A framework for measuring the performance of innovation districts: Aligning policy and purpose with pragmatism

Abstract–This paper introduces a performance measurement framework for Innovation Districts. A focus on innovation districts is emerging as a novel approach to innovation policymaking, combining elements of innovation systems, cluster analysis, and urban design. Despite their rising popularity with innovation policymakers, there has been remarkably little theorising or operationalisation of innovation performance metrics. While the urban planning literature pioneered the concept of an innovation district, the activities involved in realising their potential have been underexamined. We combine insights from the literature on innovation systems, urban planning, and entrepreneurial ecosystems to overcome these gaps. We develop and validate a performance measurement framework based on interviews with 67 innovation experts across six innovation districts in the state of New South Wales (NSW) in Australia. We propose that the scope and pragmatism of the framework will enable researchers, policymakers and practitioners to monitor and evaluate the performance of innovation districts effectively.

Managerial relevance statement–This framework in this study presents managers a comprehensive overview of a relatively concise set of innovation metrics that they can monitor within their organisation. Across an innovation ecosystem, it can serve as a set of standard metrics which can inform collective KPIs at the level of an innovation district. Until data collection is more integrated with corporate tax records, enterprises may need to first agree on how to share potentially commercially confidential data. For policy makers, such aggregated statistics reveal the profile of one or more innovation districts, and enable taking a more

evidenced approach to investing in grants, infrastructure, precinct activation or other initiatives in a given area.

Index Terms–Innovation districts, innovation policy, evaluation, innovation performance, innovation systems, urban design, place-based innovation.

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I. INTRODUCTION

The establishment of Innovation Districts has become a global phenomenon as policymakers attempt to proactively design local environmental conditions conducive to knowledge-intensive innovation and socioeconomic development [1]. Innovation districts refer to geographic areas with a concentration of innovation-focused organisations such as startups, scale-ups, research-intensive organisations, and entrepreneurship support organisations [2]. Diverse benefits have been associated with these dynamic geographic areas, including creating innovation-related jobs, developing new industries, accelerating the commercialisation of ideas, and urban regeneration [2], [3]. Against a background of rapid technological changes and pressing societal and environmental challenges, policymakers are increasingly attracted to the idea of building innovation districts to enhance resilience and competitiveness in their jurisdictions [4], [5].

From a policy perspective, innovation districts are promoted as instruments to catalyse placed-based innovation and entrepreneurship, laying the groundwork for technological breakthroughs and creating new business models [6], [7]. Despite the increasing interest in innovation districts in urban and local policy and practice, scholars have warned about the potential risks of becoming another buzzword or branding tool if it is not effectively operationalised to inform sustainable innovation policy design and implementation [8], [9]. Furthermore, criticisms about possible negative externalities such as gentrification and social exclusion [10], [11] demand the establishment of mechanisms for regular review and adjustment of innovation districts to ensure their continued relevance and effectiveness in stimulating place-based innovation [12], [13].

Early literature on innovation districts emphasised urban design and societal benefits to local communities [14]. Recent extensions integrate more innovation-related measures and are focussed on a specific district [4], or a more generalised framework that is district agnostic

[15]. However, these studies only offer conceptual frameworks for understanding the performance of innovations, with limited guidance on how these innovation metrics could be operationalised and implemented pragmatically.

Responding to calls for a stronger focus on the concept of innovation in the literature on innovation districts [4], [15], we build upon the innovation systems and entrepreneurial ecosystems literature to develop a framework to measure innovation performance at the level of an innovation district. We argue that a cohesive innovation performance measurement framework is needed to enable the collection of evidence about innovation performance across innovation districts.

A cohesive innovation performance measurement framework has the potential to advance research and practice regarding the performance of innovation districts by better understanding the interplay of innovation drivers, inhibitors and outputs, offering concrete metrics to shape decision-making processes [8].

We utilised a qualitative deductive-inductive approach [16], [17] to develop a framework to measure innovation performance at the innovation district level. The deductive component involved a comprehensive review of the academic and grey literature on innovation systems and entrepreneurial ecosystems to identify relevant innovation metrics suitable for contextualising at the district level. The inductive component entailed validating and expanding those metrics through interviews with 67 experts in multiple innovation districts in New South Wales (NSW), Australia.

Our synthesis of the literature and interview insights led to the development of a new framework for measuring innovation performance at the district level that is consistent with the innovation systems and entrepreneurial ecosystems literature. The framework includes input and output measures of diverse resources for each ‘stage’ of innovation in the ecosystem and factors that may drive or inhibit innovation in a given innovation district.

This research contributes to the innovation systems, innovation districts and innovation policy literature in three ways. First, we offer a holistic framework that facilitates identifying and evaluating relevant input and output resources necessary for innovation districts to function successfully as a local place-based innovation system. Second, we highlight the importance of innovation drivers in the environment that may enable or inhibit innovation within innovation districts.

Finally, we contribute to the innovation district literature by bringing the innovation processes to the forefront. In doing so, we aim to provide policymakers with a means to implement an effective measurement tool for longitudinal monitoring at the level of innovation districts and, therefore, a means of evaluating and coordinating different innovation policies. Likewise, it provides researchers with a set of measures consistent with innovation systems datasets for further research globally about innovation districts, their performance and evolution.

The paper continues as follows. Section 2 summarises the literature on innovation districts, innovation systems, entrepreneurial ecosystems and measurement approaches. Section 3 presents the deductive-inductive methodology for triangulating and validating the relevance of the innovation performance measures at the innovation district level. Section 4 synthesises the literature and the empirical research into an innovation performance measurement framework. Section 5 discusses the contributions of the framework, opportunities for further research, and limitations.

II. LITERATURE REVIEW

A. Innovation Districts

The concept of innovation districts combines elements of urban design, entrepreneurship, innovation, and human capital to promote the development of urban areas [1], [18]. Katz and Wagner (p.1, [2]) define innovation districts as “geographic areas where leading-edge anchor

institutions and companies cluster and connect with start-ups, business incubators, and accelerators." Despite explicit references to anchor organisations and institutions that foster innovation activities, the innovation district literature has remained deeply connected with urban design, with conceptual proximity to the emphasis of earlier work on walkability and diversification of neighbourhood-level urban design to prioritise social connectivity [19]. Most of the extant literature on innovation districts adopts this approach along with planning and land use perspectives, with an assumed link between urban design and the competitiveness of the innovation districts [15], [1], [20], [21].

Like other innovation-related frameworks that consider geographical areas and boundaries, the concept of innovation districts underscores the spatiality of innovation, here with a specific focus on the local dimension [15]. This is analogous to territorial innovation systems perspectives such as regional innovation systems, clusters, and industrial districts, which are grounded in the spatial proximity of multiple actors who are connected through networks that facilitate learning and knowledge spillovers [22], [23], [24].

Initially, innovation districts were centred on enclosed neighbourhood boundaries and single-purpose use, primarily concerned with creating jobs and industrial development [1]. However, a recent shift has expanded the attention to mixed-use and boundary-spanning districts, along with the recognition of additional factors such as providing a jobs-housing balance, environmental developments, and social equality [25], [26]. In this light, identifying and establishing innovation districts represent a policy response to support transitions to a knowledge economy, leveraging agglomeration economies and providing social benefits [3]. Hence, policymakers are increasingly implementing deliberative interventions in an attempt to create supportive environments for place-based innovation systems.

Research into innovation districts from the urban planning perspective emphasises the importance of how individuals commute and interact with each other, such as in laneways,

atriums, green spaces, events spaces and offices [1]. While social interactions and networks are known antecedents of innovation, this stream of innovation district literature provides a "plethora of meanings and rationales for innovation districts" [10]. It remains silent, however, about the innovation processes and their measurement. Thus, to achieve a comprehensive understanding of the role of *innovation* within Innovation Districts, we now turn to the literature on innovation systems and entrepreneurial ecosystems where we draw on related frameworks that can be adapted to the context of innovation districts.

