Promoting Entrepreneurial Universities in India: A Case Study of IIT Madras

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Abstract

Entrepreneurial Universities (EUs) are gaining increasing significance across the globe, as a source of deep-tech start-ups. EUs through the generation of knowledge-based entrepreneurship, along with teaching and research, are emerging as a new source of deep-tech startups in the developed world. Among the emerging economies, India has the potential to emerge as the leading *Start-up Nation* globally. If an increasing number of deep-tech start-ups has to emerge from India, it is imperative to consciously and explicitly promote EUs. However, EUs are a new phenomenon and efforts to promote EUs are at their infancy in India as of now. Though India pursues an exclusive "startup promotion policy" at the national level as well as at the regional levels since the middle of the last decade, there is no explicit emphasis on EUs yet. Against this backdrop, this article explores the evolution of IIT Madras as an EU along with its Research Park, its major entities, their interrelationship, and role they play in the generation of deep-tech start-ups. Subsequently, the article proposes an EU structure for deep-tech startups, in the context of IIT Madras. Finally, the article brings out how IIT Madras has gained Sustainable Competitive Advantage through its EU and then derives policy implications for the promotion of EUs.

Keywords: Entrepreneurial University, Deep-tech startups, Knowledge commercialization, Innovation ecosystem, Research Park, IIT Madras

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1. Introduction

Knowledge-based entrepreneurship, as a means of deep-tech start-ups, is gaining steady importance, particularly in the developed world. Knowledge has a decisive role in enhancing production for economic growth, and **Entrepreneurial Universities (EUs)** play a crucial role in the generation of knowledge and its commercialization for new venture creation (Feola, et al, 2021; Klein and Peterira, 2020). EUs can transform an economy through their entrepreneurial contributions for economic growth, employment creation and competitiveness in global markets. EUs are knowledge producers as much as its disseminators (Guerrero and Urbano, 2012). EUs would contain multiple support measures for entrepreneurship as well as developers of administrative techniques, strategies, or competitive postures (Prokop, 2024). Those economies who can successfully promote entrepreneurial universities will be able to take a distinct lead against the rest in terms of competitiveness and economic prosperity. In fact, EUs play an essential role in economic development in different countries (Arroyabe, et al, 2022).

Given the above, India being an emerging knowledge power (D'Costa, 2015), a centre of innovation and creative ideas (Natarajan, 2013), it is high time we explicitly encourage EUs as a means of high-quality entrepreneurship (for deep-tech start-ups), for accelerating employment generation and economic growth. This assumes significance in the context of India's New Education Policy (NEP) 2020 (Ministry of Human Resource Development, 2020). But the questions that naturally arise are: How do we promote EUs? What should be its structure and mechanism? Do we have any *desi* model to look upon? If yes, what lessons can we derive out of it? This paper attempts to understand these issues and emphasises the need to promote EUs in India. This is done based on the experience of IIT Madras, which was declared as the 'Top Innovative Educational Institute in India in 2020' (for the third time in a row) (Ministry of Education, 2021), and its 'Research Park Model' has been considered for replication in other IITs and IISc, Bangalore in the 'Start-up India Policy' in 2016 (Startupindia, 2016).

2. Entrepreneurial Universities: A Literature Review

What significance or uniqueness EUs have for start-up nurturing? Formal education is one of the sources of knowledge, which influences one's ability to perceive an opportunity - to one of the consequences of entrepreneurship - one's ability to act on that perception and thus to be innovative (Link, 2014). Thus "capitalization of knowledge" is at the heart of EUs, linking universities to users of knowledge more tightly and establishing the university as an economic actor (Etzkowitz, 2020). EUs not only continuously generate and accumulate knowledge, but they disseminate the generated knowledge and exploit them through entrepreneurship (Adesola and Datta, 2020). Thus, EUs are important sources of many new ideas in science and technology that contribute to innovations. By producing new knowledge, and exposing students to that knowledge, EUs not only generate new ideas but prepare

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knowledgeable, inventive, and motivated graduates who can carry and transform those ideas into business enterprises (Prokop, 2024). EUs have evolved as a "natural" incubator supporting entrepreneurship, innovation, and sustainability in the university community (e.g., students, alumni, and staff) (Guerrero, et al, 2023).

Thus, universities have the potential to play a key role in generating ideas or ideation and taking it forward for the creation of Proof of Concept (POC) and Prototype Development to culminate in a Minimum Viable Product (MVP), and early market identification for venture creation. To be specific, they are an ideal ground for ideation, innovation generation and commercialization for venture creation (US Department of Commerce, 2013). Given this, establishment of innovation and entrepreneurship ecosystems involving TBIs and technology transfer offices, among others, in universities is justifiable as they can play a decisive role in promoting venture creation through student and faculty entrepreneurship, based on their generated and accumulated knowledge and ideation. In the EU, entrepreneurship is at the core of the mission of the institution and this idea permeates the whole institution (Sanyal, 2023).

