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Blueprint For a Federal AI Strategy

Catalysing National AI Priorities Through Regional Innovation Systems

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Geopolitics & Geoeconomics

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Pune International Centre (PIC) is an independent and multidimensional policy think tank based in Pune, India. PIC aims to generate informed public discourse through research, dialogue, and collaboration across key areas such as national security, international relations, social innovation, sustainable energy, governance, and arts and culture. Through debates, lectures, publications, and collaborative initiatives, PIC contributes to qualitative and well-informed policy outcomes.

Abstract

The general-purpose nature of AI technologies means that it has cross-industry effects; that is, it not only reshapes prevailing economic logic and business models but also potentially configures how particular industries are organised. This means *the success of India's national AI priorities depends critically on a federated strategy that leverages industrial and sectoral strength across its top regional innovation hubs of Bengaluru, Delhi NCR, Hyderabad, Mumbai-Pune, and Chennai*. Each of these tech hubs are co-located with industrial clusters such as automobile and electronic manufacturing, biopharma, and defence, with high AI innovation imperatives. These offer substantial opportunities for demand aggregation with the government playing a key role in creating policy and platform for discovery and innovation alignment. This paper unpacks these distributed innovation dynamics and suggests how effective institutional design, targeted incentive structures, and interdisciplinary research and talent development could not only help India unlock economic value from AI adoption but also create comparative advantage to secure strategic autonomy through differentiation and deep industrial and sectoral expertise.

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1. Introduction

Artificial intelligence (AI) is projected to contribute an additional US$500–600 billion to India's GDP by 2035 over and above the current rate of growth (NITI Aayog, 2025). India is in the top 25 per cent of countries in terms of AI readiness, indicating high ambition and the potential to accelerate AI adoption through policy and targeted investments (Schwaerzler et al., 2024). India ranks third in Stanford's AI vibrancy index after the two AI superpowers, United States (US) and China, with its ecosystem showing promise across research and development (R&D), talent, responsible AI, economy, policy and governance, public opinion and infrastructure (Fattorini et al., 2025). However, *bridging the gap from India's 2024 Global Vibrancy Index score of 21.59 with US' 78.60 and China's 36.95 requires serious consideration of mediating factors that can translate AI's general purpose technological potential to projected economic growth.*

These mediating or conversion factors bridge the gap between potential, progress, and economic development. India's current national AI policy tends to focus on building national capacities in data, models, and infrastructures which serve as important inputs for AI innovation. However, economic change and growth depend as much on inputs as the diffusion, adoption, and the ability to anticipate and meet demands across sectors and industries (Carlsson & Stankiewicz, 1991). Both development and diffusion stand to benefit from spatially distributed regional technological clusters or hubs that have grown over time with accumulation of knowledge, infrastructure, capital, talent, and dense interdependent networks. Leveraging existing technical capabilities and diversifying across existing industrial capacity hold high potential for catalysing economic growth (Hidalgo et al., 2007).

This paper argues that the success of India's national AI strategy depends on crafting and incorporating a federal AI policy approach that is able to aggregate and align regional innovation dynamics with AI capabilities towards national economic outcomes.

1.1. Spatial Distribution and Clustering of Innovation Capacity

The current pace of innovation tends to be geographically concentrated in specific regions. Regions from San Francisco to Shenzhen to Bengaluru serve as engines converting innovation activity to economic value, underlying the projections of trillion-dollar GDPs. The top 100 innovation clusters worldwide account for 70 per cent of PCT filings[1] and venture capital deals as well as 50 per cent of all scientific publications. Further, the top 10 clusters make up 40 per cent of PCT filings, 35 per cent of venture capital deals, and 15 per cent of global scientific publications (WIPO, 2025). In the US, the Bay Area comprising of San Francisco and San Jose metropolitan areas contribute approximately 25 per cent of the country's conference papers, patents, and companies. Together with 13 other early adopters, they represented two-thirds of the country's AI assets and capabilities, according to a report published in 2021 (Muro & Liu, 2021). The AI "superstars" of San Francisco and San Jose have unrivalled success in talent, innovation, and adoption (Muro & Methkupally, 2025).

According to the Global Innovation Index 2025, India has four innovation clusters in the global top 100, with two in the top 30. Bengaluru ranks 21, followed by Delhi at 26, Mumbai at 46, and Chennai at 84. In addition, Hyderabad and Pune are emerging startup and innovation hubs in the country, ranking 102 and 112, respectively, "knocking at the door of the top 100" (p. 8) (WIPO, 2025). These regions also have a high concentration of AI startups in the country—with Karnataka having 20 per cent; Delhi, Haryana, and Uttar Pradesh combined hosting 22 per cent; Maharashtra having 15 per cent; and Telangana and Tamil Nadu hosting 9 per cent and 8 per cent, respectively. Together they represent 64 per cent of all startups and 66 per cent of AI startups in the country.[2]

These regional agglomerations or clustering of industry and technology form important components of regional innovation systems. These regional innovations systems stand structured around these economic conditions that have developed over time through

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[1] PCT filings refer to published patent applications under the WIPO Patent Cooperation Treaty
[2] DPIIT recognised startups (https://www.startupindia.gov.in/digital-map/maps) accessed 06 January 2026

knowledge spillovers, commercial networks, suppliers, customers, and labour pools (Vásquez et al., 2025). These economic conditions engendered by clustering creates ecosystems of complementary resources and relationships including but not limited to interdependencies between firms, industries, and institutions. The sum of these economic conditions helps to discover, anticipate, and create economic value by leveraging existing mechanisms as well as reduce the commercial risks of undertaking novel combinations of existing resources, serving as means and mechanisms to take advantage of economic opportunities. This paper unpacks how regional innovation systems as functions of industrial clusters, embedded technology ecosystems, and complementary relationships between actors and institutions can help inform policy design to advance national AI strategy and economic goals.