B. Innovation Systems

Research on innovation systems emerged in the 1980s, with a growing interest in studying the environment and systems around innovation [27]. This stream of literature emphasises that innovation is a source of economic growth that arises and occurs within a system that, if functional, supports innovation activities [27]. As such, research on systems of innovation examines the structure and networks within a system and how its institutions and organisations interact to facilitate learning and knowledge spillovers and, hence, foster technological and organisational innovation [27], [28].

Systems of innovation have been studied at various levels, initially focussed on national innovation systems [29], [30], [31] and then expanding to regional innovation systems [32], [33], sectoral innovation systems [34], [35], and technological innovation systems [36]. Related systems perspectives on innovation include triple/quadruple helix [37], [38], [39], [40], cluster-based theories [41], and entrepreneurial ecosystems [42], [43]. For the objectives and boundaries of this study, we focus on regional innovation systems (RIS) and entrepreneurial ecosystems (EE) as appropriate frameworks for capturing innovation and innovation performance at the local/district level. The following sub-sections briefly review the literature on regional innovation systems and entrepreneurial ecosystems.

1) Regional Innovation Systems: The regional innovation systems (RIS) approach focuses on generating innovation and builds upon influences from the literature on national innovation systems, economic geography, industrial districts, and clusters [33]. Conceptually, regional innovation systems emphasise an evolutionary system of innovation approach with institutions and learning processes at its centre, connected through networks and influenced by innovation policy [33], [44]. The unit of analysis is the region, comprising a system of institutions, firms, and organisations that innovate by absorbing and generating knowledge and ultimately contributing to regional development [45], [32]. As such, with a focus on regional and metropolitan areas, the regional innovations systems approach reveals the critical importance of territorial scales and dynamics to support innovation-based economies [46]. While the national scale appeals to federal policymakers and researchers, the aggregated scale does not leave room for analysis of the micro-foundations of innovation and a more holistic view of innovation systems.

Due to its explicit foundation in and integration of innovation policy [44], the RIS approach has proven to be of practical relevance in guiding policy initiatives [8], allowing for a deeper understanding of the role of geospatial proximity and interactions between organisations and institutions to drive innovation processes [5], [47]. Thereby, the RIS perspective highlights the collective effort of multiple actors and entities in driving regional socioeconomic development and improved competitiveness of a region [45], drawing attention to place-based structures and capabilities such as infrastructure, knowledge and skills, financial resources, institutional frameworks, and policy initiatives [46]. In particular, the RIS approach is a practical framework to assess the innovation performance of a geographically bounded area; cf. [48], [49], [50].

Geographically, RIS research typically focuses on an area between the local and the national level, often intersecting with more than one sectoral innovation system [51]. However,

the RIS approach offers flexibility concerning its geographical scope, with recent research contextualising the RIS framework to innovation precincts [52], [53], which are more mono-sectoral versions of innovation districts. As such, the geographic scale of RIS offers the opportunity to be adapted to build on and operationalise into an innovation district measurement framework. Complex systems research also enables changing scales that recognise the nested nature of systems and their subsystems [54]. Challenges with RIS research are its emphasis on the structural elements, often lacking a focus on the agency and dynamics of actors, and how to operationalise and measure the relevant concepts to present valuable insights for policy applications [55], [56]. We, therefore, turn to the literature on entrepreneurial ecosystems.

2) Entrepreneurial Ecosystems: The entrepreneurial ecosystems (EE) approach emphasises the creation of new ventures as the outcome [57]. EE research has been applied at different levels, including local, regional and sub-national [58]. An EE is characterised as a set of interdependent actors and factors (such as human and financial capital networks and support services) governed in such a way that they enable productive entrepreneurship [42]. This framework has gained much momentum because it sees ecosystems as non-linear, complex and adaptive [59], [60], highlighting the networked and interdependent nature of subsystems and the effects of time and recycling of resources in their evolution.

This approach regards entrepreneurial activity as the primary outcome [42] and entrepreneurship as the key driver of economic development [61]. The EE frameworks arose to unpack the role of the entrepreneur in innovation systems [42] under the assumption that entrepreneurs "create opportunities for innovation" (ibid., [42]. In EEs, innovation is thus an implicit means to an end, where the ends include venture creation, job creation, revenue generation and other forms of tangible and intangible value creation that are central to public policy. Despite the potential for longitudinal analysis of the dynamics of EEs, the EE

framework has primarily been used in a static descriptive sense, including identifying innovation drivers and measuring their impact. However, recent studies have demonstrated that the EE framework is flexible, including hybridising it with other literature, particularly with RIS [62].

In synthesis, both RIS and EE literatures recognise similar factors that drive innovation and entrepreneurship and provide insights into how such activities could be measured. The RIS literature emphasises knowledge spillovers and innovation, which become a foundation for entrepreneurial value creation and economic development, as emphasised in the EE literature. Together, they provide a promising foundation for measuring innovation districts for research and policy purposes.

C. Measurement of Localised Innovation Systems

Innovation performance measurement is important for theory development, testing and for policy design and coordination. On the national and regional level, popular frameworks to measure innovation performance include the OECD Oslo Manual and Frascati Manual, which provide governments with guidelines for collecting and interpreting data on innovation [63], [64]. Measurement approaches for sub-regional or sub-city levels – such as the innovation district level – are much scarcer and span the literature on innovation systems, entrepreneurial ecosystems, precincts and urban planning. Table I summarises key academic research and policy reports measuring or presenting heat-mapping of innovation performance at (or near) the level of innovation districts.

TABLE I
STUDIES MEASURING THE PRESENCE AND PROMINENCE OF INNOVATION DISTRICTS

Literature streams	Key indicators & variables	Geographical focus	Empirical/ Conceptual	Source(s)
Entrepreneurial ecosystems	Firm formation rates; firm growth rates; IPOs; Patent registrations	Postcode level; 49 US states	Empirical	[65]
	Grants; Patents; Publications; Products; Seed & Venture capital	County level, US	Empirical	[66]
	Governance; Entrepreneurial culture; Finance; Talent; Knowledge; New venture formation	273 European regions (NUTS 2 level)	Empirical	[61]
	Entrepreneurial conversations meetups	City level, Scotland, UK	Empirical	[67]
Innovation ecosystems	Robustness; Density; Potential absorptive capacity; Innovation; Productivity; Realised absorptive capacity; Creativity	Innovation ecosystem	Conceptual	[68]
Innovation ecosystems; Triple-helix	Indicators related to Urban; Economic; Social; Governance	Innovation district	Conceptual	[15]
Innovation precincts	Education; R&D spending; Collaboration; Patents; Startups; Revenue growth; Venture capital	Statistical areas covering New South Wales, Australia	Empirical	[52], [53], [69]
Regional innovation systems	European Innovation Scoreboard data	161 European regions (NUTS 2 level)	Empirical	[50]
Urban planning	Census employment data; estimated innovation-related revenue	50 innovation districts in the US	Empirical	[45], [70]
Urban planning; Innovation districts	Critical mass; Innovation capacity; Diversity and inclusion; Quality of place, Leadership	Innovation district examples from the US	Conceptual	[2]

Table I shows a blurring of literatures and concepts around innovation, entrepreneurship, and urban planning. Additionally, the studies in Table I use different data sources and methods to assess innovation at (or close to) the level of innovation districts. For example, some studies rely on the existing database of the European Innovation Scoreboard, offering technology-intensive metrics [61], while others draw from unique sources such as data collected from meetup social media events taking place at regional levels [67].

In sum, the merging of these literatures underlines the need for an integrative conceptual framework to measure the innovation performance of innovation districts that can be used

across cities and countries and use existing data sources for historic and longitudinal analysis. While urban design plays a significant factor, an overemphasis on urban planning risks distracting from measuring the innovation processes enabled by it.