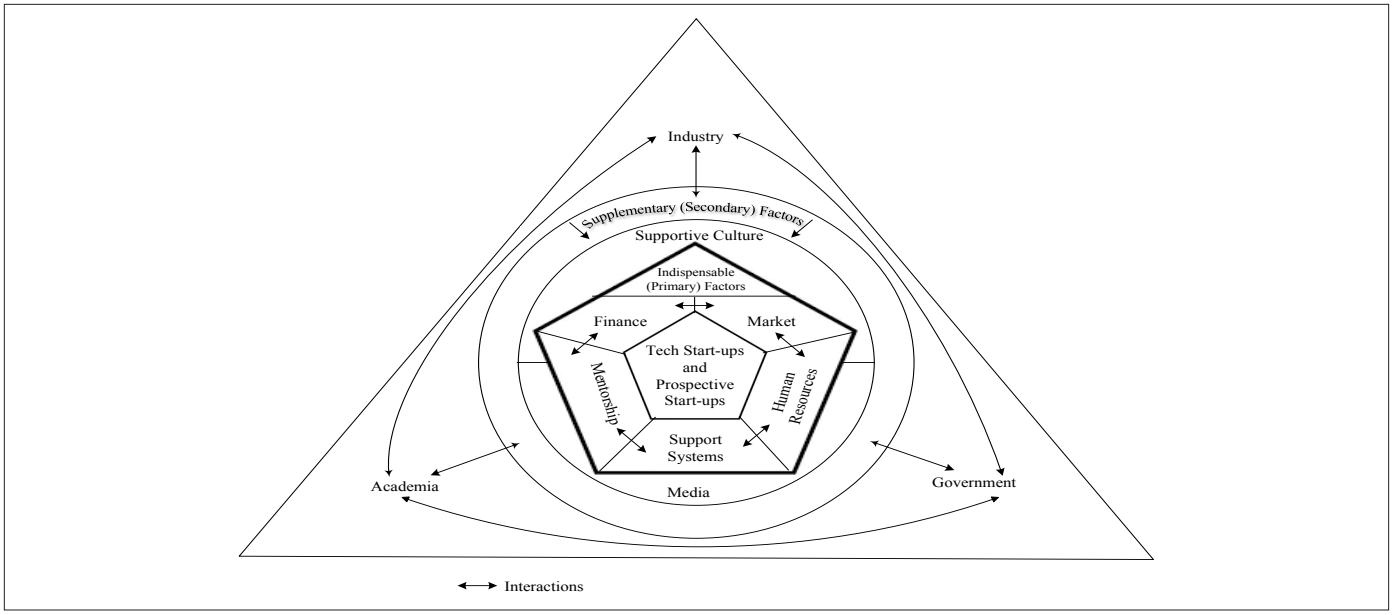
Accordingly, universities across the world are required to operate more entrepreneurially, commercializing the results of their research and spinning out new, knowledge-based ventures. EUs would view their graduates not only as future job applicants but also as future job creators, and the organization and content of teaching and research activities would reflect this conception (Guerrero-Cano et. al., 2014). As part of this strategy, universities are creating institutional arrangements comprising Technology Transfer Offices, Incubators, Entrepreneurship Development Centers, and internal seed funds for research commercialization (Abreau and Grinevich, 2024). This has gradually and steadily led to a considerable increase in the generation of university-based technology entrepreneurship via patenting, licensing, start-up creation, and university-industry partnerships. Therefore, university-based innovation-entrepreneurship ecosystems are growing in importance and are increasingly the focus of public policy (Bedo, Erdos and Pittaway, 2020).

EUs can develop entrepreneurship through innovations because they would have nurtured an entrepreneurial ecosystem with the help of their own hard and soft infrastructure built over the period, as well as through their alumni spread across governments, industry, and academia. EUs will have high quality faculty, accumulated intellectual capital with high scientific productivities which have a significant influence on start-up creations (Rao and Mulloth, 2017).

EUs will have strong research collaborations with other academic and industrial enterprises nationally as well as internationally. Faculty and students exchange between international universities would have given them a global exposure steadily.

Thus, internationalization of education would be a significant feature of EUs. In addition, they will have their own incubators to nurture entrepreneurship. EUs, in general, have a strong network of industries (who can play a vital role in patent commercialization and as early market adopters, among others), Angels and Venture Capitalists, industry-based alumni as business mentors and start-up cofounders, and their superannuated faculty as technology mentors, among others. Thus, EU will have an entrepreneurial ecosystem with a basic structure including all its elements: sources of entrepreneurship, human resources, business and technology mentorship, finance, market, and support systems (incubation support), with a triple helix base comprising academia, industry, and government (Figure 1). It will have an entrepreneurial culture of its own, with adequate media attention and support as well.

Figure 1: An Entrepreneurial Ecosystem



Source: Bala Subrahmanya (2021)

Therefore, EUs are natural incubators, at the very heart of innovation, creativity, and economic growth by providing support structures for faculty and students to begin new intellectual and commercial enterprises (Pugh, et al, 2018). EUs are an ideal ground for ideation, innovation, and commercialization for venture creation through teaching, research, and entrepreneurship promotion. It is a natural incubator which tries to provide a fertile environment in which university community (faculty, students, and employees) can investigate, evaluate, and explore ideas that could be transformed into entrepreneurial initiatives (Prokop, 2024).

Research Gap:

The above literature review brings out that an EU must have some pre-requisites if it must emerge successfully to generate tech start-ups. Research focused faculty, students, and employees with an internal infrastructure and external networks are imperative for the emergence of an EU. There must be an effective coordination between these networks. However, as of now, there is no adequate clarity on the structure, process, and performance of an EU in any context (Meissner, 2018). Particularly, EUs assume significance for promotion in the context of emerging economies like India as a means of generating deep-tech startups for accelerating its economic growth. It is against this backdrop that we attempt to understand the structure, process, and performance of an EU in the Indian context, based on a case study of IIT Madras, an institute of national importance. But the significance of IIT Madras must be perceived within Indian economy which is considered to have a high potential to emerge as a leading *Start-up Nation* globally.

3. Research Objectives, Scope and Methodology

3.1 Research Objectives

The proposed study has the following research objectives:

- To illustrate the potential to promote EUs in the larger context of Indian economy,
- To examine the origin and structure of an EU in the context of IIT Madras, and
- To explore the process and performance of deep tech startup generation in the EU.

3.2 Scope

These research objectives are studied with reference to IIT Madras, as a case study. IIT Madras was chosen for the case study because, it was declared as the 'Top Innovative Educational Institute in India in 2020' (for the third time in a row) (Ministry of Education, 2021), and its 'Research Park Model' was considered for replication in other IITs and IISc, Bangalore in the 'Start-up India Policy' in 2016 (Startupindia, 2016).

3.3 Methods of Data Collection and Analysis

A thematic analysis was carried out with a focus on IIT Madras (along with its Research Park) as an EU. Thematic analysis involved the identification and reporting of patterns in a data set, which are then interpreted for their inherent meaning and develop a conceptual model (Naeem, et al, 2023). The authors gathered qualitative data based on already published literature from the print media as well as internet/web-based resources pertaining to IIT Madras focusing on news relating to nurturing and generating deep-tech startups from the institute, over a period. This enabled us to identify the entities of EU in IIT Madras, their interrelationships, and define the structure accordingly. This was followed by an analysis of performance of the EU in terms of generating deep-tech startups spread over sectors and number of startups.

4. Indian Economy: High Potential to emerge as a Start-up Nation Globally?

At the outset, it is necessary to understand the resource base and policy environment prevailing in Indian economy for promoting EUs. India has the human resource base, steadily growing income base, and a vast base of higher education institutions: (i) More than 50% of India's population is younger than 25 years old and more than 65% of the population is 35 years old; (ii) Per capita income increased from US$ 540 in 2003 to US$ 2400 in 2022; (iii) India has more than 1000 universities, and 44,000 independent higher education institutions, more than 2500 engineering institutions which generate more than 1.5 million graduates annually (Ministry of Finance, 2023). Together, they form the base for entrepreneurship, human resources, and market potential, among others.