This helps highlight how startups in emerging technologies and technological applications like AI stand to gain from and contribute to the long history of economic clustering of technological progress and capabilities, leveraging locational advantages like labour pools, supplier networks, financing, knowledge spillovers, along with infrastructure and costs of living (Boschma & Frenken, 2006; Vásquez et al., 2025). This works within the broader context of interdependency among firms, existence of enabling institutions, and the supportive and proactive regulatory and policy environment that led to their emergence in the first place.

Existing ecosystem advantages prime existing clusters to capture opportunities arising from new and emerging technologies. Future progress comes to be grounded in regional histories of development and augmented by abilities to recombine technological capabilities and existing knowledge and pools of expertise (Boschma et al., 2017). Co-location within existing technology clusters mitigates some of the attendant commercial risks in downstream adoption as well as provides a steady ecosystem that reduces the search and market costs for startups and entrepreneurs (Vásquez et al., 2025).

Regions with a strong presence of multinational firms are strong reasons for AI companies to co-locate due to the possibility of combinatorial innovation, infrastructure access, and ready customers base (Vásquez et al., 2025). This paper develops case profiles of the top five innovation clusters in India based on their global rankings to understand how regional innovation systems can accelerate AI driven economic growth. As mentioned above, these are Bengaluru, Delhi National Capital Region (Delhi NCR), Mumbai–Pune, Chennai, and Hyderabad. Mumbai and Pune are considered together because of their proximity and location within the state. Delhi NCR is taken as Delhi, Gurugram, and Noida within the National Capital Region. Case profiles in this paper show how historical contingencies in the form of initial infrastructure investments and anchor multinational firms helped attract other firms and capital. This leads to the growth of technology ecosystems and industrial clusters in Bengaluru, Hyderabad, and Delhi NCR, a momentum that is continuing with the development and expansion of global capability centres (GCCs) that makes these locations key talent pools for AI product and process innovation.

1.2. Approach and Structure of the Paper

Recent policy and strategy propositions highlight the role of AI for value creation in key industries and sectors such as manufacturing, banking, pharmaceuticals, and automotive (NITI Aayog, 2025). This paper builds on these propositions and identifies the regional clusters, wherein these sectors and industries are located to argue for the importance of a strong federal AI and industrial policy. As India's AI journey gathers momentum, it becomes important to develop strong systemic linkages and leverage existing strengths in addition to developing capabilities in foundational AI innovation inputs.

The general-purpose nature of AI technologies means that the technology has cross-industry effects, that is, it not only reshapes prevailing economic logic and business models but also potentially configures how particular industries are organised (Cockburn et al., 2019). This requires deeper collaboration between upstream players

like telecommunications providers, hyperscalers, and private data centre providers as well as actors such as startups, governments, and research and academic institutions (Srikanth, 2025) in addition to enterprises and industries as potential users, adopters, and deployers. Boundaries of AI innovation are expanding with 60 per cent of organisations opting to co-innovate with startups to leverage speed, agility, and latest tech, presenting unique opportunities for economic advancement (EY-CII, 2025).

As businesses strive to translate AI investments into economic value, it foregrounds the need to identify how such ongoing innovation comes to include not just technological push and pull factors but also a range of institutions, actors, networks, and the nature of relationships and interdependencies among them. National strategies come to be catalysed and anchored through the spatial distribution of factors like talent, technical expertise, suppliers, and technological capacities, and resources. Understanding this spatial distribution of resources, capabilities, and networks helps identify how India's regional innovation systems can be harnessed towards AI-led transformations that can help unlock economic and public value across sectors and industries. Identifying key innovation enablers will help synergise national and regional efforts in building India's AI capabilities.

This paper proceeds to explore these mediating factors and catalysts through a tiered framework of analysis that involves (i) unpacking the primary components of regional innovation systems in terms of AI ecosystem, industrial clusters, and academic and research institutions as primary sites of innovation, diffusion, and economic opportunities; then, within them, (ii) interdependencies between actors, institutional mechanisms, and historical contingencies that serve as determinants of the process as underlying conditions for converting technological capabilities into economic outcomes; (iii) this then helps surface the conversion factors for translating inputs and contingencies into economic growth requiring policy intervention and serving as elements of a federal AI policy. The following three sections unpack each of these elements of the framework. The fourth section highlights the limitations of a cluster-driven strategy and attendant tensions that an effective policy design would need to

factor in and address. Finally, the recommendations contain suggested pathways for consideration within a federal AI and industrial strategy. The paper also contains case profiles of the clusters studied as illustrative (not exhaustive) overviews of the cluster makeup that presents the economic opportunity set to inform policy.

2. Regional Innovation Systems: AI Ecosystems, Industrial Clusters, and Research Institutions

AI-led economic transformation is inextricably linked to capabilities for AI development and diffusion at one level and creating pathways for adoption across industries and sectors at another. This involves creating bridges and pathways between upstream AI inputs of data, models, compute; application development for specific industry requirements; and finally, adoption and uptake. In essence, this means designing policy that is able to link and reduce coordination costs within the AI ecosystem and between the AI ecosystem and industrial clusters while effectively leveraging and sustaining systemic and locational advantages such as availability of human capital, knowledge spillovers, institutional mechanisms, and proximity and access through demand aggregation.

2.1. AI Ecosystem

AI capabilities have come to support a quarter of tasks in global businesses, a share that is expected to rise to 41 per cent in the next two years (SAP & Oxford Economics, 2025). However, AI-led transformations in enterprises and business have encountered scaling constraints beyond proofs-of-concept and pilots, with data cited as a key bottleneck. In a survey of 1,600 senior executives across eight global markets, 75 per cent respondents report incomplete data as a key challenge (SAP & Oxford Economics, 2025). While 75 per cent of enterprises are able to succeed with pilots, fewer than 20 per cent are able to scale them to production with even fewer delivering returns on investment within the first year (Peddiboyina, 2025).

