our findings for different contingency factors (e.g., national culture), which could reveal the intricacies of countries' NSI.

Overall, this study provided valuable insights into the role played by industrial diversity and competition in national innovation processes. Albeit the discussion of which agglomeration externality are more important for innovation is already extensive (see, e.g., H. L. F. de Groot et al. (2016)), the question of how such agglomeration externalities influence innovation processes has been less studied. By reconciling this discussion with the literature on the NSI, we gain a better understanding of how industrial diversity and competition interact to shape countries' NSI–our findings denote that high levels of diversity and competition lead to effectively converting innovation inputs into innovation outputs.

Appendix

Table A.1. OLS Results for Main Effects and Interaction Using Institutions Pillar.

	Model 1			Model 2			Model 3		
	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*
Constant	28.943	0.883	.000	27.201	0.988	.000	25.499	1.192	.000
Institutions	10.248	0.891	.000	8.128	1.086	.000	5.606	1.589	.001
Ind. diversity				4.605	1.234	.000	4.238	1.161	.001
Competition							2.439	1.373	.080
Institutions × Ind. diversity				2.983	0.861	.001	3.803	1.872	.046
Institutions × Competition							2.347	1.162	.047
Ind. diversity × Competition							−1.265	1.431	.379
Institutions × Ind. Diversity × Competition							1.203	1.313	.362
n		86			86			86	
Adj. R^2		0.614			0.674			0.719	
F-stat		132.320			56.832			34.074	

Note. Dependent variable: Innovation outputs.

Table A.2. OLS Results for Main Effects and Interaction Using Human Capital and Research Pillar.

	Model 1			Model 2			Model 3		
	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*
Constant	28.943	0.735	.000	27.714	1.077	.000	27.548	1.139	.000
Human capital and research	11.176	0.704	.000	9.677	0.998	.000	7.438	1.221	.000
Ind. diversity				2.676	1.397	.059	1.902	1.376	.171
Competition							2.784	1.246	.028
Human capital and research × Ind. diversity				1.969	1.158	.093	0.922	1.296	.479
Human capital and research × Competition							0.935	1.299	.474
Ind. diversity × Competition							0.677	1.384	.636
Human capital and research × Ind. diversity × Competition							1.117	1.545	.472
n		86			86			86	
Adj. R^2		0.732			0.741			0.783	
F-stat		251.859			88.106			58.628	

Note. Dependent variable: Innovation outputs.

Table A.3. OLS Results for Main Effects and Interaction Using Infrastructure Pillar.

	Model 1			Model 2			Model 3		
	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*
Constant	28.943	0.790	.000	27.148	1.054	.000	26.673	1.159	.000
Infrastructure	10.865	0.804	.000	10.263	1.228	.000	7.624	1.246	.000
Ind. diversity				2.272	1.625	.166	2.020	1.600	.211
Competition							2.828	1.149	.016
Infrastructure × Ind. diversity				2.538	0.938	.008	2.111	1.447	.149
Infrastructure × Competition							1.140	1.469	.440
Ind. diversity × Competition							0.468	1.709	.706
Infrastructure × Ind. diversity × Competition							1.053	1.213	.388
n		86			86			86	
Adj. R^2		0.692			0.716			0.765	
F-stat		182.564			67.736			30.812	

Note. Dependent variable: Innovation outputs.

Table A.4. OLS Results for Main Effects and Interaction Using Market Sophistication Pillar.

	Model 1			Model 2			Model 3		
	Coeff	S.E.	p	Coeff	S.E.	p	Coeff	S.E.	p
Constant	28.943	1.009	.000	28.212	0.962	.000	28.096	0.998	.000
Market sophistication	9.212	0.893	.000	6.790	1.006	.000	4.639	0.990	.000
Ind. diversity				5.917	0.984	.066	5.203	1.186	.000
Competition							4.541	1.064	.000
Market sophistication × Ind. diversity				2.080	1.058	.053	0.840	1.151	.468
Market sophistication × Competition							0.181	0.761	.813
Ind. diversity × Competition							1.405	1.014	.170
Market sophistication × Ind. diversity × Competition							−0.104	0.990	.917
n		86			86			86	
Adj. R^2		0.494			0.635			0.716	
F-stat		106.452			53.069			34.867	

Note. Dependent variable: Innovation outputs.

Table A.5. OLS Results for Main Effects and Interaction Using Business Sophistication Pillar.

	Model 1			Model 2			Model 3		
	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*	Coeff	*S.E.*	*p*
Constant	28.943	0.605	.000	28.489	0.738	.000	28.597	1.101	.000
Business sophistication	11.805	0.605	.000	10.286	0.755	.000	9.603	1.463	.000
Ind. diversity				2.549	0.959	.009	2.826	1.516	.066
Competition							1.295	1.370	.348
Business sophistication × Ind. diversity				0.860	0.891	.337	1.725	1.577	.277
Business sophistication × Competition							−0.268	1.687	.874
Ind. diversity × Competition							−0.979	2.058	.636
Business sophistication × Ind. diversity × Competition							−0.319	1.812	.861
n		86			86			86	
Adj. R^2		0.819			0.832			0.834	
F-stat		381.072			150.853			53.936	

Note. Dependent variable: Innovation outputs.

Credit Statement

Marcelo Duarte: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Funding acquisition; **Fernando Carvalho**: Conceptualization, Methodology, Validation, Writing - Review & Editing, Supervision, Project administration, Funding acquisition; **Manuel Ferreira**: Writing - Review & Editing, Visualization, Supervision, Funding acquisition

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Data is available from the corresponding author upon reasonable request.

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