D. Developing an innovation measurement framework: Dimensions and visualisation

The breadth and diversity of innovation processes and their measurement in the literature require an overarching framework to categorise and group individual factors and performance indicators. To develop a framework to understand the performance of innovation districts, we draw on the Community Capitals Framework (CCF) as a useful means to organise the breadth and diversity of resources involved in innovation systems and processes [71], [72], [73]. The CCF applies a systems perspective to analyse development, change and impact resulting from the availability and interaction of eight types of capital [71]. Capital of various forms is closely connected with innovation and innovation outcomes [74], which makes the CCF a suitable framework for organising innovation-related factors and indicators.

The CCF categorises capital components within a system as financial, social, cultural, intellectual, human, political, built and natural capitals. Stakeholders within innovation systems interact and create value by transforming one form of capital into another - for example, by utilising human capital to create new knowledge [75]. Emery and Flora [71] define the capitals as follows. *Financial capital* captures financial resources to fund innovation, such as revenues, debt, investment, and (tax) credits. *Human capital* is the set of "skills and abilities of people to develop and enhance their resources" (p. 21), often referred to as talent. For this study, we separate intellectual capital from human capital because of how well-established intellectual capital and codified forms of knowledge are within the innovation systems literature [76], [77]. *Intellectual capital* represents the codified or routinised forms of knowledge that can be converted into a technology or other scalable form to generate innovation outputs (e.g. new products, services, revenues, jobs, etc.). *Cultural capital* reflects how people interact with

others in a system and "how creativity, innovation, and influence emerge and are nurtured" (p. 21, [71]), affecting management styles and risk appetite. *Political capital* reflects "access to power, organisations, connection to resources and power brokers" (p. 21, [71]). *Social capital* captures ties, networks and connections between people, which can be cohesive and dense or loose, building bridges to other systems. *Built capital* refers to infrastructure-supporting activities, including space and equipment. *Natural capital* captures the specific natural assets of a location, such as natural resources, amenities and geographic specificities.

On an aggregate level, these capitals capture the full spectrum of innovation activities, from basic research to venture formation or licensing through to new market entry, as visualised in Figure 1. This figure is an illustrative simplification of a system of innovation as a nearly linear sequence of diverse stages and resources (capitals), with each stage feeding into the next. While feedback loops and lags exist in the system, they are not visualised to avoid cluttering the figure. For instance, revenues generate financial capital, fueling a wide range of further activities, such as more IP protection, licensing, new jobs, facilities and equipment or market expansion.

To simplify Figure 1 further, we can represent the system temporally, where the aggregated capitals at time 't' are inputs for organisations to manipulate into outputs by 't+1', e.g. one business cycle, as visualised in Figure 2. As the next cycle starts, these outputs are inputs to be manipulated in that next cycle.

These cycles of innovation activities are thus dependent on the available capital from the previous cycle and environmental conditions, such as government policies or regional culture). Over more extended periods of time, these environmental conditions can also be shaped by the innovation activities within the system.