In cognisance, data investments are expected in rise by 23 per cent over the next two years in tandem with the rise in AI investments by 37 per cent (SAP & Oxford Economics, 2025). However, the real challenge lies in converting piecemeal implementation to actual return on investment. Successful deployments of AI, coupled with economic returns, would come to depend on redefined organisation processes, capacity for experimentation, and learning and refinement based on established feedback loops (Iansiti & Lakhani, 2020; Jacobides et al., 2021). This requires complementary investment and alignment across foundational elements of the AI ecosystem of data, models, and compute as well as knowledge, expertise, talent, customers, and suppliers (Brynjolfsson et al., 2019). At the moment, only AI hyperscalers and Big Tech firms like Google, Amazon, and Microsoft have full ecosystem capabilities (Jacobides et al., 2021).

Diffusion of AI across economic agents, uptake in downstream innovation, adoption across sectors and industries, and unlocking economy-wide value as a general-purpose technology would require leveraging existing technological capabilities, infrastructure, and deepening linkages with ecosystem actors. Consequently, economic growth comes to be contingent on both investment in technology as well as investment in organisational processes and inter-organisational and inter-institutional linkages that can help convert value propositions into products and services (Jacobides et al., 2021). This includes understanding conditions of infrastructure, utilities, and locational and ecosystem advantages that influence economic opportunities for innovation and entrepreneurship.

The national AI strategy is designed to address primary capability gaps in data and compute while supporting the development of linguistically and contextually relevant models. 38,000 GPUs are planned to be deployed under the IndiaAI Mission with the aim of establishing 600 data labs to boost AI research and innovation (Inc42, 2025). The AI Mission has also selected 12 entities spanning startups and enterprises to build foundational LLMs varying across different scales and capabilities (Rudra, 2025). This

includes awarding contract letters to cloud service providers like E2E Networks to provide GPU resources (Upadhyaya, 2025).

As the world moves towards increased adoption and usage of AI, this is leading to an increase in compute demand driving up demand for AI data centres (Stewart et al., 2025). India's AI ambition and accelerating adoption is driving compute demand with data centre capacity expected to grow five-fold by 2030, requiring US$ 30 billion in capital expenditure (Urfi, 2025). The increase in data centre capacity is bringing about a concomitant demand in utilities like power and water and requires the additional locational advantages to be situated.

Mumbai and Chennai currently account for 70 per cent of data centre capacity driven by Mumbai being the financial hub and Chennai being close to landing stations for undersea cables (Urfi, 2025). States like Andhra Pradesh are optimising their geostrategic locational advantages and proactive policies in utilities by positioning coastal cities like Vishakhapatnam as prime investment locations while aligning support for land, energy, and water to attract investment from companies like Google who have put in US$15 billion in the state to develop its first AI Hub in city (Google, 2025).

Building technological capabilities at the national level is indeed important to develop sovereign capabilities, reduce dependencies, and develop more representative and contextually relevant models attuned to Indian contexts. This would help in reducing barriers to entrepreneurship and promote innovation at the last mile, particularly in social sectors wherein there is limited private incentive to invest. However, this national policy push stands to be strengthened by opportunities from existing tech and industrial hubs which offer important locations to maximise the cross-industry effects of AI wherein solutions can work towards aggregate economic and productive efficiency.

2.2. Industrial Clusters, Innovation Imperatives, and Economic Opportunities

India's AI roadmap for development and economic growth identifies key sectors for AI-driven efficiency gains such as manufacturing, pharmaceutical, banking, and automotives (NITI Aayog, 2025). The case profiles highlight how these industrial hubs are co-located with existing and emerging innovation clusters such as automobile manufacturing for Pune and Chennai, electronics and automobile manufacturing for Chennai and Delhi NCR, biotechnology and pharmaceuticals for Bengaluru, Hyderabad as well as the Mumbai-Pune corridor, and banking and finance for Mumbai.

AI in manufacturing has the potential to increase productivity and efficiency through predictive maintenance, quality control, and advanced planning. In India, AI adoption in manufacturing registered a sharp rise from eight per cent to 22 per cent within a year in FY2024 (Hindu Bureau, 2025). The AI market in pharmaceuticals is projected to hit US$16.49 billion by 2034, powering drug discovery, clinical trials, and precision medicine. Further, 75 per cent of CXOs (Chief Experience Officers) in India's life sciences industry reported that the use of AI has contributed significantly to cost reduction (EY Parthenon & Microsoft, 2025). Generative AI is set to deliver productivity gains of 44–46 per cent for banking operations in India while improving productivity levels in financial services by 34–38 per cent (EY, 2025).

Biotechnology and pharmaceutical industries are investing heavily in AI. Lupin is deploying AI in its R&D programme near Pune which employs 1,400 scientists. PopVax from Hyderabad is designing mRNA vaccines using AI-based computational protein designs with Biocon investing in protein modelling and genomics-driven cancer therapies. Other companies like Sun Pharmaceuticals, Dr. Reddy's, Cipla, and Glenmark are integrating AI across diagnostics, screening, prediction, imaging, and research (Bordoloi, 2025).

However, there exists a significant talent crunch with 94 per cent of auto makers in India struggling to recruit the requisite talent for advanced systems involving AI, autonomous systems, and advanced driver assistance. This is illustrative of a demand gap, indicating space for adopting external digital solutions and presenting a significant scope for startups and entrepreneurs to develop solutions aligned to industry requirements (The Hindu Bureau, 2025d).

This highlights reciprocal economic opportunities in clusters wherein technological and industrial clusters provide locational advantages for AI innovation in terms of infrastructure, and supplier and customer networks while also gaining advantages through access to solutions driving productivity and efficiency gains. These meso- and macro-economic conditions are important to understand the ways in which India's AI journey stands to be strengthened, particularly with AI determining economic value proposition for businesses within and across industrial boundaries (Iansiti & Lakhani, 2020).