In addition, more and more MNCs of the world are increasingly entering India through Foreign Direct Investments (FDI). The FDI inflow to India increased from US$ 24 billion in 2021 to US$ 50 billion in 2022 (DPIIT, 2024). Many of these MNCs support start-up ecosystems in the form of nurturing tech start-ups through their exclusive 'corporate accelerators', Corporate Venture Capital (CVC), sabbatical leave for their employees for entrepreneurship, corporate entrepreneurship for intrapreneurship and start-ins, apart from mentoring (Varadharaju and Bala Subrahmanya, 2024).

Exclusive policies are emerging across the country: 31 out of 36 States and Union Territories have an exclusive start-up policy in the country today, apart from that of the national government (Startupindia, 2024). National government is strongly encouraging the setting up of Technology Business Incubators in educational institutions for promoting entrepreneurship. Digital India initiative is another policy which would transform start-up ecosystems radically. Digital India initiative was launched in July 2015 to transform the country into a digitally empowered society and a knowledge-based economy through infrastructural upgrades, ensuring digital access, digital inclusion, digital empowerment and bridging the digital divide, which would foster entrepreneurship and innovation (HSBC, 2023; PIB, 2022a).

An increasing number of 'returnee entrepreneurs' is emerging in India who look for domestic co-founders and lead to knowledge spillovers within the country (Pruthi, 2018). Many of them would have gone for higher education and/or employment from science/engineering and management institutions including IISc/IITs/IIMs to developed coun-

tries before returning to India, with 'superior' knowledge capital, social capital, and financial capital, apart from managerial and entrepreneurial skills (Qin and Shin, 2017). The source for 'returnee entrepreneurs' is Indian diaspora which is the highest in the world today: of the total 18 million Indian diaspora, more than 56% is in the developed world (The Economist, 2023).

All these facts indicate India's high potential to generate a steadily increasing number of start-ups, tech start-ups, and deep-tech start-ups along with building its entrepreneurial ecosystems. Apart from Bangalore, NCR Delhi, Mumbai, Hyderabad, Pune and Chennai, more and more cities are getting recognition as the next generation start-up hubs in India (Yourstory, 2023). In fact, India is witnessing the emergence of an increasing number of start-ups year after year: about 2/3 of the total registered start-ups in India have emerged during 2020-2022. An increasing number of start-ups is becoming Unicorns: there are 111 unicorns as of October 2023, of which 68 unicorns (>60%) emerged during 2020-2023. India is considered the second largest start-up ecosystem in the world today (Startupindia, 2024).

While the start-up ecosystems in India are thriving across the country with the emergence of more and more start-up hubs, they see the spring up of start-ups of varying quality. However, the rate of survival/exit of start-ups is not yet ascertained, though it is widely believed that while thousands emerge, only a few hundred survives, and a few scales up every year. Our leading start-up ecosystems like that of Bangalore and Hyderabad are still evolving, and thus are not fully matured, leave alone self-sustainable like that of Silicon Valley or Israel (Bala Subrahmanya, 2021). A significant proportion of the start-ups is in the service sector with a focus on the domestic market. It is not clear how many of the start-ups are truly innovative, and patent-based, which are likely to have a global focus. Given this, explicit promotion of EUs is imperative for achieving high-quality start-ups with a higher life-expectancy rate: they can become the real "game changers". Among all, IITs in India can be a potential source for promoting EUs, as they occupy a unique position on the global technological landscape (Salam, 2018).

5. IITs: A Backdrop:

The first conceptualization of the Indian Institutes of Technology (IITs) can be traced back to the end of WWII and before India's independence when Sir Ardeshir Dalal from the Viceroy's Executive Council foresaw that the future prosperity of India depended on technology and conceptualized the institutes (Council of Indian Institute of Technology, 2023). Post independence, Jawaharlal Nehru pioneered the establishment of IITs to provide trained technical personnel of international class to the nation to act as technology leaders for the future of the country. The first IIT to come up was IIT Kharagpur in 1950 followed by IIT Bombay (1958), IIT Madras (1959), IIT Kanpur (1959), and IIT Delhi (1961) (Council of Indian Institute of Technology, 2023). The IIT system has 23 Institutes of Technology today (Department of Higher Education, 2024). These institutes are globally recognized as centres of academic excellence and are reputed for the outstanding calibre of the graduates emerging from them.

Faculty at IITs is recruited through a rigorous process, and only PhD qualified candidates with proven research credentials are recruited. Faculty emoluments are paid by the government of India. Students for under-graduate programs are selected through Joint Entrance Examination (JEE) (main followed by an advanced one for those who qualify in the main examination), which is considered one of the toughest exams in the world. Hardly 2% of those who appear for the JEE main examination finally make it to the IITs (Niazi, 2022). Those who make it can get subsidized education, facilitated by the government of India (Sharma, 2016). Graduate Aptitude Test in Engineering (GATE) qualified graduates, among others, are admitted to post-graduate and research programs and are paid scholarship by the government of India.

Thus, IITs are considered to possess India's brightest minds in the form of highly qualified faculty and intelligent students. This apart, IITs get regular budgetary grants from the government of India, for building and sustaining their infrastructure, among others (Yadav, 2023). Thus, government support occupies a decisive role in the formation and functioning of IITs. Among the IITs, IIT Madras stands apart as it has won National Intellectual Property Awards 2021 & 2022 for being the top academic institution in India for patent filing, grants, and commercialization (PIB, 2022b).

6. IIT Madras: A High Impact Entrepreneurial University

6.1. IIT Madras: Status

IIT Madras was established with German technical assistance in 1959. It is one among the foremost institutes of national importance in higher technological education, basic and applied research. Today IIT Madras has 591 faculty members comprising Assistant, Associate and Full Professors, 677 staff members, 2105 under-graduate students, 4112 post graduate students, 746 MS research students and 2963 PhD research scholars spread over 17 academic departments (IIT Madras, 2024). This forms the human resource base of the Institute. As of now, the Institute has 829 projects and 146 patents (IIT Madras, 2024).

The Institute has global engagement in the form of (i) international student and faculty exchange programmes, (ii) Research program exchanges, (iii) Joint degree programmes, (iv) 'Study abroad' programmes, and (v) conducts international conferences and symposiums regularly. The Institute has an office of Alumni and Corporate Relations (ACR) which serves as the primary interface between the Institute and alumni. In addition, it serves the student community by facilitating mentorships with alumni, among others (IIT Madras, 2023). IIT Madras Alumni Association, founded in 1964, has a membership of over 55,000 alumni spread across multiple chapters around the globe (IIT Alumni Association, 2024).