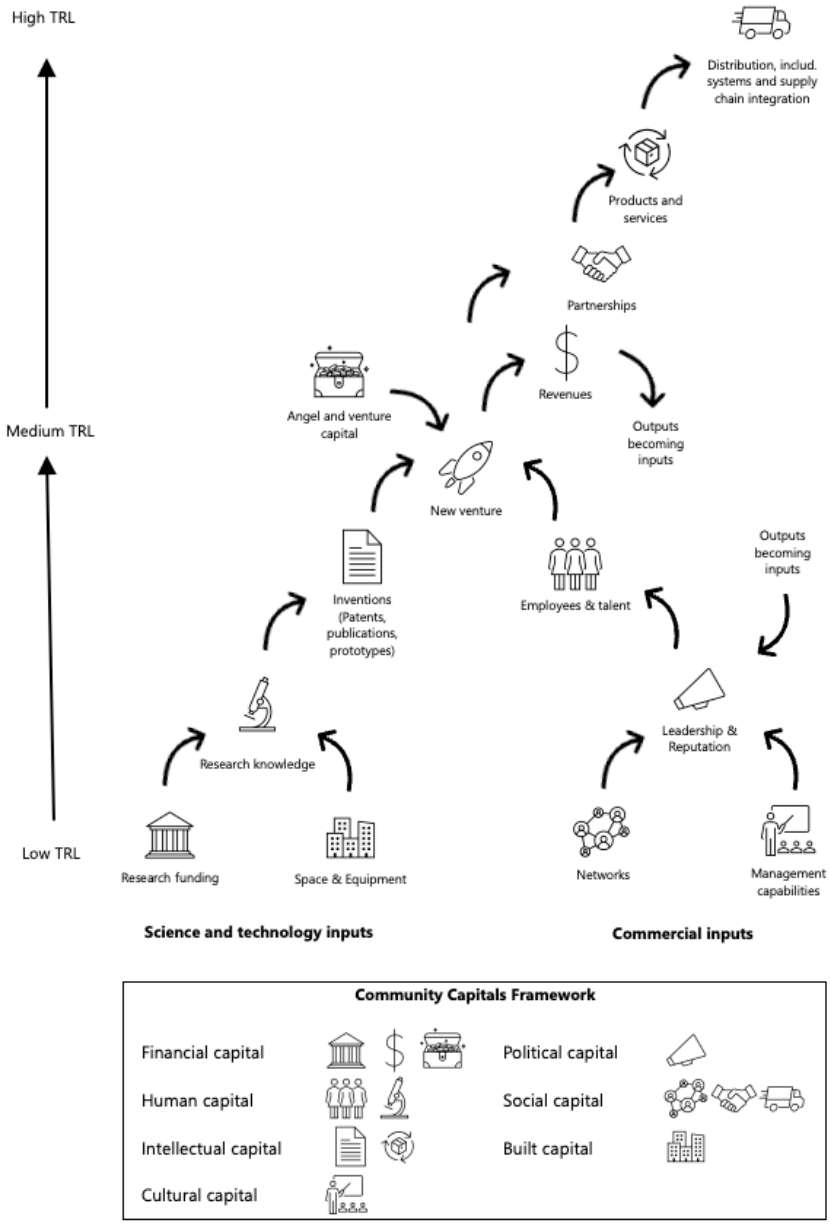


FIG. 1. AN INNOVATION SYSTEM AS A NEARLY LINEAR PROCESS

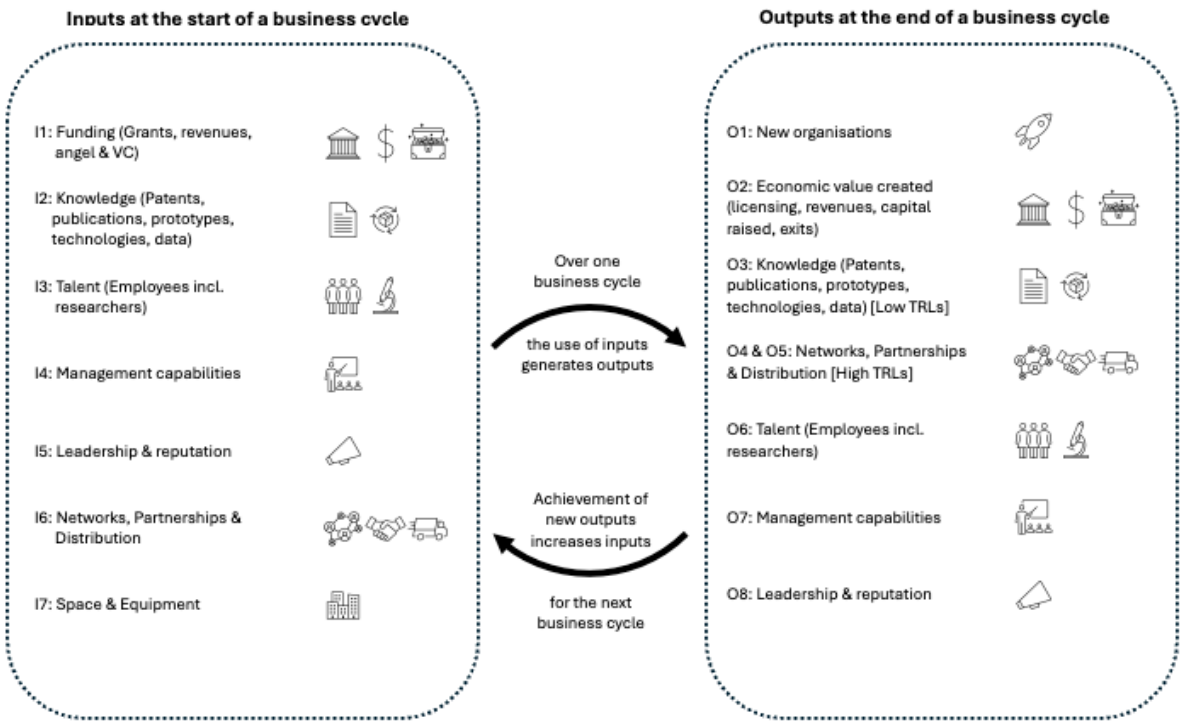


FIG. 2: AN INNOVATION SYSTEM AS A SET OF INTERACTING INPUTS AND OUTPUTS

III. METHODOLOGY

This research adopted a qualitative approach to understand how innovation performance can be measured at the innovation district level. We used a deductive-inductive approach in the research process [16], [17]. The deductive component involved a comprehensive review of the literature to identify relevant innovation metrics suitable for contextualisation at the district level. The inductive component entailed validating those metrics and being open to emergent metrics from interviews with experts working across multiple innovation districts. The framework shown in Figures 1 and 2, and Tables II and III results from synthesising these two approaches through an iterative and reflexive process [78].

A. Research Context

The context of our study is the Australian state of New South Wales (NSW). NSW is Australia's largest state, with a gross state product (GSP) comparable to US states like

Massachusetts, Michigan, and Virginia and the gross domestic product (GDP) of countries like Belgium, Sweden, and Norway. The NSW Government's strong commitment to innovation districts was institutionalised with the creation of the Greater Cities Commission (GCC) in 2015. The initial goal of the GCC was to plan and coordinate Australia's first global multi-city region. The GCC was tasked to build an economy where all innovation districts and assets collaborate to compete, creating a globally competitive AUD 485 billion region. Our study focused on innovation experts across seven innovation districts (i.e., Tech Central, Westmead, Macquarie Park, the Western Sydney Aerotropolis, Central Coast, Newcastle, and Wollongong).

B. Sampling

We collaborated with a state government department to generate an initial list of key stakeholders to interview across seven geographic areas specified by that department. We coded the stakeholder list by geography and industry sector to ensure targeted stakeholders were distributed across the geographic areas and all state government-designated 'priority industries' related to technological innovation [79]. Stakeholders were also classified into three broad categories: enterprises, intermediaries and research organisations.

- *Enterprises* include founders and senior managers representing organisations ranging from startups, small and medium-sized enterprises (SMEs), scaleups and larger incumbent firms.
- *Intermediaries* include representatives of organisations, such as incubator and accelerator operators and specialised service providers, that directly support enterprises. This category included a mix of private, non-profit, publicly funded and university-based incubators, startup support organisations and professional service providers.
- *Research organisations* encompass senior university leadership, research office staff who support academics, and academics involved in commercialising their research (e.g., via a spinoff or licensing).

The sample was snowballed using prompts at two points in the process. We contacted senior university leaders across the state and asked for referrals to other stakeholders with first-hand innovation experience in their organisation or network. Additionally, after every interview, participants were asked for additional referrals. The initial stakeholder list and subsequent snowball sampling resulted in 211 prospective contacts, of which we contacted 153, and 94 responded to our request for an interview. The final sample included 67 respondents.

C. Data Collection

We utilised semi-structured interviews as the primary data collection technique, given their ability to provide rich data for analysis [80]. The interviews aimed at understanding which resources were critical for innovation activities, and which metrics were meaningful to the participants rather than those viewed as symbolic or to which stakeholders otherwise cannot relate. The interviews were semi-structured and lasted between 45-90 minutes. Our interview guide included open questions and optional prompts for the interviewer to probe deeper into a given response. While the general flow of questions was the same for all interviews, the line of inquiry was tailored to each stakeholder type to adapt to their context and experience.

We first asked participants how they are innovative and what drives them to be innovative. By not prescribing what we mean by *innovation*, we aimed to capture a broad range of innovation activities and outcomes as perceived by participants. We then asked participants about innovation inputs, outputs and potential measures of innovativeness in relation to their experiences. To inform policy making, we also asked what each participant believed the main drivers (or inhibitors) of innovation were, where drivers are factors external to their organisation. Additional questions included querying the degree to which participants saw their organisation as part of a localised innovation (eco)system and which other innovation districts or ecosystems they considered to be influential or serving as benchmarks.

This thorough data collection process, guided by the principle of saturation [81], resulted in 67 interviews. At this point, evidence regarding activities, inputs, outputs, and metrics began to converge, and further interviews were not pursued as their perspectives were too similar to those of other interviewees in the same sector and geography. Of the interviewees, we classified 31 as working for intermediaries, ten as working for enterprises, and 26 for research organisations.

D. Data Analysis

The data analysis unfolded in several stages. First, research team members transcribed interviews and coded them independently using a pragmatic approach of open and axial coding [82]. They then discussed their initial codes and agreed on a combined set. Once all coding was completed, code categories were shared and discussed with the rest of the research team, and the wording was finalised. In addition to the internal analysis by the research team, we facilitated discussions with state government policymakers, other innovation systems academics and various practitioners from the ecosystem.

The analysis combined secondary data from the academic literature, government-supplied innovation policy reports, and other diverse sources to complement the empirical evidence. Engaging with this secondary data enhanced the validity of our findings [81] by ensuring multiple data sources were used.

IV. FINDINGS

Our analysis resulted in a framework that proposes a novel and pragmatic approach to measuring innovation district performance by examining three dimensions usually fragmented in the innovation systems literature: innovation inputs, innovation outputs, and innovation drivers. This section describes each of the dimensions and their respective elements.

A. Innovation Inputs

Innovation inputs (I) are resources that are within reach of innovating organisations. They are not automatically available to all enterprises but can be obtained with reasonable effort. The study resulted in eight input types, based on the CCF, as explained below.

I1) Financial capital: Financial resources are the lifeblood of innovation. The innovation process can be capital-intensive at all stages, from research and development to foreign market entry. Financial capital can be converted into other forms of capital, such as knowledge, talent, networks and physical capital. Funding sources are diverse, including but not limited to grants, revenues (or, more specifically, profits), or angel and venture capital.

Early-stage innovation almost completely depends on grants unless heavily subsidised via another cash-flow-generating activity. One of the first benchmarks for innovators is if their product or service is in the market and generating *revenues*. Revenues confirm that they create immediate value for a customer or third party. For academic entrepreneurs, revenues exclude grants but are directly analogous to contract research, especially from industry. The role of *angel and venture capital* is well documented in the literature. They are a major funding source for technology-based firms, alongside investments related to strategic partnerships. The dependence on financial capital was mentioned across several interviews; for instance: "What drives innovation is excellence and competitiveness and money." Interviewee 12 (Enterprise, Eastern Harbour City).