The conversion of AI capabilities into economic growth stands to be mediated by firm-level considerations as well as composition of the market and inter-linkages with institutions, resource availability, and policy support. However, growth may be constrained not by the potential and promise of AI capabilities but the essential conditions that may be hard to achieve or get right in the first instance (Aghion et al., 2019). This highlights the need to align innovation, economic, and industrial priorities within policy design, that is, upstream innovation inputs of data, compute, and models with downstream pathways for adoption, uptake, and impact in industrial clusters.

As ecosystems evolve, initial or historical conditions determine their trajectory as industrial boundaries, inter-institutional linkages, market structures, value propositions continue to change over time (Basole, 2021). With economic activity regionally distributed and predicated on locational advantages, regional innovation systems, institutional backing, and knowledge flows determine the evolutionary trajectory of AI

companies and their competitiveness (Jin & Miles, 2025). In short, they determine the extent to which policy driven development of national capabilities intersect with regional growth engines to achieve overall economic priorities.

2.3. Institutional Mechanisms and Industrial Collaborations for Research and Development

Value chains are increasingly embedded in regional or local clusters. This means that national systems will need to take into account the ways in which businesses collaborate with each other, combine resources, and navigate the broader environment in order to leverage them into building national capabilities (Granstrand & Holgersson, 2020). National capacities stand to be bolstered by strengthening regional factors and enablers. Each region has unique enablers in the form of the structure of the economy, institutional efficiency and presence, and knowledge and competencies.

All regions have the presence of strong academic institutions like the Indian Institute of Science (IISc) and International Institute of Information Technology (IIIT) Bangalore, IIT (Indian Institute of Technology) Bombay, IIT Madras in Chennai, COEP Technological University in Pune, and IIT and IIIT Hyderabad. These regions have strong track record of industry academia collaboration. For example, IISc and Wipro partnered to develop R&D and capabilities in advanced AI models, digital infrastructures, and autonomous networks (Wipro, 2025a). IIT Bombay has partnered with Optiver to undertake interdisciplinary research in AI and global financial markets (Optiver, 2025). COEP Pune has partnered with Bajaj Auto for skill development in electrical engineering (Boralkar, 2025). IIT Hyderabad's TiHAN (Technology Innovation Hub for Autonomous Navigation) platform provides a test bed for autonomous navigation including industry leaders such as Renesas, L&T Technologies, Suzuki, Mitsubishi Motors, and Tata Motors and Tata Technologies, among others (TiHAN, n.d.). With L&T Technologies, it is collaborating on Advanced Driver Assistance System (ADAS) and Cellular Vehicle-to-Everything (CV2X) communication (L&T Technology Services, 2024).

Further, in terms of skill development, Telangana Council of Higher Education (TGCHE) and Bulk Drug Manufacturers Association of India (BDMAI) have signed a Memorandum of Understanding (MoU) to develop knowledge, skills, and competencies in R&D, quality control, quality assurance, plant maintenance, and safety and regulations (The Hindu Bureau, 2025a). NIPER (National Institute of Pharmaceutical Education and Research) Hyderabad has MoUs with Bharath Biotech and Dr. Reddy's Laboratories to carry out advanced research in developing new vaccines and advanced industrial training, respectively (NIPER Hyderabad, n.d.-a).

Notably, IIT Madras' MoU with Robert Bosch Engineering and Business Solutions in 2017 helped set up a centre on data science and AI that has been working on basic and applied AI research (Bosch, 2017). IIT Madras' AI4Bharat research lab is working on Indic large language models (LLMs) with support from public and private partnership and support (AI4Bharat, n.d.). It then went on to receive INR 110 crore endowment from the Wadhwani Impact Trust to set up the Wadhwani School of Data Science and AI (IIT Madras, 2024). IIT Madras and its business and technology innovation hub—IITM Pravartak Technologies Foundation—partnered with Ziroh Labs, a California-based startup, to establish a Centre for AI Research to work on compute accessibility in India with its Kompact AI platform working to help run LLMs on local systems without the need for expensive GPUs (IIT Madras, 2025).

IIT Delhi has partnerships to drive innovation in electronics with Micron on semiconductor research in electronic materials and AI-driven modelling and a partnership with LG Electronics on sustainable technologies, AI, and smart manufacturing (IIT Delhi, 2025a, 2025b). It also has partnerships with Yamaha Motors, Hyundai Motor Group, and Honda Cars India Limited to work on areas spanning autonomous mobility, robotics, AI, along with healthtech and agritech (Yamaha) (IIT Delhi, 2025c), battery and electrification research (Hyundai) (IIT Delhi, 2025d), and cooperative intelligence to enhance human–machine understanding and interaction (Honda) (IIT Delhi, 2024).

2.4. Aligning AI Ecosystems and Industrial Clusters

The country's competitive advantage lies in how these conditions can be leveraged towards national priorities and enabling conditions created to develop both upstream capabilities in terms of innovation inputs and downstream advantages in aligning innovation and industrial requirements and easing pathways for adoption. This involves at one level, effectively assessing and facilitating the provision of innovation input requirements of data, compute, and models. At another, there is a need to develop mechanisms and platforms for discovery of industrial requirements. This would help in solution development to facilitate alignment of AI innovation with established problem statements by leveraging existing momentum in R&D and policy and institutional provisions. Therefore, it becomes important to take into account spatial development processes and leveraging the regional clusters for recombinant and generative growth (Cooke, 2016).

The examples above illustrate that geographically concentrated ecosystems of businesses, suppliers, vendors, universities, and institutions have a symbiotic relationship. Regional clusters can help drive AI innovation on two fronts: (a) enhancing differentiation through competitive pressure from co-located rivals and (b) locational and networked benefits as well as learning advantages providing an edge over non-clustered firms (Ebers, 2001). Further, AI offers clusters opportunities to co-specialise based on industry presence, academic linkages, and talent circulation which enables recombination of their resources fostering more agility and time to market. Economic structures, histories, and institutions all contribute to competitive success (Porter, 1990). Existing concentrations allow potential for higher interaction with external sources of innovation and the ability to respond to demand and supply situations. These existing capacities also attract funding and investments, creating a circularity that operates in self-reinforcing cycles (Cooke, 2002).