IIT Madras has a strong collaboration with industry in the form of doing research and consultancy projects for industry involving both faculty and students, and industry executives doing PhD in the Institute on a regular basis. Thus, 'research focused' high quality faculty and students,

extensive international orientation, a strong alumni base, and an active industry collaboration developed over the period are the hall marks of IIT Madras which laid the foundation for nurturing IIT Madras as an EU. All this would have enabled the institute to nurture innovation and entrepreneurship and emerge as the leading innovative institute in the country.

6.2 EU Ecosystem in IIT Madras: Structure and Entities

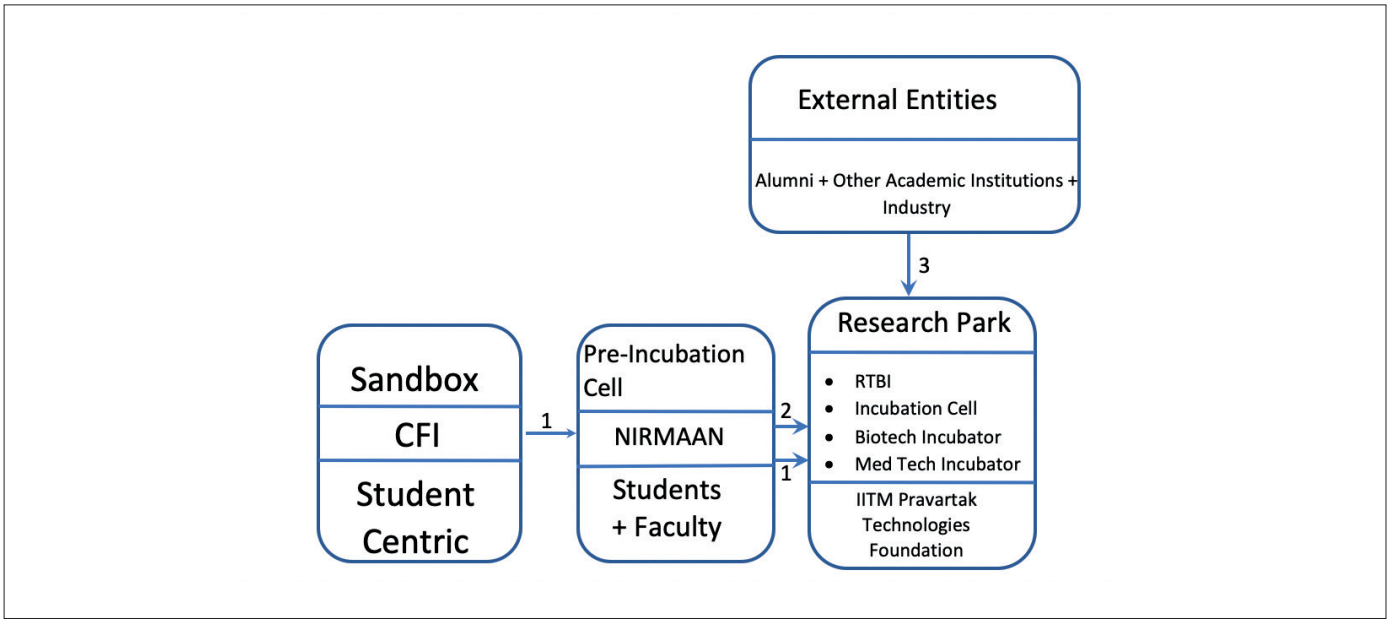
Thus, the foundation for the first EU in India was laid at IIT Madras much before the formulation of an exclusive Start-up promotion policy of India. In fact, the 'Start-up India policy 2016' has proposed to replicate the Research Park model of IIT Madras in six other IITs and IISc, Bangalore. But EU ecosystem of IIT Madras extends beyond its Research Park (hereafter RP). The different entities of EU ecosystem at IIT Madras along with their respective years of emergence are given in Table 1. As evident, these entities have been created over a period of one and half decades. The EU ecosystem has emerged over a period, based on learning and experience, and not based on any pre-defined plan. Given this, it is appropriate to understand how these different entities are related to one another, and how do they generate entrepreneurship for deep-tech start-ups.

Table 1: EU Entities at IIT Madras

Serial No.	Name of the entity	Year of establishment
1	Research Technology & Business Incubator (RTBI)	2006
2	Centre for Innovation (CFI) [Sandbox]	2008
3	Research Park (RP)	2010
4	Incubation Cell (IC) – Mother Incubator	2013
5	Biotech Incubator	2014
6	Nirmaan (Pre-Incubation Cell)	2015
7	Med Tech Incubator	2016
8	IITM Pravartak Technologies Foundation	2020

The different entities of IIT Madras EU ecosystem, among others, can be classified under three major segments, namely, (i) Sandbox known as Centre for Innovation (CFI), (ii) Pre-Incubation Cell known as Nirmaan, and (iii) RP which comprises four Technology Business Incubators, namely, Incubation Cell, Rural Technology and Business Incubator, Biotech Incubator, and Med Tech Incubator; and IITM Pravartak Technologies Foundation (Figure 2).

Figure 2: EU Entities and their Inter-relationships



As has been depicted in Figure 2, full-fledged entrepreneurship in the form of start-ups emerge from RP of IIT Madras. RP, the first university-based research park in India, has three entry modes as the sources of entrepreneurship, two of them is internal and the third one is external. The first internal mode is CFI, a sandbox which is student centred and prospective student entrepreneurs enter RP via Nirmaan, a pre-incubation centre, whereas the second source is IIT Madras faculty (along with their students and staff) originating from Nirmaan and enter RP subsequently. The third source is external entities comprising institute alumni and prospective start-up founders from other institutions or industries, who directly join one of the four incubators of RP. A description on the origin, objectives, and functions of each of these entities is in order.

6.2.1 CFI: A Sandbox

Centre For Innovation (CFI) is a sandbox formed to encourage student led entrepreneurship. The emergence and functioning of numerous informal clubs in the hostels by undergraduate students from diverse disciplines of engineering and science to discuss and nurture their technology ideas attracted the attention of Institute authorities leading to the formation of CFI in 2008. CFI is aimed at encouraging undergraduate students to ideate in the form of projects for developing a Proof of Concept (POC) for prototype development. An earlier central workshop was renovated and identified as the CFI lab for students to experiment their ideas for ideation. Recently, it has been relocated into Sudha and Shankar Innovation Hub, funded by the alumni, IITM and the government. The objective of CFI is to enable a student club to 'walk in with an idea and walk out with a product'.

CFI has been primarily a student led and student managed set up where faculty members play only an advisory role as and when required. In the process of ideation, junior undergraduate students are mentored by senior undergraduate, post graduate and research students. Students with entrepreneurial orientation are encouraged in CFI for ideation to successfully prepare a POC. Students who successfully complete their projects and achieve POC will earn four credits (as part of their undergraduate program), based on due evaluation done by the faculty. It is important to note that only technical skills of students are tested and not their business skills.