I2) Intellectual capital: Knowledge or intellectual capital can have many dimensions. Some of the most common quantifiable and codified forms are patents and publications (e.g., [83], [84], [85], with patent analysis and scientometrics being their entire fields of research). From a business perspective, patents are an input, often seen as the beginning of a commercial journey. Meanwhile, for many university-based researchers, patents are an output measure:

> *"Patents are kind of lagging indicators. They're not leading indicators, so they're just measures of innovation, but they're not demonstrating that it's actually translated." (Interviewee 27, Research, Eastern Harbour City)*

Working backward from an issued patent, other potentially quantifiable inputs identified include provisional patents, academic publications and invention disclosures.

Other forms of knowledge identified include technology, market knowledge, and proprietary analytical methods. Adopting and integrating *new technologies* is a central component of innovation at the organisational and individual levels. The rapid evolution of technology presents continuous opportunities to be an early adopter for enhancing processes, developing new products, and entering new markets [86]. C*ustomer-centric* market knowledge is useful for developing products, services, and solutions. These knowledge-related inputs can be measured and interpreted using increasingly advanced *data-analytic methods*. Even knowledge of such methods is another input to innovation, especially for organisations undergoing or completing a digital transformation process. For the sake of a pragmatic framework and given the current scarcity of data-analytic market knowledge, we focus on patents.

I3) Human capital: Talent is another critical input to innovation and comes from various sources and different levels of qualification: graduates (from high school, undergraduate and graduate programs), workplace experience and professional development, and imported from outside the system (e.g., immigration). One of the foundations of the triple helix and innovation systems literatures is the premise that university graduates go into industry. When prompted for suggestions about metrics relating to talent concerning technology innovation, there was convergence on measuring the number of employees with advanced degrees, (Highly Qualified Personnel or HQP), directly analogous to other studies that have measured the percentage of employees with PhDs (e.g., [87], [88]).

However, questions remain about the role of culture and graduate careers. Japen's "Salarymen" culture is a prime example about how graduates, their parents, and future spouses prioritise getting a stable corporate job over the uncertainty of working in companies or

founding a venture with as-yet unrealised high-growth potential. Interviewee 38 (Intermediary, Multi-City) highlights this interaction by describing how young founders lack established pathways to build innovative ventures and teams to complement their own capabilities:

> *"There is a shortage of a way to step into a conveyor belt which takes you through to success, and that conveyor belt is something which takes a young entrepreneur who's got fire in their belly, has a great idea but doesn't understand marketing, communications management, finances and every aspect of successfully running a business."*

I4) Cultural capital: Management and managerial capabilities are pivotal in cultivating innovation. Managing an innovation culture within an organisation is imperative to nurture creativity and the development of new ideas. Innovation management capabilities evidenced through the interviews include encouraging diversity, embracing failure, harnessing personal motivations, and allocating undirected time to innovate. The following quote indicates the pursuit of *diversity* in organisations as an input to innovation by bringing different perspectives to problem-solving:

> *"We recognise that if you don't actually have the right teams together, innovation is certainly limited because you need to have diversity of mindsets, diversity of thinking, diversity of groups and teams in order to get the best results." (Interviewee 06, Intermediary, Eastern Harbour City)*

By *embracing failure*, managers provide psychological safety to engage in behaviours that lead to innovation, such as experimentation, collaboration, and learning from mistakes. *Motivation* and a *sense of purpose* can contribute to innovation in both organisational and individual contexts. Purpose-driven organisations tend to attract talent that aligns with their mission and values. For innovators, intrinsic motivation stems from an internal desire to accomplish something meaningful and is particularly potent for challenging the status quo and driving innovation. *Time* is a precious and perishable resource related to innovation. Innovations often emerge from exploration, experimentation, and reflection, which require dedicated time. In many organisational settings, the pressure for immediate productivity and incremental efficiency gains can hinder innovation by not allowing individuals the time to think creatively and try new approaches. In terms of measurement, well-established surveys exist,

including fear of failure (e.g. Global Entrepreneurship Monitor). However, how any workplace within an innovation district cultivates a culture for innovation is likely only assessable via custom workplace surveys. Thus, we omit this dimension from a more geographical and industry-agnostic framework.

I5) Political capital: Leadership is not exclusively the domain of ecosystem leaders and politicians but a resource or capability that anyone in the system can acquire, develop and exercise. Compared to management's link to planning, goal setting, coaching and performance, leadership is more closely related to inspiration, motivation, mentoring, and role modelling [89]. Leadership can build legitimacy and plays a crucial role in lobbying and advocating for others in the system, whether for customers, suppliers, partners or employees. It also includes interacting with the broader ecosystem leadership. A direct connection with the immediate environment makes this form of leadership an external input to innovation rather than a driver. Although political capital and leadership can be hard to capture or quantify, leadership is a necessary input to innovation, as highlighted by Interviewee 21 (Intermediary, Central River City): *"So, challenge the status quo, that is the dictionary definition of innovation...challenge the status quo means you need a leadership that's up for that."*

Echoing the definition of innovation being the antithesis to the status quo, Interviewee 10 (Enterprise, Eastern Harbour City), connected the political capital with the leaders in the innovation system:

> *"There was so much comfort in the status quo. Strong leaders identify those people [who wanted to do things differently]. Strong leaders give them the permission and the space to go and try those things and the permission to fail or create a safe space to do that. I think for me it's test to learn, not test and learn."*

As a construct, political capital remains a challenge to operationalise and frequently absent from innovation systems metrics (e.g. [15] and [52]). Indicators may include the number of politicians (e.g. Minsters, Secretaries and Deputy Secretaries, Mayors, Councillors) or other ecosystem leaders who are vocally and legitimately advocating for innovation. On the note of

legitimacy, another proxy measure may the number of official government policy reports, action plans, blueprints, or mission statements that actively advocate for an innovation-based economy.

Broadening political capital to include ecosystem leaders who are not politicians, another proxy would be to measure the degree to which the public media cultivates an open discourse about innovation, such as the number of public media mentions, which compete for airtime or attention against other public interest topics.

I6) Social capital: Building robust networks is integral to innovation. Networks facilitate the exchange of knowledge, resources, and trade. They connect innovators with potential collaborators, investors, and customers. Furthermore, trust is a critical element in networks and innovation (e.g., [90], [91]). As a general insight about networks, they are a key resource for sharing ideas [92]. Interviewee 5 (Research, Eastern Harbour City) reinforces the value of diverse inputs within an innovation network:

> *"The fact that someone might bring in an idea from left field can make an innovation much more impactful."*

For local relationships, such as peer-to-peer learning between founders, intermediary organisations play a crucial role in brokering trust and relationships and facilitating network connections through their events and programs. However, the interviews highlighted the importance of different levels of networks: local, regional, and global.

The breadth and depth of the interview comments revealed complementarities between dense connections within the local innovation system, as well as connections to the global sector:

> *"In earlier research stages, these connections are international. We are speaking about really fundamental research. So, this is where international connections are more prominent. But the tech district or any other kind of local district, will probably come more prominently or permanently into play at later TRL, in the late material stages." (Interviewee 3, Research, Eastern Harbour City)*

I7) Built capital: The physical spaces of coworking spaces, accelerators, incubators and startup hubs, and various event spaces were prominently featured in the interview comments as an enabling factor for innovation. Particularly for research-intensive innovators, access to highly specialised labs is a critical input, as explained by Interviewee 51 (Research, Eastern Harbour City):

> *"The big driver for innovation is the convening power of our research infrastructure...And when you're convening so many people coming to the same place to do science, you're forging those links for new collaborations in the outcomes. So that's a big driver for innovation here...our strategy and approach to an ecosystem has been around how you optimise and how we create more of that serendipitous interaction around our infrastructure."*

Because of how idiosyncratic the space and equipment needs are for each enterprise, measuring the built capital remains challenging beyond quite generic measures like office floor space.