AI as a general-purpose technology engenders cumulative innovation effects larger than the success of individual AI firms. In regional innovation systems, factor conditions

such as skilled resources, suppliers, investments, enabling institutions, etc. are more readily available (Porter, 1990). Clusters enable competitive and collaborative dynamics across multiple levels: (a) inter-institutional level wherein a symbiotic relationship exists between academic institutions, industrial R&D, talent, and access to compute which feed into product and business model innovation; (b) sectoral and industry ecosystems, and how (c) they make up the overall economic structure and fabric of the region (OECD, 1999). The linkages among the various elements within the ecosystem can be innovation linkages, business linkages, knowledge exchange, interaction, and cooperation (OECD, 1999).

In order to understand pathways to convert AI capabilities into economic growth, it becomes important to unpack the process underpinned by these linkages of actors, relationships, and interdependencies that enables or constrains economic potential and innovation activity. Regional innovation systems help analyse and identify the conversion factors that translate technological capabilities to economic growth (Carlsson & Stankiewicz, 1991). They aggregate into national systems of innovation and boost the overall economic potential of technology-driven value creation across all segments of the economy (Cooke et al., 1997).

3. Interdependencies Between Actors, Institutions, and Systemic Conditions in Innovation and Economic Growth

As discussed, innovation in clusters proceeds on account of competition from peers as well locational advantages that can help draw from complementary strengths, e.g., closeness to data centres which helps reduce latency for heavy computational workloads as well as industrial clusters and IT companies that provide access to a ready market for commercialisation and opportunities to co-innovate and co-specialise. Just as locational advantages stem from the upstream ecosystem advantages of compute, they also offer downstream benefits in the form of access to customers, the opportunities to co-specialise with peers, and co-innovate with clients themselves. Each of the locations under study have grown through a combination of infrastructure

and policy support from the government, anchor firms and subsequent industrial expansion, and the presence of technical institutes and subsequent ecosystem advantages have reduced the cost of building a business in these locations as opposed to non-cluster locations.

3.1. Actors

The composition of regional innovation systems benefits from interdependencies between actors such as the government, Indian IT firms, multilateral corporations, private investment and financial firms, as well entities such as GCCs. Initial investments by the government in supportive policies and infrastructure led to inflow of private and/or foreign capital creating historical contingencies that led to subsequent expansion and growth. This creates knowledge spillovers and entrepreneurial ecosystems, labour pools, and industry networks that provide the conditions for firms to channellise innovation inputs into innovation activity.

Bengaluru benefited from Centre and State government policy synergies in promotion of software services, and Hyderabad benefitted from initial infrastructure investment by the government and the arrival of Microsoft as an anchor firm. Pune emerged as an IT hub in the 1990s; the city was one of the first three Software Technology Parks in the country along with Bangalore and Bhubaneswar. In Pune, Tata Motors set up the first plant in 1954 in collaboration with Merecedes-Benz (Sen Gupta, 2013), a pattern similar to the setup of Maurti Suzuki in Gurgaon that sowed the seed for the development of an industrial hub. Tamil Nadu's State Industries Promotion Corporation of Tamil Nadu Limited (SIPCOT), established in 1971, continues to play a key role in industrial promotion and infrastructure development through industrial parks (SIPCOT, n.d.).

Presently, the Central government supports startups and innovation through a range of incentives anchored by different ministries and departments (DPIIT, n.d.). This includes the Ministry of Corporate Affairs for fast-track approval processes to Central Board of Direct Taxes for harmonising taxation regimes and tax incentives, Reserve Bank of India

for simplifying reporting of foreign investment, and the Department for Promotion of Industry and Internal Trade (DPIIT) for Foreign Direct Investment (FDI) policy, among others. This is complemented by individual states with all states in which the studied clusters are located, providing a combination of support with almost all providing support towards intellectual property (IP) and patent filing. States like Telangana and Haryana provide SGST and tax incentives while Tamil Nadu and Maharashtra have significant support towards ease of doing business and compliance along with policies for public procurement from startups. Tamil Nadu has a one-stop shop and helpdesk set to register a startup with 10 days of online application while Maharashtra has worked towards easing norms and compliance along with compensation towards stamp duty and registration fees for registered startups.

Consequently, the government has been a key actor and has played a leading role through a combination of policy support and infrastructure investment to help businesses overcome the initial investment dilemma in uncharted territory. In addition to state support acting as a catalyst, multinational firms and proximate industrial belts can act as potential customers. The pattern of attracting a flagship company or multinational firm that in turn attracts other multinational firms repeated in other locations by creating an ecosystem and talent pool around it. Veritas Software and Persistent Systems, both located or founded in Pune, contributed more than 200 entrepreneurs and senior executives in various product and software firms in the city (ET Bureau, 2014). Starting with General Electric, over time, Gurgaon attracted companies like Siemens which ended up providing crucial support to major US innovations like NASA's Jet Propulsion Lab in the form of design software portfolio to digitally design, simulate, and assemble the vehicle before building prototypes. Further, Hyderabad started its journey by hosting Microsoft's first development centre outside the US in 1998 (Karmali, 1998).

Indian IT firms like Infosys, Wipro, Tata Consultancy Services (TCS), and HCLTech, LTIMindtree won major international multi-million-dollar international digital transformation deals with AI at the core. Companies like TCS are in turn investing in

developing data centre capacity, with plans to invest US$6-7 billion over the next six to seven years to build 1 gigawatt (GW) AI data centres (Pandey, 2025b). Around the mid-2010s, IT giants started setting up their venture capital arms to invest in cross-sectoral solutions across startups to stay ahead of the curve and take advantage of agile and cost-effective innovation as opposed to in-house development or up-front acquisition (Mishra, 2015). In 2025, Wipro invested US$200 million in startup growth with one of its aims being to support enterprise IT solutions. (Wipro, 2025b). IT companies are increasingly serving as important partners for startups to co-specialise in solution development through scale, capital, and digital transformation expertise.

