

# Mapping Twin Transitions in Regional Innovation Systems: a Configurational Approach

Maione V.<sup>1</sup>[0009-0000-1872-0434], Ponsiglione C.<sup>1</sup>[0000-0002-8953-5911], and  
Primario S.<sup>1</sup>[0000-0002-4728-0666], Paier M.<sup>2</sup>[0000-0002-4648-4819], Bürscher T.<sup>2</sup>[0009-0007-8399-247X]

<sup>1</sup> Dept. of Industrial Engineering, University of Naples - Federico II

<sup>2</sup> AIT Austrian Institute of Technology GmbH, Vienna, Austria  
vincenzo.maione5@unina.it

**Abstract.** Twin transition has become a structural priority in European regional policy. Yet, despite ambitious initiatives such as NextGenerationEU and the 2021–2027 Cohesion Policy, we still lack a clear understanding of how it unfolds across different regional contexts —particularly given persistent disparities in structural capacity and institutional agency. This paper addresses this gap by developing a configurational framework that links regional industrial path development to achievements in the twin transition domain. The framework is grounded in a systematic review of empirical case studies, which allows us to derive a set of structural and institutional causal conditions. These conditions are then operationalized and tested through fuzzy-set Qualitative Comparative Analysis of Italian NUTS-2 regions. The results show that no single factor is necessary; rather, distinct combinations of conditions foster regional specialization in twin transition domain. Moreover, the findings indicate that twin transition is not driven by a single dominant path, but can be achieved through multiple configurations of path development. Conceptually, the study advances the operationalization of path development; methodologically, it demonstrates the value of configurational approaches for analyzing regional transformation and offers a scalable diagnostic tool for place-based strategies.

**Keywords:** Twin Transition, Regional path development, Regional innovation systems, Complex systems, Fuzzy-set Qualitative Comparative Analysis

## 1 Introduction

In the 2021 Strategic Foresight Report (2021), the European Commission emphasized that the success of the twin transitions will depend on the capacity of regions to mobilize their technological, institutional, and cognitive resources. Understanding how regions develop—or fail to develop—the necessary capabilities has therefore become a central concern for both researchers and policymakers (OECD, 2022).

Within this context, evolutionary economic geography (EEG) offers a valuable perspective, viewing regions as evolving systems whose development paths are shaped by inherited structures, institutional agency, and knowledge dynamics. The conceptu-

alisation of regional path development provides a framework for analysing how regions transform over time through mechanisms such as extension, upgrading, branching, diversification, creation, and importation (Hassink et al., 2019). These paths reflect the interplay between established capabilities and emergent opportunities, under both internal and external pressures (Boschma, 2017).

Yet, despite its relevance, the framework lacks shared operational architecture. Existing studies often rely on case-specific interpretations, limiting comparability and cumulative knowledge. Moreover, little is known about how specific development paths lead to the twin transition

This paper addresses these gaps by:

1. Systematising the application of the path development framework through a review and classification of empirical studies, helping to consolidate its conceptual and operational foundations.
2. Proposing a configurational model that links path development to twin transition outcome.

We test the model on Italian NUTS-2 regions over the period 2008–2017 using fuzzy-set Qualitative Comparative Analysis (fsQCA), identifying combinations of causal conditions that enable regional achievement in the twin transition domain.

## 2 Literature Background

Grounded in the distinction between path dependence and path creation (Martin & Sunley, 2006), the framework of path development has evolved into a typology encompassing mechanisms such as extension, upgrading, branching, diversification, importation, and creation (Grillitsch et al., 2018; Hassink et al., 2019; Tripl et al., 2020). Building on this conceptual framework, we carried out a structured literature review with the aim of identifying empirical studies that explicitly applied the regional development path (RDP) typology across regional contexts. The outcome of the systematic review is summarised in Table 1

Although the path development typology is theoretically consolidated, its empirical application remains fragmented and case-specific, often lacking shared criteria for comparison. Moreover, it tends to treat development paths as discrete, while, in reality, regional change often results from hybrid or overlapping paths shaped by the interaction of multiple actors and institutional logics (Binz et al., 2016a; Grillitsch et al., 2018). This complexity is particularly salient in the context of the twin transition, which requires the simultaneous pursuit of decarbonization and digitalization, often involving concurrent mechanisms of the typology.

To the best of our knowledge, no study has systematically examined how specific combinations of development paths underpin regional achievement in the twin transition, nor has the typology been validated through comparative evidence. To address this gap, we propose a configurational framework linking development paths to the twin transition, grounded in a systematic review of empirical cases. We operationalise this framework and apply fsQCA to Italian regions, leveraging their structural diversity and policy relevance within the EU.