I8) Natural capital: Access to natural resources is often overlooked or taken for granted as an input to innovation. However, the impact of access to unique local natural environments was evident in some interviews. For example, the following quote illustrates how the natural surroundings can shape local innovation:

> *"The whole world is looking to us because we're stable. We're far away. We've got abundant sunshine and natural resources. So, we've got that incredible combination. And if we manage this well, we're setting up the sovereign wealth of our nation for generations to come. We are diversifying away from coal. It'd be less than 50% of exports by 2030. We've got these high voltage power lines that can take the power from the offshore wind turbines to the nation. So, it's just the right place at the right time in part." (Interview 55, Research, Lower Hunter and Greater Newcastle City)*

Natural capital is hard to quantify in relation to its use by an innovation ecosystem. As a proxy measure, natural capital valuations may be used, which are indicative of the natural resources available in a region, and the cost of offsetting them in case of industrialisation of that space. This puts a direct economic value on the soil, vegetation, and inhabiting species, but does not capture the secondary value of the natural capital (e.g. harbours for shipping, terrain for housing, industry and transportation, latitude for solar power generation, or potential for wave, hydro or wind power generation).

B. Innovation Outputs

Considering the literature and the interview data, five different types of outputs were identified. These include forming new organisations, economic value creation (e.g., new revenues, new funding, and job growth), increases in Technology Readiness Levels (TRLs), new capabilities and increased reputation.

Instead of treating output types and their measures separately, we have combined them to reflect the nature of stakeholders' responses, who often struggle to delineate an output type without considering how to quantify it. We have also expanded the five types of outputs into eight categories (O1-O8) to differentiate between bands of TRL and different kinds of capabilities.

O*1) New organisations:* New organisations become an output when a decision is made that a new organisation would be the best vehicle to nurture a new opportunity. Counts of enterprises or new business registrations are a standard metric (e.g., [13], [63], [64]). Interviewee 23 (Intermediary, Eastern Harbour City) reinforces that the number of startups or spinout companies is a general metric of innovation:

> *"...if you don't really mind too much about what type of innovation and take that very broadly, then it could just be startups or kind of spinouts of corporates."*

O2) Economic value created: As a continuation of Input 1, financial resources are the lifeblood of innovation. All the innovation activities, whether by research organisations or enterprises, have economic implications. These economic flows can be measured as research commercialisation income, revenues generated, jobs created, and follow-on funding received. That said, economic value creation was not necessarily the only goal of innovation districts, as Interviewee 34 (Intermediary, Eastern Harbour City) commented,

> *"You can't measure your achievement unless you know your objectives. Is your objective jobs, urban renewal, or quality of life?"*

O3-O5) Increases in Technology Readiness Levels (TRLs): TRLs are a widely used method for estimating the maturity of technologies. Developed by NASA and commonly used

in government projects, TRLs have also been applied in innovative companies to enable consistent discussions of technical maturity across different types of technology. TRLs are based on a scale ranging from 1 to 10, with 10 representing the most mature technology. For example, a TRL 1-2 level technology is in its invention phase. Potential performance metrics at this stage are limited to invention disclosures and patent applications or patent licenses. This is followed by a maturity level (TRL 3-6), where technology development results in new products and services, and then the production and partnerships level (TRL 7-10). For simplicity, we grouped the attainment of each TRL into three bands of TLR as O3 to O5.

Universities, research institutions, and intermediaries use other measures that roughly correlate with TRLs, such as records of inventions, number of provisional and full patents, and number of spinouts and investments raised. Meanwhile, many enterprises and some universities explicitly monitor TRLs. Interviewee 36 (Enterprise, Lower Hunter and Greater Newcastle City) describes their use of TRL as follows:

> *"It's all based on technology readiness levels. So, below TRL 3, Technology Readiness Level 3, it's all research and innovation. Once the concept has been proven, it gets handed over to development, part of research and development instead of research and innovation. Then, that goes through up to probably TRL 6. And once we achieve that, the commercialisation and manufacturing, they start getting involved at an early stage before we hit TRL 6 because the company has to prepare and make decisions on whether there are any capital investments required, if the company will manufacture itself, if the company will involve other companies in the manufacturing and how the supply chain will work."*

O6) Capability development: Capability development applies to leadership and management capabilities and employee capabilities. Because they can both be developed by the same people, we collapse them here because they represent changes in human capital (I3). Interviewee 57 describes the approach taken by an intermediary organisation in the Central Coast to measure capabilities:

> *"...that'll set us a baseline for what we'll measure during the program and get a sense of how we have improved business capability [of founders]. Are they more effective at moving ideas through their business? Do they commercialise more quickly? Are they more confident in their decision making that I know how to measure risk and return on investment, that I know how to forecast the potential size of the prize for innovation? Are they more connected? Has it generated more ideas? Has it generated more disruptive ideas, more transformative ideas*

on that kind of continuum of renovation versus disruption? And we'll look at things like, has their business grown as a result of more innovation effectiveness. So has their business grown with the view that that leads to industry growth with the view that that leads to economic prosperity for the region and job growth."

Another blunt measure of the increase in capabilities is closely related to economic value created (O2), namely jobs. Counting the number of jobs created is a common measure for policymakers while overlooking the qualitative aspects of each job or on-the-job capability development.

O7) Reputational gains: Reputation is important at the individual and system levels. While reports and rankings like Startup Genome are well known, only a few participants flagged reputation as an essential output to measure, which its intangible nature might explain. Measuring reputation can involve complex algorithms like PageRank, but it can also be approximated through simpler metrics like publications, media outputs and attention metrics of those outputs, such as page views, citations and altmetrics. In this vein, Interviewee 6 (Intermediary, Eastern Harbour City) explains that media coverage and attention metrics of their research outputs are considered critical measures of success:

"We do a lot of publicity. We do a lot of media work getting our outcomes out there. And we count that as a measure of success because our work is so clinical, and it's very important for people to know about it. And so, we look at the media's take up of our story. So, we create stories regularly about the research. A recent example was the wind farms research, which looked at whether the sound affects your health. And we did quite a lot of publicity because, actually, it's not important pushing that out to medical practitioners, it's important that the general public knows what those results are...So we call that as a measure of our success in terms of getting our innovations out into the public space." (Interviewee 6, Intermediary, Eastern Harbour City)

C. Measures of Innovation Inputs and Outputs

For each resource used as inputs or generated as outputs by enterprises in innovation districts, we matched them with the most accurate and longitudinally reliable data sources we could identify. We generally preferred data from official sources and records. In the context of Australia, this includes the Australian Bureau of Statistics (ABS) or the Australian Tax Office (ATO), which have equivalents in other countries [13]. While the sources listed below are

Australia-centric, any OECD country generally uses the same measures for inter-jurisdictional comparability, as do other countries' governments.

We also integrate supranational sources, such as the World Intellectual Property Organization (WIPO) or the well-regarded Global Entrepreneurship Monitor (GEM). The capitals and their measurement are summarised in Tables II and III as inputs and outputs of a given business cycle, respectively.

TABLE II: MEASURES OF INNOVATION INPUTS FOR INNOVATION DISTRICTS

Capital [References]	Measure	Source(s)
I1: Financial [61], [66], [15], [52], [53], [69], [50], [45], [70]	Profit margin increase	ABS
	Total Profit/Loss	ATO
	Usage of R&D Tax Incentive	ABS
	Expenditure on R&D	ATO
	Government funding obtained	ABS
	Angel and venture capital received	ATO, Pitchbook, Crunchbase, Dealroom, Startup Muster
I2: Intellectual [66], [61], [67], [68], [15], [52], [53], [69], [50], [2]	Active international patents	ABS
	Patents granted and applied; patent families	WIPO
	Ideas from research publications	ABS
	Scientific publications	Scopus, Clarivate / Web of Science
	Market research, Customer validation	ABS
I3: Human [61], [15], [52], [53], [69], [50], [45], [70], [2]	Highest level of education attained	ABS
	Employees dedicated to R&D	ABS
	Employees, roles, skills (endorsed)	LinkedIn
	Skills used (and shortages), Use of skilled migrants	ABS
	Use of internal and external training	ABS
	Use of Strategic planning & KPIs	ABS
I4: Cultural	Fear of failure	GEM
I5: Political	Count of government officials who publicly advocate for innovation	Factiva
	Counts of policy reports, action plans or 'blueprints'	
	Public media mentions	
I6: Social [67], [68], [15], [52], [53], [69]	Collaborations	ABS
	Social network connections	LinkedIn
	Event participation	Humanitix, Eventbrite, Meetup.com
	Publication and patent co-authorship	Clarivate / Web of Science, Derwent
I7: Built [15]	Commute time in Household travel survey	State government survey
I8: Natural [2]	Natural capital accounting, aka Environmental economic accounts	ABS

In many circumstances, the output measures in Table III are the same as the input measures in Table II, just lagged by one business cycle. For limitations of these data sources, see our limitations section.