India is also home to Global Capability Centres which serve as offshore units for global companies that provide specialised services to their parent companies in IT, R&D, customer support, or business operations. Bengaluru, Delhi NCR, Mumbai-Pune, Hyderabad, and Chennai host 92 per cent of all GCC capacity in the country (Goel & Bhat, 2025b). While locating GCCs in India are premised upon cost arbitrage, more than 92 per cent leaders confirm that GCCs in India now serve as important hubs of innovation with 87 per cent taking ownerships of end-to-end global processes while 45 per cent participate in global decision-making (Sen & Marwah, 2025). GCCs also invest heavily in skill development with 23 per cent of budgetary resources going towards talent development with reskilling initiatives standing at 71 per cent in 2025 (Sen & Marwah, 2025). GCCs are also collaborating with academia in two key ways: (i) advanced special projects that involve working on applied research and consultancies with placement opportunities, and (ii) establishing or supporting on-campus incubators and startup cells to foster solutioning for existing organisational problems and provide support for scale and commercialisation (Ghatak, 2024). This highlights the role of GCCs in supporting advanced research and talent development and opportunities to co-develop solutions. Academic institutions form a critical node between GCCs, multi-national companies (MNCs), and IT firms with companies' activities supporting academic research projects.

Further, MNCs like Google, Microsoft, Meta, and Amazon are deepening their investments in India with combined US$68 billion from Microsoft, Amazon, and Google with focus on ramping up digital infrastructure. OpenAI opened its first office in India in New Delhi with Meta investing in new office in Bengaluru to advance its AI push (Das Sharma, 2025). Amazon's investment of US$35 billion builds on its existing US$40 billion investment to develop local cloud and AI infrastructure while Microsoft's investment will go towards building hyperscale cloud regions–essentially a data centre cluster in Hyderabad (Dey, 2025). This foregrounds the role of tech giants in developing the AI ecosystem and innovation inputs.

These developments illustrate evolutionary dynamics of innovations driven by state support, historical contingencies, and interdependent relationships between actors and institutions. This helps attract foreign investment and revenue through both export of services as well as international companies directly investing in these cities to set up their campuses and development centres while at the same time investing in human capital development through skilling.

3.2. Policy Landscape

Policies play a key role in structuring incentives, support, and innovation activity. At the Central level, the IndiaAI Mission aims to develop national capabilities in AI through a focus on foundational building blocks of data, compute, and models at one level as well as promoting India-specific application development in social sectors of healthcare, agriculture, climate change, governance, and assistive learning technologies; skill development by supporting tertiary education, research, as well as technical education; AI startup financing; as well as safe and trusted AI pillar investing in projects focusing on technical aspects of responsible AI (Press Information Bureau, 2025).

Ministry of Electronics and Information Technology's (MeitY's) Startup Hub aims to act as an ecosystem developer and enabler while also acting as an incubator and accelerator. It works on network development with 6,148 startups, 517 incubators, 36

accelerators, 43 Centres of Excellence, 486 mentors, and 265 investors.[3] Additionally, corporate partnerships exist with the State Bank of India, Tally, Razorpay, and Micron, Google, and Meta with support spanning knowledge, finance, mentorship, resources access, as well as training, upskilling and support through accelerators and challenges (MeitY Startup Hub, n.d.).

The Startup India initiative under the DPIIT provides support in the form of self-certification with labour and environment laws, patent filing and IPR support, tax exemptions, public procurement facilitation, as well as ease of winding up (Startup India, n.d.). In addition to ecosystem and startup policy, individual states have data centre policies that aim at providing fiscal incentives, subsidies, exemptions from stamp duty, as well exemption from pollution control under Telangana and labour laws under Uttar Pradesh. Telecom Regulatory Authority of India's (TRAI's) recommendations on data centres suggested the streamlining of operational burden on data centres and easing compliance and registration. In 2022, Department of Economic Affairs, Ministry of Finance, designated data centres as infrastructures via a notification under the 'communication' category (ICRIER, n.d.).

State data centre policies offer a range of financial and non-financial benefits with Telangana, Uttar Pradesh, Haryana, Karnataka, and Tamil Nadu having dedicated data centre policies and Maharashtra's IT/ITES Policy 2023 granting infrastructure status to data centres at par with railways, road, and power (Mehta et al., 2023). Haryana Cabinet approved INR 474 crore for AI development project in partnership with the World Bank to develop AI capacities in the state with key components including the development of the Global Artificial Intelligence Centre (GAIC) in Gurugram and the Haryana Advanced Computing Facility (HACF) in Panchkula along with skilling initiatives (PTI, 2025).

The Uttar Pradesh government aims to develop Lucknow as an AI city to position it as the next AI hub with a corpus of INR 10,732 crore and set up eight data centres under its

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[3] As on 09 January 2026 (https://msh.meity.gov.in/network/startup)

data centre policy having received investment proposals of INR 21,343 crore out of an estimated INR 30,000 crore investment (HT Correspondent, 2026a, 2026b).

On the other hand, Maharashtra has launched a sector specific AI policy on agriculture with an initial budget allocation of INR 500 crore (Govt. of Maharashtra, n.d.). While Tamil Nadu's AI policy focuses on safe and ethical applications, its deeptech policy allocates INR 100 crore to support startups with targets of 10 technology transfer or licensing agreements with academic institutions for commercialisation by industry and facilitate a 25 per cent increase in annual patent filing while also supporting skilling initiatives for 10,000 students in AI, robotics, and biotech (Nadig, 2026b).