The cost of project experiments of students in CFI is met by the Institute through diverting a part of the students' fee as the seed fund. CFI in any year comprises anywhere between 300 to 400 clubs comprising a couple of students. The student clubs which can complete their projects and generate a POC successfully, as evaluated by the faculty, will graduate, and move into Nirmaan, the pre-incubation cell, to work towards prototype development. Those who are not able to develop a POC will leave the CFI. On an average, about 10% of the student clubs successfully graduates into Nirmaan annually.

5.2.2 Nirmaan: A Pre-Incubation Cell

POCs of student projects successfully emerged from CFI did not have any further support system for start-up formation till the formation of RP in 2010, particularly after the formation of Incubation Cell (within RP) in 2013. Subsequently, POCs of students which entered RP for start-up formation were found to be inadequately matured for incubation support. At the same time, Institute authorities felt the need to encourage entrepreneurial spirit of faculty members by laying emphasis on research commercialization. Towards this end, Nirmaan as a pre-incubation cell was created in 2015.

It is the place where start-up dreams of students (who graduated and entered from CFI) and faculty (along with their research students and laboratory staff) are nurtured. It is a pre-incubator where ideated POCs (either from the students or from the research laboratories of faculty) mature towards incubation. Thus, Nirmaan was born as a feeder to the incubators of RP, and a link from the CFI (a via media between CFI and RP).

About 10% of the student clubs which enter Nirmaan is able to graduate further to enter one of the incubators of RP. Those who cannot achieve prototype development and/or lack market potential will exit from Nirmaan. Students who can get admission to one of the incubators of RP for further nurturing their start-up dreams are given the option of deferred placements (for two years) as a security, to encourage their risk-taking and entrepreneurial orientation (to offset their worry about losing the opportunity of getting a campus placement forever). But students need not always enter Nirmaan from CFI, rather they can bypass CFI, if they have a viable product development idea which has a potential market value and nurtured in a faculty research laboratory.

To encourage entrepreneurship among faculty members, Entrepreneur-in-Residence (EIR) program was introduced for faculty members. If a faculty member has developed a technology (in the research laboratory involving research students and staff) for a prospective start-up, he/she can work towards the formation of a start-up where he/she remains as a Chief Technology Officer or as a technology mentor of such a start-up. Such start-ups can be run by their students or by outside experts. The objective is to promote systemically driven tech start-ups.

Nirmaan supports product development, achieve product-market-fit and obtain pre-seed funding. In addition, it conducts training sessions on legal and taxation issues, apart from guiding new venture formation. It will even facilitate to obtain critical human resources, if necessary, both from within the institute and outside. Thus, Nirmaan provides critical support for product development, obtaining early finance and early market identification, which lay the foundation for new venture formation.

6.2.3 External Entities

While CFI and Nirmaan are exclusively meant for students, Nirmaan is meant for faculty members as well. However, RP comprising multiple incubators are open for external individuals/groups comprising institute alumni and/or ex-industry personnel, among others.

The pre-incubation process for the selection of incubates for the incubators of RP is well defined. The entry routes through CFI and Nirmaan for students and through Nirmaan for faculty led groups is well regulated. But the third route through external entities is regulated through an application process and its scrutiny.

RP comprises four incubators, but the Incubation Cell is considered the mother incubator of all. The applications of external entities, which are received regularly round the year, are considered on merit, and based on the suitability for the existing expertise in RP. An internal team periodically screens the applications for further consideration. Both technology viability and market potential are assessed. Technology evaluation is done by the IIT Madras faculty whereas market prospects are evaluated by an internal team supported by its network of business mentors including institute alumni and industry experts. The external applicants considered for admission are offered free shared space for a period of 18 months, extendable by another 18 months beyond which, one can opt for a space (shared and/or exclusive) at a subsidized rate.

Ideally, only applicants who come with a potential technology with an identified market are shortlisted. However, if applicants come with a good prospective technology for a product but without identifying an appropriate market (i.e., with product-market-fit), such proposals are still admitted for mentoring. Therefore, RP incubators would include prospective start-up founders with moderate maturity (after product-market validation) but without attaining adequate product-market-fit, in addition to those who have a sound technology as well as market base.

Those who are admitted are provided with multiple facilities, apart from free shared space (about four to six seats) and access to hard and soft infrastructure within RP. This plays a major role in product development for launching the start-up. Technology mentoring is provided by IIT Madras faculty and retired faculty. Business mentoring is provided by IIT Madras alumni and industry experts. Many of them are either serial entrepreneurs or angels/venture capitalists or occupying key positions in the corporate sector. Mentoring clinics for the incubates are held regularly. Human resources are provided by the students/graduates/alumni of IIT Madras. Industry collaborations of IIT Madras play a vital role in identifying early product adopters for the prospective tech start-ups.

Once a start-up is formed with product development and market identification, it acts as a signal for graduation. At this stage, the start-up would have obtained institutional follow-on funding. It is on a stable path for conducting its operations, generating revenue to take care of its costs, and achieve market stability. But those who have taken an unduly long time to achieve product-market-fit do fail and exit from the incubators. Agility to capture the identified market proves decisive. Some of the prospective start-ups failed because their products were considered too early to enter the Indian market, or they were merely ineffective copycats from the developed world.

Apart from the four incubators, RP comprises IITM Pravartak Technologies Foundation established in 2020. Its objective is technology development, entrepreneurship development, human resource development, and international collaboration. It provides an ecosystem that promotes fundamental research to translate into products, thus integrating academics, industry, government, and international organizations. It includes a technology innovation hub on Sensors, Networking, Actuators, and Control Systems (SNAS). Among others, it promotes deep-tech start-ups (IITM Pravartak, 2024).

The deep-tech start-up generating process at IIT Madras is summarized and presented in Table 2. It describes the sources of entrepreneurship, its location of origin, selection criteria, facilities provided within, criteria for graduation, process of graduation, and causes of failure. The EU ecosystem is described covering CFI, Nirmaan, and RP with four incubators. IITM Technologies Foundation is an independent company but complements the EU ecosystem of IIT Madras for generating deep-tech start-ups.