TABLE III: MEASURES OF INNOVATION OUTPUTS FOR INNOVATION DISTRICTS

Outputs [Reference]	Measure	Source(s)
O1: New organisations [65], [66], [61], [15], [52], [53], [69]	Businesses by industry, entries, exits, change	ABS
	University spinoffs	SCOPR*
	Number of startups	Pitchbook, Crunchbase, Dealroom, Startup Muster
O2: Economic value [65], [66], [61], [15], [52], [53], [69], [45], [70]	Licensing out of IP rights	ABS
	Commercialisation income	SCOPR
	Revenues from new innovations	ABS
	Angel and venture capital raised	ATO, Pitchbook, Crunchbase, Dealroom, Startup Muster
O3: TRL 1-2 [65], [66], [15], [52], [53], [69], [50]	Invention disclosures and patented IP	SCOPR
	Scientific publications	Scopus, Clarivate / Web of Science
O4: TRL 3-6 [15]	New or significantly improved products or services	ABS
	Increased exports for most significant innovation	ABS
O5: TRL 7-10 [52], [53], [69]	Collaborations	ABS
O6: Capability development [68], [15], [52], [53], [69], [50], [45], [40]	Highest level of education attained	ABS
	Employees dedicated to R&D	ABS
	Employees, roles, skills (endorsed)	LinkedIn
	Skills used (and shortages), Use of skilled migrants	ABS
	Use of internal and external training	ABS
	Use of Strategic planning & KPIs	ABS
O7: Reputational gains	Citations of research (academic, social, media, policy)	Dimensions.ai Altmetrics, WIPO
	Media mentions	Factiva, D&B Hoovers
	Employment reputation	Glassdoor
	Ranking	Startup Genome

* Survey of Commercialisation Outcomes from Public Research

D. Drivers of innovation

While validating innovation activities and metrics can be used at the level of innovation districts, we also identified drivers of innovation. Drivers can be quite idiosyncratic and very difficult to measure, so we focus on their description. Where possible, we note potential avenues for their quantification.

These drivers are factors in the environment, external to organisations, that stimulate those organisations to be innovative and generate innovation outputs. Drivers often materialise by increasing the availability of and accessibility to innovation inputs. This environmental level is the level at which governments are best placed to intervene, with policies that shape the shorter- or longer-term availability of resources in the system. The analysis identified seven types of innovation drivers (D).

D1) Innovation policy targeted at the innovators: Examples of these types of policy instruments include tax incentives for R&D and investors, grant schemes and visa programs that provide direct benefits to specific innovators. For example, Interviewee 25 highlighted the critical importance of R&D tax incentives:

> *"The R&D tax incentive is excellent. And I think it's massively underrated. We wouldn't be here if it wasn't for the R&D tax incentive, we would be in the US.'" (Intermediary, Multi-City)*

Quantifiable innovation policy drivers include the use of R&D tax incentives, totals of various innovation-related grant schemes (incl tech, education, health, agriculture or other sector specific programs) and counts of skilled migrant visas.

D2) Innovation policy targeted at the cluster or precinct level: These policies are designed to increase the availability of specialised infrastructure for the collective benefit of an ecosystem segment. This includes policies that support basic infrastructure like public transit, ports and harbours. It also includes investment in specialised buildings, labs, and equipment.

> *"Innovation in deep technologies is a long game and capital intensive. We need to get machinery, a lot more prototyping, and shared facilities." (Interviewee 11, Research, Multi-City)*

Quantifiable infrastructure policy drivers include the quantity and magnitude of programs to build infrastructure for a network of researchers, usually at the fringes of a university or health district, such as new medical labs, (nano)fabrication labs, or other bespoke spaces. More generic infrastructure may be quantified as a percentage of population who have a 30-minute or less commute and broadband home internet access.

D3) Regulatory environment: This includes the set of laws, policies and guidelines, typically at the federal level, that apply to all organisations. Examples that regulate the development and commercialisation of innovations are IP protection laws, workers' rights, consumer protection and compliance with sustainability standards, immigration policies and government procurement policies. Interviewee 25 notes the benefits and risks of encouraging local or domestic procurement and recommends a co-development process to de-risk the impact:

> *"Governments shouldn't buy second-rate products to stimulate local industry. [However,] they can think about the staging of procurement requirements to make it easier for startups to contribute or to enter into co-development projects." (Intermediary, Multi-City)*

This category of driver is especially challenging to quantify. It includes the existence of broad regulations, such as robust IP regulations, and fair or minimum wage regulations. And it may include site or organisation specific regulations, such as trial areas for autonomous vehicles, or (government) organisation-specific procurement policies and their enforcement.

D4) Long-term vision and planning: These include formal government plans and role modelling by ecosystem leaders and anchors that are expected to be long-term oriented. Classic examples include National Innovation Agendas, R&D Roadmaps, and other official vision statements. Interviewee 61 identified ones specifically at the innovation district level:

> *"In the last so five years, government really has prioritised 3 new Innovation Districts: Tech Central, Aerotropolis and Westmead and it's taken a view that these should be the three priorities for the state and that they should not only get prioritisation but they should have prioritisation within a domain. So Westmead is medical, Tech Central is some digital or quantum, and Aerotropolis is advanced manufacturing." (Research, Eastern Harbour City)*

Here too, the plans and road maps are difficult to quantify, and at least need to be considered in more descriptive terms.

D5) Innovation culture and environment: These drivers reflect broader societal values regarding innovation, entrepreneurship, diversity of ideas, risk, and uncertainty. In Australia, idiosyncratic cultural aspects are deeply rooted in society and negatively affect innovation (e.g.,

Tall Poppy Syndrome) while also encouraging anyone to have "A Fair Go". The appetite for innovation is culturally tempered by a risk aversion and preference for corporate careers.

> *''...stick to your knitting, go get a job in the bank and don't try anything new because we're Australians we're built on avoiding anything new or novel or interesting and that culture has created a lot of anxiety in the venture ecosystem." (Interviewee 25, Intermediary, Multi-City)*

Some indicators of culture exist, such as 'fear of failure' measures by the Global Entrepreneurship Monitor [93] or aggregated psychological data of 'openness' and other Big Five personality traits related to innovation [94].

D6) Competition and collaboration: Classic cluster theory explains that co-location in larger clusters increases the pressure to compete and differentiate and provides a more significant number of collaboration options [41]. New entrants can face disproportionate competition in markets dominated by oligopolies that can use non-market strategies to compete. However, these incumbents can also become partners and stepping stones to international markets.

> *"This country doesn't have the critical mass to allow itself to be isolated. We leverage existing physical infrastructure with a localised approach, but we also try to foster synergies across capabilities that are dispersed across the territory. Hubs bridge their local environment to connect more broadly with the region, but with the nation and then with the international value flows." (Interviewee 44, Research, Out of State)*

While measures exist about the competitiveness of doing business at the country level [95], they remain to be operationalised at the city or innovation district level.