Table 1. Regional Cases Classified by Path Development Mechanisms

Reference	Region	RDP
(Morisson & Mayer, 2021)	Vierzon	Creation, Unrelated diversification
(Bellandi et al., 2021)	Macerata, Fermo, Sassuolo	Extension, Renewal
(Isaksen & Trippel, 2017)	Arendal-Grimstad, Mühlviertel	Creation
(Trippel & Otto, 2009)	Styria, Saarland	Creation, extension, unelated diversification
(Asheim, 2019)	Mazovia, Emilia Romagna	Creation, Unrelated diversification, importation, upgrading
(Chaminade et al., 2019)	Prato, Boras	Creation, extension, renewal
(Ostapenko et al., 2024)	Douro	Related branching, renewal
(Nieth & Radinger-Peer, 2023)	Aalborg, Kaiserslautern, Twente	Creation, extension, upgrading, importation
(Nilsen & Njøs, 2022)	Norway	Importation
(Corodescu-Roșca et al., 2023)	Timisoara, Cluj Napoca	Extension, upgrading
(Binz & Gong, 2022)	California, Hamburg	Creation, importation
(Wang et al., 2012)	Zhongguancun, Bangalore, Silicon Valley	Creation
(Cassia et al., 2008)	Cambridge, Goteborg, Baden-Württemberg, Singapore, Pittsburgh, Milwaukee	Renewal
(Simmie, 2012)	Denmark	Creation
(Isaksen, 2015)	Lister	Creation, extension
(Binz et al., 2016b)	Beijing	Creation

### 3 The methodology and the model

Because regional transformation emerges from complex causal dynamics, fsQCA is particularly well suited to identifying the causal configurations underlying twin transition outcomes. (Ragin, 2014). In this study, fsQCA is applied to Italian NUTS-2 regions, with the outcome defined as the revealed technological advantage (RTA) in the twin transition domain over the period 2018 - 2021 (Debackere et al., 1999), adjusted by a reliability factor based on patent-count thresholds. In line with the literature,  $RTA = 1$  is the benchmark for technological specialization (Haščič & Migotto, 2015); calibration therefore assigns full membership to values above 1 and non-membership to values below 1.

The selection of causal conditions builds on both theoretical insights from EEG and empirical patterns emerging from the literature review. Table 2 reports the set of causal conditions, their operational definitions, data sources, and references. Conditions were calibrated into fuzzy sets using the direct method, with anchor points at the 25th, 50th, and 75th percentiles (Fiss, 2011; Garcia-Castro & Ariño, 2016). Each condition is first tested for necessity, adopting a consistency threshold of 0.90. Subsequently, sufficiency is assessed by constructing and logically minimising the truth table, following standard procedures to derive complex, intermediate, and parsimoni-

ous solutions. A minimum consistency threshold of 0.75 was applied to identify configurations considered empirically sufficient. The analysis was conducted in R.

Table 2. Causal Conditions

Label	Dimension	Index	Source	References
UV	Unrelated Variety	Unrelated Variety	Eurostat	(Frenken et al., 2007)
EKIA	Structural complexity	Employment in Knowledge-intensive activities	Regional Innovation scoreboard	(European Commission et al., 2023)
FDI	FDI Intensity	FDI inward stock % GDP	OECD	(Fu, 2007)
ICOLL	Collaborative R&D activity	Innovative SMEs collaborating with others	Regional innovation Scoreboard	(European Commission et al., 2023)
PP	Policy Pressure	Historic EU payments annual timeseries - modelled	Cohesion Data	(Mohl & Hagen, 2010)
RII	Innovation Performance	Regional Innovation Index	Regional Innovation Scoreboard	(European Commission et al., 2023)
NEWB	Entrepreneurial Activity	Business entries	OECD Data Explorer	(Fritsch, 2011)

## 4 Results

The necessity analysis confirms that no individual condition satisfies the established consistency threshold of 0.90 for necessity, indicating that none of the enabling factors is independently conducive to the twin transition. This finding reinforces the configurational premise of the study, namely that regional outcomes result from context-specific combinations of enablers. A summary of the results is reported in Table 3.

Table 3. Necessity analysis for the twin transition outcome.