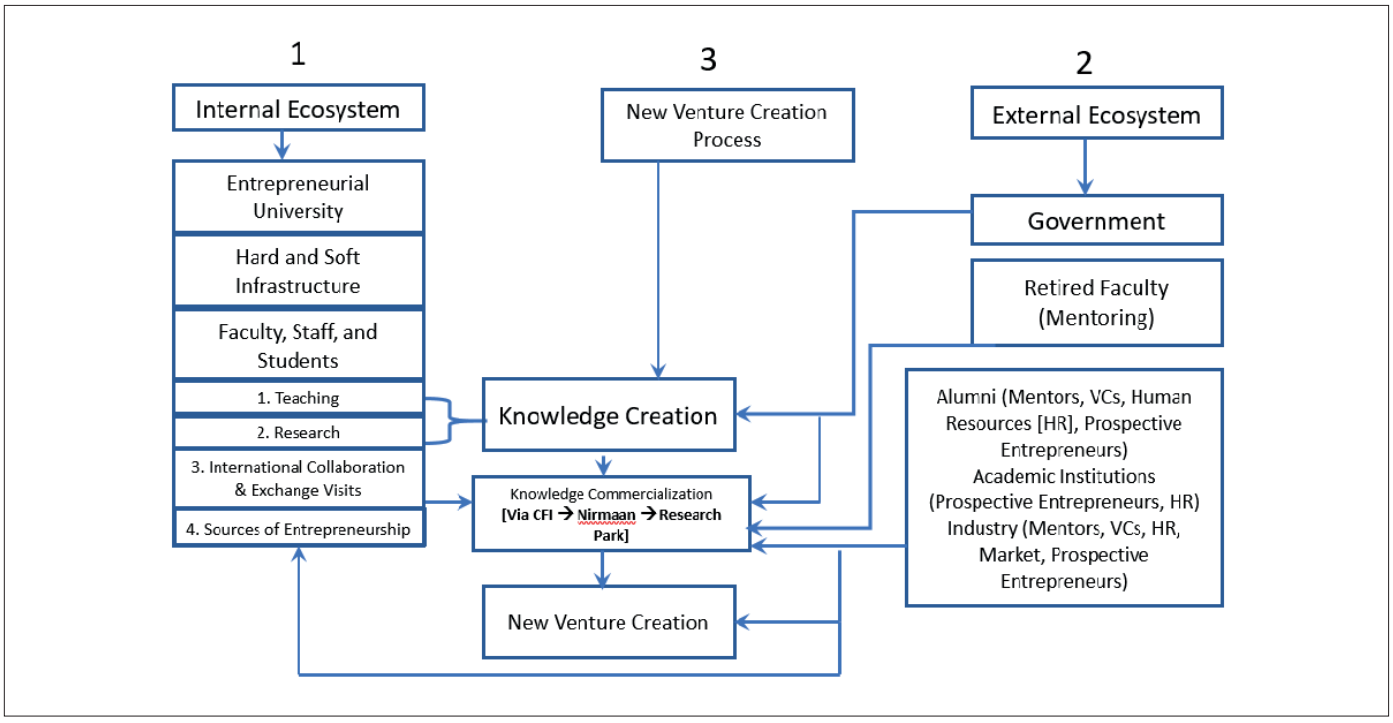
Table 2: Deep-tech Start-up Generating Process

Sources of entrepreneurship	Location of origin	Criteria for selection	Facilities provided for incubation	Criteria for graduation	Process of graduation	Causes of failure
Under-graduate students	A Sandbox (CFI)	Nil. Under-graduate students form groups based on mutual understanding and complementarity to explore ideas	Technology mentoring to juniors by seniors, advisory role by faculty, and seed support for projects (a part of the fees paid is diverted as seed founds)	Successful conceptual-ization of ideas in the form of projects (POC)	From CFI to Nirmaan	Not able to conceptualize an idea
Students, Staff and Faculty with students	A Pre-incubation cell (Nirmaan)	Selected projects from CFI, and faculty lab-based projects	Technology mentoring by faculty and alumni; seed grants for POC to PD	Successful development of PD, with market potential	From Nir-maan to one of the TBIs of RP	Not able to develop a PD or lack of market potential
External entities (alumni/others)	Four TBIs of RP: RTBI, IC, Biotech TBI, & Med Tech TBI	Selected proposals from Nirmaan and proposals evaluated by faculty for tech-nology content and by in-house experts, alumni, and industry experts for business potential.	Tech mentoring by IITM faculty and retired faculty for MVP and product testing; business mentoring by alumni and industry experts for market identification and obtaining early market adopters; human resources; finance from Angels or VCs	PD to MVP & PMF, Self-sustainability in the form of revenue genera-tion, obtaining external funds, initial market penetration	Formation of a PLC, and exit from the TBI with a proven busi-ness model for growth	Not able to develop a MVP and achieve PMF, and generate revenue

7. Analysis and Discussion:

Figure 3 presents the EU structure for deep-tech start-ups as it prevails today in IIT Madras. The EU ecosystem has two major components: internal and external. The internal ecosystem comprises IIT Madras as an EU with its hard and soft infrastructure. Hard infrastructure would include its land and buildings, research laboratories, library, industry-institute interaction centres, etc. Soft infrastructure would consist of software, e-library resources, internet facilities, etc. The three major human resources are faculty, staff, and students. They are involved in teaching, research, and are the sources of entrepreneurship. The external ecosystem comprises the national government, retired faculty of the institute, alumni, other academic institutions, and industries, particularly the corporate sector.

Figure 3: EU Structure for Deep-tech Start-ups



The teaching, research, and international collaborations and visits of faculty generate knowledge, leads to idea generation among students, and their research findings would offer scope for patents. This creates the path for knowledge commercialization: (i) students who ideate on their own, enter CFI and work towards developing a POC, and who succeed then graduate into Nirmaan for prototype development, and further into one of the incubators in RP for new venture creation, and (ii) faculty who engage in research (with the help of staff and research students), develop a new technology and/or obtain a patent enter Nirmaan for prototype development, and then join one of the incubators of RP for new venture creation.

The third source of entrepreneurship emerges externally from either institute alumni, other academic institutions, or former industry personnel. They directly enter one of the incubators of RP with a potential product and possibly, a market as well, for knowledge commercialization and new venture creation. This might include returnee entrepreneurs, serial entrepreneurs, or second entrepreneurial attempt of earlier failed entrepreneurs. Overall, they add to the knowledge generation and commercialization process and therefore, vibrancy of the ecosystem.

Government plays a major supportive role for knowledge creation as well as knowledge commercialization, as it provides periodic grants for scholarships of students, subsidized education, salaries of faculty and staff, hard and soft infrastructure, among others. In addition, government facilitates international collaborations of faculty, and international exchange of students and faculty. Further, government protects and promotes Intellectual Property Rights of start-ups, and their innovation and creativity through a scheme facilitating Start-Ups Intellectual Property Protection (SIPP) since 2016. The scheme facilitates start-ups in filing and processing of their patent, design, or trademark application through the assistance of IP facilitators whose fee was borne by the government (PIB, 2022c).