D7) Broader ecosystem conditions: These conditions are generally not classified elsewhere, such as amenities that provide a higher quality of life and enable more capacity for productivity, affordable daycare and affordable housing. These broader conditions can influence individuals' willingness or capacity to engage with their environment, affecting how much they can afford to explore and more incidental opportunities to network and identify opportunities. Creating an environment that supports individuals not just professionally but also personally can be essential for sustaining innovation in the long term. See Table IV for suggested proxy measures.

TABLE IV: EXAMPLES OF INNOVATION DRIVERS FOR INNOVATION DISTRICTS

Drivers	**Examples**
D1: Innovation policy targeted at the innovators	Taxation and incentives (e.g., Taxation rates, purpose, industry and place specific taxation incentives) Federal grant schemes (e.g., Programs, funds and grants which support the development of the innovation ecosystem from the Federal government and its departments) State grant schemes (e.g., Programs, funds and grants which support the development of the innovation ecosystem from State governments and their departments) Visas (e.g., Federal visa programs)
D2: Innovation policy targeted at the cluster or precinct level	Amenity and mobility (e.g., roads, rail and public transport investments towards a 30 minute-city) Industry specific and/or specialised infrastructure (e.g., Access to relevant labs, equipment & facilities) Digital connectivity (e.g., Universal high-speed internet access through different telecommunication modes)
D3: Regulatory environment	IP protection Industry standards and regulations Procurement policies
D4: Long-term vision and planning	Federal (e.g., National Innovation and Science Agendas) State (e.g., State plans, State R&D roadmaps)
D5: Innovation culture and environment	Fear of failure Perceived opportunities Entrepreneurial intentions
D6: Competition and collaboration	Market concentration levels and trends reported by state and/or federal government and by sector
D7: Broader ecosystem conditions	Macro-economic conditions (e.g., market size/demand, FX, inflation, interest rates, cost of living, affordability)

V. DISCUSSION

This study contributes to the intersection of innovation systems, entrepreneurial ecosystems, and the literature on innovation districts. In the innovation district literature, we show the value of incorporating regional innovation systems thinking into place-based innovation activities while recognising the complex systems nature of the precinct. This is a departure from the innovation district literature's emphasis on urban planning and allows for an extension beyond cluster-, spillover-, agglomeration-, or other co-location-based theories (e.g. [50]).

This study also advances regional innovation systems and entrepreneurial ecosystems research by providing a holistic and replicable framework to operationalise and measure

innovation performance at the level of innovation districts. We offer a holistic framework that facilitates identifying and evaluating relevant input and output resources necessary for innovation districts to function successfully as a local place-based innovation system. We recognise that reducing a system to an aggregation of inputs and outputs does not entirely capture their interrelationships and the system's dynamics; it nonetheless captures the role of time from one business cycle to another. This framework enables a more longitudinal analysis of which resources within the system are more or less abundant and the impact on the system's performance.

In that regard, our analysis highlights the importance of innovation drivers that influence the munificence of environmental resources and provide conditions that may enable or inhibit innovation within innovation districts. These drivers are particularly interesting to policymakers who coordinate policies to reduce barriers and find the right balance of enablers [96], [7] and firms who choose which innovation district they want to grow their firms in.

Recent empirical studies on innovation districts and entrepreneurial ecosystems have offered proxy measures (e.g. [67], [48], [65]) or more comprehensive measures at a regional level (e.g., NUTS2 or county, such as [66] or [61]). The proxy measures do not enable deriving a more holistic profile of each innovation district, and the regional measures do not capture details at the city or innovation district level. What is needed is a more holistic framework of multiple measures linked to reliable data sources at the level of innovation districts, preferably as few data sources as possible. The triple-helix literature has attempted to provide such a framework [15]. However, their use of Delphi Analysis does not have the depth of validation among practitioners as this study, nor does it leverage a more parsimonious set of official data sources as our framework. We hope that the framework we develop and its alignment with official national and OECD measures will enable researchers to further study the evolution and system

dynamics of innovation districts from a more holistic and longitudinal perspective and in a way that takes into account each innovation district's unique profile.

A. Contribution to innovation policy and practice

This study contributes to innovation policy and practice by providing policymakers with a means to implement an effective measurement tool for longitudinal monitoring at the level of innovation districts and, therefore, a means of evaluating and coordinating different innovation policies. As indicated by the drivers of innovation and the role of managers in organisations, coordination of policies for innovation districts will entail interacting with federal policies, tailoring state-level policies, bespoke innovation district policies, and interacting with firm-internal policies. This multi-level policy coordination is an easily overlooked artifact of innovation systems' nested and networked nature. The study also advances the research stream on innovation districts by deriving a comprehensive conceptual framework that proposes empirical metrics to measure placed-based innovation, thereby responding to calls for a stronger focus on the concept of innovation in the literature on innovation districts.

B. Limitations of the measurement framework

While most measures in the framework are collected by governments as part of the OECD manuals, in many instances, the nationwide sampling of the data has historically only allowed for disaggregation by state but not yet by city or innovation district. However, the Australian government links business data from the tax office with these measures to allow for more comprehensive analysis using a single database. In addition, some states are conducting surveys using these metrics to drill down to the innovation district level, with some of that data then being shared back to the federal statistics bureau. More rigorous methodologies of collecting innovation district data exist, especially for more subjective measures like leadership and culture, but remain impractical for longitudinal data collection analysis (e.g. [53]).

A common workaround for comprehensive data sets is the use of proxy data (e.g., [67], [47], [65]), including commercial data sets. However, in addition to concerns about construct validity, using proxy measures risks being reliant on the integrity and accuracy of those data sets. Using a limited set of proxy measures only allows for identifying concentrations or hot spots of innovation. Still, it lacks the qualitative texture, such as sector specificity, R&D intensity or partnerships, leveraging of various policies (e.g., immigration, basic research grants, R&D tax incentives).

We also note a conceptual limitation of innovation districts. The urban planning perspective usually prescribes a fixed area of land, like a science park, but it can also be prescribed at the level of a postcode, suburb, or municipality. While this aligns with urban planning and local and municipal economic development, it downplays the degree to which innovation districts are connected within their nearby local environment, the region or globally.

We also note a surprising limitation in the framework as validated by individuals in the system and vetted by state innovation policy makers, in that no stakeholder or policy maker suggested a metric that is specific to the whole of the system. Such measures might include the economic complexity of the local economy or the network centrality or clustering coefficient of the stakeholders within the system. Consequently, to maintain an empirically validated and parsimonious measurement framework, we omit these measures. In lieu of more sophisticated system-level metrics, each of the current measures in the framework is primarily an aggregation of innovation activities at the firm level. Updating the framework may involve normalising or averaging some metrics by the number of businesses for better comparability across districts or time.

For pragmatic reasons, we have reduced the role of time to measuring inputs and outputs over a business cycle. While this starts to recognise the importance of time in innovation systems, more longitudinal analysis is required to explore time lags between when inputs are

converted into outputs and how long it takes for those outputs to recirculate as inputs. For example, in some ecosystems, successful exits of venture-backed firms are faster or slower at providing angel and venture capital for the next generation of firms. For policy evaluation, longer-term data analysis is required, which appreciates that ecosystems can take decades to evolve and cannot be created on green fields simply by pouring billions of dollars into new buildings.

VI. CONCLUSION

This study contributes to the innovation districts literature by presenting the innovation district as a (complex) innovation system. In doing so, it places greater emphasis on innovation than on space and urban planning and brings the role of time to light. This study also contributes to the innovation systems literature by presenting a pragmatic framework with measures that can be operationalised across jurisdictions and possibly decades of data.

These theoretical contributions are underpinned by the empirical and methodological contribution of providing a framework, validated through interviewing 67 practitioners across multiple regions, districts and sectors, that can be put into practice using official data sources that provide increasingly detailed geographic granularity. The framework and proposed measures were also vetted by a peer network of innovation systems academics who acted as a scientific advisory board and the team of state government policymakers.

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