Karnataka is investing in startups and AI through its startup policy with allocations of INR 570 crore for deeptech startup with the aim of creating 25,000 startups by 2030 (BL Bengaluru Bureau, 2026). Telangana has an AI framework focusing on governance, skill development, research and innovation, models, and access to computing (MeitY Startup Hub, n.d.). Its MoU with C-DAC (Centre for Development of Advanced Computing) allows 142 AI startups under the Telangana AI Mission to access high-performance AI computing infrastructure under the National Supercomputing Mission (C-DAC, 2023). It is also developing a 200-acre AI city near Hyderabad with a focus on infrastructure, networks, R&D, and high-performance computing and data centres (AI City Hyderabad, n.d.). Telangana's T-Hub serves as an incubator providing access to infrastructure and ecosystem for startups and innovation supporting over 2,000 startups with Google setting startup hub in India in T-Hub (T-Hub, n.d.-a).

3.3. Interdependencies and Systemic Advantages

The historical and systemic advantages combined with policy support described above create enabling conditions for AI innovation. New and emerging technologies like AI come with technical and market risks due to insufficient market information available to entrepreneurs (Carlsson & Stankiewicz, 1991). AI economic activity clustering with existing technology hubs can help mitigate commercial risks by locating themselves in

regions with strong "intra-industry spillovers" and innovation incentives. This includes the presence of complementary actors in the form of suppliers, users, and customers; knowledge networks; skilled workforce pool; access to research and development through presence of important academic institutions.

Many startups spinoff from existing companies which highlights the importance of networks to overcome information asymmetries in technology ventures. For example, former employees of Urban Company have gone on to found 33 startups spanning sectors such as SaaS (Software as a Service), fintech, logistics, etc. (Inc42 Datalabs, 2026). Similarly, Meesho's former employees have founded 26 startups across a similarly diverse range of sectors (Inc42 Datalabs, 2025).

Venture capital firms also remain key players within the ecosystem with Bengaluru, Delhi NCR, and Mumbai getting a key chunk of investor capital with Bengaluru raising $4.5 Bn across 300 deals, Delhi NCR raising $2.2 Bn in funding with 224 deals and Mumbai raising $2 Bn in about 146 deals. Pune, Chennai, and Hyderabad form the top three emerging startup hubs with Pune-based startups raising US$5.1 billion+ across 421 deals during 2014-25, Hyderabad US$3.3 Billion+ across 416 deals, and Chennai raising US$5.1 billion+ across 410 deals during the same time period (Sharma, 2026).

A recent study showed a marked concentration of AI companies in a few European hubs. According to the study, 10 regions in the UK and Europe hold 60 per cent of Europe's AI startups (Vásquez et al., 2025). The reason behind this concentration is attributed to co-location with technical institutions, applied research capabilities, and targeted venture capital and private investment. The study showed that major knowledge hubs are key to mitigating technological risks, and the reduction of technology risk enhances the economic opportunity to create value for co-located industries. As a general-purpose technology, AI both benefits from external economies of scale to reduce commercial risks while creating externalities across sectors and

industries through process efficiencies and product innovation. Consequently, AI has a much larger economic impact than the success of individual firms.

Clusters create densities of people, processes, and resources. Government creating support for enabling conditions in existing clusters would contribute effectively towards their growth and alignment with national objectives. Institutional infrastructure can involve formal and informal arrangements that can facilitate interaction and complementarity. They help in sustaining and supporting the adaptiveness of the innovation system and managing uncertainty and risk. It is important to create mechanisms that absorb or diffuse the risk faced by individual actors (Carlsson & Stankiewicz, 1991). Clustering also leads to legitimation through regulatory and/or normative means such as tax incentives or special economic zones and the creation of positive externalities, that is, system-level utilities that also come to be available to actors or newer entrants not responsible for creating them (Ulmanen & Bergek, 2021).

4. Identifying Areas for Policy Intervention: Elements of a Federal AI Policy

The previous sections identified the sites of innovation and economic opportunities within regional innovation systems as well as actors, interdependencies, and historical contingencies therein. This section identifies areas of policy intervention and elements of a federal AI policy.

India's startup, innovation, and AI journey is spread across different ministries, departments and national missions. Each of these initiatives requires the alignment of additional administrative units spanning taxes, corporate affairs, financial regulations, commerce and industrial policy, among others. In addition to this, states also have their own initiatives related to startups, AI, and innovation. The aggregate effect appears to be of maximisation of overall innovation activity as opposed to targeted support.

A common strategic focus across Central and state policies have been to support as many startup and innovation activities as possible with access to infrastructure, networks, incentives, and ease of compliance. However, startups and private capital activity tend to veer towards surety and quickness of returns focusing on consumer-focused technologies delivering consumption-led growth. This highlights an untapped potential to direct public investment towards startups and industrial innovation that can lead to synergistic growth in each of these innovation clusters.

Elements of a federal AI policy are premised on fostering innovation through demand aggregation, developing interdisciplinary talent capacity, effective management to reduce coordination costs, supporting private investment, and effectively channellising complementary positive feedback loops.

- **Demand Aggregation:** Innovation in industrial and sectoral AI that can improve manufacturing efficiency, production times, or drug discovery can have cumulative boosting effects on the economies as a whole. This underscores the need to incorporate policy mechanisms to aggregate demand across clusters for AI-led digital transformation aided by industry associations. Each of these clusters has a strong presence of specific industries which are rapidly adopting AI solutions and facing constraints for in-house development. Manufacturing, biotechnology, and pharmaceutical industries dominate all of the cluster locations. Additionally, there is presence of public sector defence and aerospace research in Bengaluru and deeptech space startups in Hyderabad. This provides a unique opportunity to direct incentives to align startup and entrepreneurial activity to develop solutions for automobile and electronic manufacturing, pharmaceuticals, and biotechnology as well as defence and aerospace. This enables firms in these industries to take advantage of co-innovation as well as agile development.