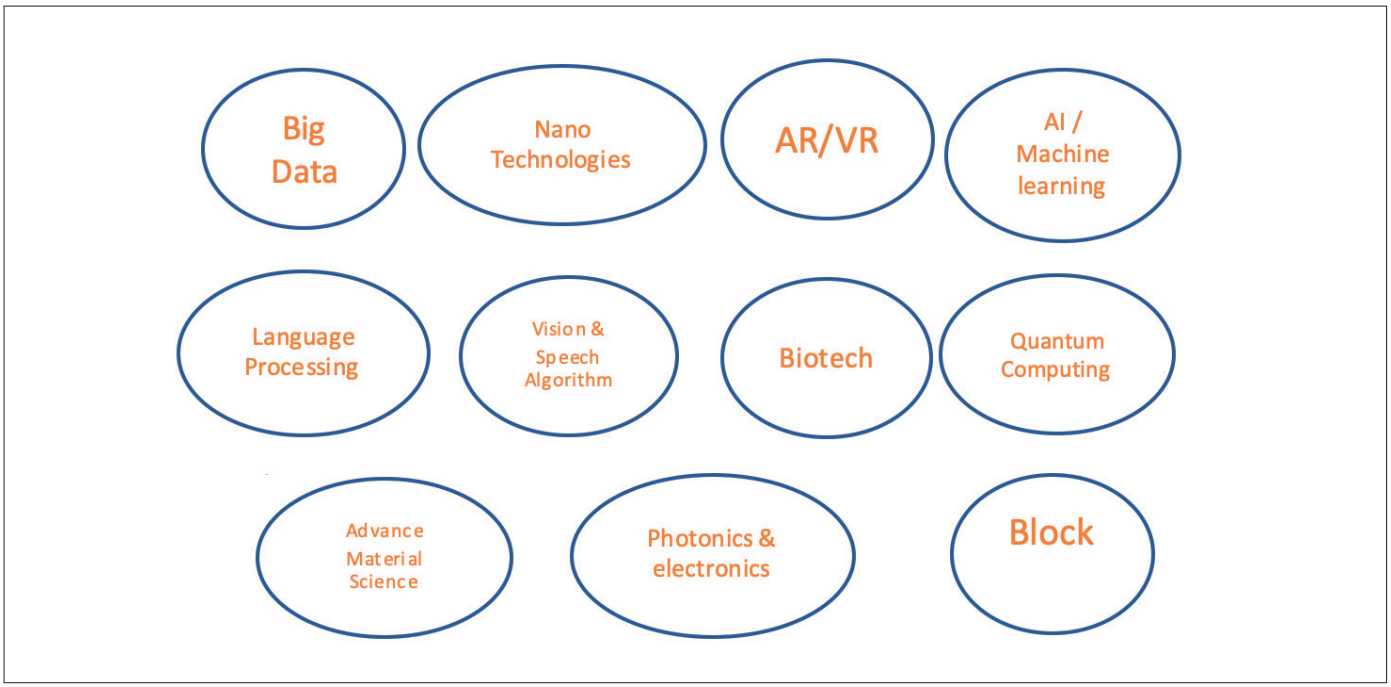
In addition to in-house faculty, the retired faculty of IIT Madras plays a crucial role in offering technology mentoring to students, and other incubatees of RP, and they also collaborate with the faculty who act as the CTOs of their own start-ups undergoing incubation in RP. The other three stakeholders of the external ecosystem, namely, IIT Madras alumni, other academic institutions, and industry personnel play multiple roles in complementing the EU of IIT Madras. They form not only the external source of entrepreneurship, but also human resources. In addition, alumni, and industry personnel offer technology/business mentorship as experienced or serial start-up founders, finance as angels or early-stage venture capitalists, market support either as early product adopters or for further market penetration, among others. Thus, together, they effectively complement the internal ecosystem of EU of IIT Madras and play a decisive role in knowledge commercialization for new venture creation.

Table 3: Key Performance Indicators of IIT Madras EU (2011-2023)

Sl. No.	Variable	Number
1	Deep-tech startups generated	350+
2	Unicorns	7
3	Soonicorns	14
4	Total valuation of startups	US$ 4.6 billion
5	Rate of survival (beyond 5 years)	>82%
6	Proportion of IIT Madras faculty engaged in startup nurturing	40%

The above describes the structure of EU as it emerged over a period in IIT Madras. The key performance indicators of EU of IIT Madras are presented in Table 3. As of now, the achievements of EU are quite heartening. The EU has generated 350+ deep-tech start-ups, during 2011-2023. Of these, seven start-ups have become unicorns and 14 soonicorns (soon-to be -unicorns). What is more significant is that, defying the global trends (where about 90% of the start-ups fail within the first five years of their emergence), more than 82% of the deep-tech start-ups have survived beyond their five years of operations. The total valuation of start-ups incubated at IIT Madras EU stood at US$4.6 billion. Of the 350+ deep-tech start-ups, nearly 100 has emerged from the faculty of IIT Madras, and nearly 40% of the existing faculty members is currently engaged in working on their own start-ups, indicating the degree/intensity of entrepreneurialism prevailing among the faculty members (Kannaiah, 2024; Goled, 2023; Sur, 2023). The major sectors of deep-tech start-ups that have emerged from IIT Madras are presented in Figure 4. These holds promise for the future.

Figure 4: Key Sectors of Deep-tech Start-ups



Source: Sur (2023)

Many of these start-ups, have made or anticipated to make a substantial social impact, such as (i) Ather Energy: electric scooter, (ii) Uniphore: the multimodal AI and automation platform, (iii) HyperVerge: the complete identity verification and Anti-Money Laundering (AML) solution provider, (iv) Tan90: which can revolutionize indoor farming, (v) Detect Technologies: which has built sensors to monitor pipeline changes in real time, and (vi) Agnikul Cosmos, which can build launch vehicles capable of taking micro and nanosatellites to Low Earth Orbit, on-demand (Kannaiah, 2024).

8. Inferences and Implications:

IIT Madras along with its RP has successfully emerged as an EU. The EU did not emerge based on any pre-conceived plan. Rather, it emerged out of the 'learning and doing process' extending over about one and a half decade. It may undergo further revisions either in terms of creating new entities or in terms of new collaborations/relationships between the existing internal and external entities. Though originally RTBI emerged alone as an exclusive rural focused Technology Business Incubator, the formation of CFI as a sandbox added the student entrepreneurship dimension to the ecosystem.