Causal Condition	Consistency	RoN	Coverage
EKIA	0.51	0.65	0.46
ICOLL	0.48	0.65	0.44
NEWB	0.73	0.69	0.61
FDI	0.69	0.74	0.64
UV	0.75	0.77	0.69
PP	0.55	0.70	0.52
RII	0.63	0.70	0.57

The sufficiency analysis identifies four sufficient solutions to explain regional achievement in the twin transition. These configurations reflect diverse combinations of structural and institutional enablers and are interpreted through the lens of path development, drawing on empirical case knowledge. The overall solution coverage is 0.51, while the overall solution consistency is 0.85. Table 4 presents the complex

solutions with core (large circles) and peripheral conditions (small circles), and their associated regional cases and path types.

Table 4. Sufficiency analysis for the twin transition outcome

	1	2	3
EKIA	⊗	●	●
ICOLL	⊗	⊗	●
NEWB	●	⊗	●
FDI	●	●	●
UV	●	●	●
PP	●	⊗	●
RII		●	●
Consistency	0.87	0.85	0.80
Raw coverage	0.20	0.08	0.26
Unique coverage	0.18	0.06	0.25
PRI	0.87	0.85	0.80
Cases with greater than 0.5 membership in term	Puglia (0.77,1); Toscana (0.51,1)	Liguria (0.54, 1)	Piemonte (0.94, 1); Lazio (0.67, 1); Lombardia (0.66, 1)
RDP	Unrelated div. Importation	Importation Unrelated div.	Creation

Across the three solutions, FDI and UV consistently emerge as core conditions, confirming the importance of external knowledge flows and unrelated variety in sustaining regional achievement in the twin transition. PP and NEWB act as differentiating factors, while RII reflects regional innovation capacity and strengthens configurations combining internal assets with external openness.

Configuration 1 ( $\sim$ EKIA\* $\sim$ ICOLL\*NEWB\*FDI\*UV\*PP) represents a path where limited knowledge-intensive employment and collaboration are offset by entrepreneurship, external knowledge inflows, and policy support. While in structurally weaker regions such as Puglia this configuration could compensate for limited internal resources, in regions like Toscana it could reinforce existing capabilities through external openness and institutional support.

Configuration 2 (EKIA\* $\sim$ ICOLL\* $\sim$ NEWB\*FDI\*UV\* $\sim$ PP\*RII) shows that knowledge intensity, external openness, and high innovation capacity can compensate for weak collaboration and entrepreneurship, corresponding to importation and unrelated diversification paths. This configuration is exemplified by Liguria.

Configuration 3 (EKIA\*ICOLL\*NEWB\*FDI\*UV\*PP\*RII) combines strong knowledge assets, entrepreneurship, policy support, external openness, and innovation performance, consistent with path creation. This pattern characterizes regions such as Piemonte, Lazio, and Lombardia.

Overall, these configurations are most clearly associated with northern Italian regions, reflecting their stronger innovation base, openness to external knowledge, and more articulated policy frameworks. The findings substantiate the configurational premise of the study: twin transition is not driven by a single dominant path, but arise from multiple configurations of path development mechanisms. These results reinforce the need for differentiated, place-based policy strategies: while in less structured regions outcomes depend on the alignment of external openness, entrepreneurship, and policy support, in more advanced areas they arise from the interplay of strong internal assets with institutional and external enablers.

## 5 Conclusion

This paper investigated how different combinations of regional path development mechanisms contribute to the twin transition. Drawing on a structured literature review and an fsQCA of Italian NUTS-2 regions, we proposed a configurational framework linking the path development typology to twin transition specialization.

The findings support the assumptions of causal complexity and equifinality: no single condition is necessary, while multiple sufficient configurations are associated with regional achievement in the twin transition. This highlights the need for place-sensitive policies that account for structural diversity across regions and foster the specific combinations of conditions through which such paths unfold.

The contribution of this study is intended to be twofold. Conceptually, the study refines the empirical operationalization of the path development framework. Methodologically, it introduces a configurational approach to regional transition analysis grounded in empirical evidence.

Nonetheless, this study has limitations. The results may be sensitive to calibration thresholds; the cross-sectional design of fsQCA limits temporal inference; and classifying regions into discrete path types simplifies trajectories and does not fully capture the nature of real-world trajectories.

Future research should broaden the scope to include European regions, enabling cross-country comparisons and testing the robustness of the framework in structurally diverse contexts. A promising avenue is the use of panel fsQCA, which would capture temporal dynamics more effectively than cross-sectional designs. Integrating the framework with policy evaluation tools would further enhance its relevance for the design of place-based transition strategies.

### **Declaration of generative AI and AI-assisted technologies in the writing process**

During the preparation of this work the authors used ChatGPT 4o in order to check grammar and spelling of the work and to improve the language style. After using this

tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

### **Ethics declaration**

This research did not require ethical approval, as it is based exclusively on publicly available secondary data and does not involve human participants, personal data, or sensitive information.

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