Subsequently, the establishment of RP as an independent company created a base for the corporatization of entrepreneurship. Though the original objective of setting up RP was to promote industry-institute research collaboration by assisting companies with a research focus to set up a base in the RP and leverage the expertise available at IIT Madras, subsequently it included RTBI and created an exclusive Incubation Cell as another incubator followed by the establishment of two more incubators, namely, Biotech incubator and Medtech incubator. However, the entry of inadequately matured student led projects into RP for incubation made the Institute authorities to create a pre-incubation cell, i.e., Nirmaan as a via media between CFI and RP. Nirmaan also provided a base for nurturing the entrepreneurial culture among faculty members. More recently, Department of Science & Technology, Government of India set up Pravartak Technologies Foundation, which lent further strength to the EU ecosystem. Prior to this, in 2017, Gopalakrishnan-Deshpande Centre for Innovation & Entrepreneurship had emerged as another source of support for start-ups. The ecosystem has proved productive in terms of nurturing innovation, commercialization, and entrepreneurship for deep-tech start-up generation in the process of its evolution.

Given the above, EU of IIT Madras has important theoretical and policy implications. Its theoretical implications can be explained in terms of the Resource-Based View (RBV) theory (Miller, 2019), which can be relevant for other academic institutions in India aiming to develop their own versions of EU. RBV theory describes a firm as a bundle of resources, which are Valuable, Rare, Inimitable and Non-substitutable (VRIN). IIT Madras can be considered (akin to a firm) as a bundle of resources, which are Valuable, Rare, Inimitable, and Non-substitutable (VRIN). Its internal resources consist of its bright and motivated faculty, brilliant students, supported by its staff, with land, building, laboratory, and library infrastructure which has been creating a technology knowledge base, which are unique, therefore, **Valuable and Rare - VR**.

Its external resources comprise its superannuated faculty, industry-based alumni, industry networks including angels and venture capitalists, interactions with other academic institutions (within the country),

government support, and its international relations. The specially created CFI, Nirmaan, and RP (with four incubators and Pravartak Technologies Foundation) are adequately supported by a combination of both internal and external resources. Together, they play a unique role in nurturing innovation and entrepreneurship for deep-tech start-ups. The process of graduation from CFI to Nirmaan and further to one of the TBIs of RP is a unique system with no parallel elsewhere, thus, it is **Inimitable (I)**.

Though equally reputed IITs do exist in India, and several private engineering institutions have come up across the country with good infrastructure, none has developed a start-up ecosystem like that of IIT Madras consisting of a Sandbox (for students), a pre-incubation cell (like Nirmaan), and multiple specialized incubators within a RP. 'Start-up India Policy 2016' has proposed to replicate RP in six other IITs and IISc, Bangalore, and on similar lines, IIT Bombay, IIT Delhi, and IISc Bangalore have modelled "ASPIRE", "Foundation for Innovation and Technology Transfer" (FITT), and Quantum Research Park (QuRP) respectively, for deep-tech start-up promotion. IIT Bombay has envisioned ASPIRE to be the nerve centre linking knowledge, expertise to boost industry-academia culture with about 40 corporates as members till date. IISc has clearly focused on quantum computing and related technologies and aims to partner with industry and mentor and support translation. Though these are viewed as positive attempts in the direction of EU, there is still a long way to go which requires thrust from the Government.

Therefore, as of now, EU of IIT Madras as a start-up ecosystem is **Non-substitutable (N)**. All the above described **Valuable, Rare, Inimitable and Non-substitutable (VRIN)** resources together have enabled IIT Madras as an EU, to develop "**Sustainable Competitive Advantage (SCA)**", to commercialize internal/external innovations and generate entrepreneurship for deep-tech start-ups successfully. Thus, the EU growth experience of IIT Madras substantiates the RBV theory for its application elsewhere.

We can draw policy implications as well from IIT Madras as an EU. First and foremost, there must be a sound and structured framework for entrepreneurship generation for a successful EU. Nurturing 'sources of innovation and entrepreneurship' internally (through students and faculty) is decisive for 'nurturing innovation and entrepreneurship' within an EU. Complementing 'internal resources' with appropriate 'external resources' forms the basis for building a productive EU. 'External resources' occupy a decisive role in knowledge commercialization for new venture creation in an EU. Understanding the critical components of a start-up ecosystem and ensuring its easy access and availability within an EU is imperative for achieving **SCA** by an EU. Finally, development of an EU is an evolutionary process, and it can only be achieved over time to gain **SCA**. Higher education institutions and universities which are keen to promote themselves as EUs must understand these critical issues. Accordingly, policy makers may strategize EU promotion as part of their respective start-up promotion policies.

The study has some critical policy implications. First and foremost, mere setting up of Research Parks may not spontaneously lead to the generation of deep-tech startups from other IITs and other Higher Education Institutes. Research Parks must be backed up by a Sand Box and a Pre-incubation cell as revealed by the experience of IIT Madras. This will encourage the much-needed nurturing of entrepreneurial orientation among students and faculty who can subsequently graduate into the incubators of Research Park for further maturity towards new venture creation. Secondly, there must be a strong knowledge base backed up by high quality research of faculty and students within the institute. With a weak research and knowledge base, deep-tech startups may hardly emerge. Therefore, policy makers must support high-quality research orientation of faculty and students. Thirdly, there must be a strong industry-institute-alumni-retired faculty network within an institute for a successful generation of EU.

9. Limitations and Scope for Future Research

While the single case study has several significant implications for promoting EUs elsewhere, it has certain limitations as well. The history, hard and soft infrastructure, and faculty of IIT Madras are unique, and therefore, EU of IIT Madras may not be easily replicable elsewhere. Given this, the proposed EU structure of deep-tech startups need not prove relevant for other higher education institutes. Therefore, its generalization may not be appropriate.

But at the same time, the present study reveals scope for future research in the context of EUs. Firstly, a study comparing EU of IIT Madras with some other IITs which generate deep-tech startups may be carried out. Alternatively, a comparative study of EU of IIT Madras with that of IIM Ahmedabad (which attracts a significant number of IIT graduates for post-graduation in management) may be undertaken. A comparative study of EU of IIT Madras with some of the reputed universities such as Oxford and Cambridge Universities in the UK or Stanford University in the USA may be carried out. Secondly, how important are networks with various entities such as industry, institute alumni, institute retired faculty, etc. may be explored in the context of EUs. Thirdly, there is scope for a quantitative analysis of the performance of startups of EUs. Finally, a comparative study of the performance of startups of EUs with those which emerged outside of the EUs will be equally relevant.

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