- **Co-specialisation with IT Firms:** Legacy IT firms are actively investing in startups to identify and scale solutions taking advantage of speed and agility over in-house

development. With these firms also investing in data centre compute capacity, developing co-specialised solutions with IT majors helps startups take advantage of scale, expertise, and compute infrastructure in building large-scale technological systems. Co-specialised solutions can shorten the time to market and adoption.

- **Cluster Aligned Inter-disciplinary R&D and Talent Development:** Focused R&D related to industries academic institutions are co-located with can facilitate student placements, creating a circular and multiplier effect on innovation and talent development down the line. This can leverage existing strengths and locational advantages. Further, it offers the opportunity for setting up institutional mechanisms for interdisciplinary applied research that can bridge AI knowledge and industry-specific knowledge to align innovation according to specific requirements of these industries.

- **Incentivising Private Capital Investment:** It would also help to nudge private capital through incentives and awareness to invest in solutions aligned to industrial requirements in each of these locations. This can be attractive because of the existing and untapped demand potential. This would at one level help catalyse economic growth through synergistic innovation, commercialisation, and application while also establishing these clusters as pioneers in application driven innovation.

- **Cluster Management:** Effective cluster management is important to forge connections and linkages between components within the system and reduce coordination and search costs. This involves facilitation and organisation of innovation activity within a given regional innovation system. This requires administrative resource allocation at a federal level with an institutional framework that enlists support from industry bodies and associations.

- **Complementary Effects:** AI as a technology is strengthened through feedback loops. Industry-focused innovation will also create upstream advantages in granular data and context-specific models that can have export potential. State's proactive data centres policies would also spur research and development in allied areas such as sustainable data centre practices running on renewable energies.

Overall, a strong federal AI policy can help transition from India's consumption driven innovation story to an economic growth-led one while also solidifying its economic growth and resilience through deep expertise and specialisation.

5. Limitations and Tensions to Consider when Adopting a Cluster-Driven Federal AI Strategy

Technology development trajectories in different locations follow different paths contingent on historical development such as existing R&D ecosystems, learning processes, and the deepening interdependence between sub-systems and ecosystems and the evolving role of institutions and policies that enabled and sustained them (Casadella & Tahi, 2023). However, this tendency of technology firms to cluster creates economies based on the agglomeration that creates a dynamic of "winner-takes-most" to the exclusion of underserved locations. As exemplified in the US, with technology, advanced industries, and innovation concentrating in the Bay Area, Los Angeles, and Seattle, small cities, towns, and rural areas remained outside the scope of economic and innovation dividends with trailing economic growth (Muro & You, 2022). Moreover, increased concentration of innovation and economic activity creates stress on infrastructure and utilities, raising congestion within cities affecting the standard of living. These domestic priorities and imperatives also stand in tension with the need for economic efficiency to develop competitiveness within a rapidly evolving geopolitical landscape.

5.1. Limitations and Tensions Within a Cluster-Driven Policy

In policy-making for developing countries like India, this path dependency creates tensions within national and regional policy to balance spatial equity and economic efficiency (Venugopalan & Misra, 2025). Conditions that offer locational advantages in clusters such as clustering of resources, knowledge spillovers, complementary innovation activities, innovation incentives, and pre-existing customer and supplier networks give rise to unequal development and spatial inequities and the concentration of economic dividends at the expense of other regions in the country like Tier II and Tier III cities, small towns, and rural areas. For e.g., Bengaluru accounts for 99 per cent of the startup capital raised in the state (Nadig, 2026a). Concentration of regional firms can lead to inequality of development particularly in developing countries like India on a growth path.

However, clusters emerge, mature, and stabilise and new clusters develop as companies explore and build clusters in new locations due to comparative local advantages. Technology companies like Hewlett Packard, Palantir, Oracle, and Tesla moved their headquarters out of California to Houston, Denver, or Austin with Google and Oracle setting up satellite and engineering offices in North Carolina while Intel announced the location of two of its semiconductor plants in Columbus, Ohio (Muro & You, 2022).

While the emergence of AI companies and capabilities follow the clustering logic, over time they also lead to a saturation point wherein firms start looking for differentiation factors. Despite Bangalore still retaining the spot as the top startup hub in the country, regional clusters in Pune, Delhi NCR, and Chennai show significant average year-on-year growth—26 per cent for Pune and Delhi NCR and 29 per cent for Chennai in comparison to 20 per cent for Bangalore, indicating maturity (D. Sharma, 2025).

As the technology matures this creates the business demand for a set of strategic priorities that cannot be met within the existing system. While early emergence of AI

industry follows the agglomeration logic in developing viable business models, additional value capture can foster regional diversity. This leads to the search for additional locational advantages. This expansion is often driven by big tech companies as much as their presence is the sticking point behind agglomeration.

For example, Google is investing US$ 15 billion in Vishakhapatnam to develop its first AI Hub in the country. In addition to a purpose-built data centre, this would also create new international subsea gateways on India's east coast (*Google*, n.d.-b). The decision to prefer Andhra Pradesh and Vishakhapatnam over established tech and innovation clusters depended on not just Vishakhapatnam's geostrategic accessibility to subsea landing stations but also the state's land, water, and energy policies, which are important for power and water intensive data centre projects with high utility demand.

This regional diversification by companies can also be reflective of underlying factors such as congestion, rising costs of living and infrastructural stress. For example, the social cost of traffic congestion in Bengaluru is estimated to be US$ 380 billion, which is equivalent to five per cent of the city's GDP. According to Bengaluru's Outer Ring Road Companies Association, the loss of two productive hours due to congestion is equivalent to 10 per cent revenue loss (Chanchani & Singh, 2025). Increased concentration is also instrumental in driving up the cost of living which chips away at savings (Times of India, 2025). The added risk of overfitting an approach to AI towards innovation clusters might neglect the needs of underserved social sectors. Towards this end, the proposition of a federal AI policy is aimed as a complementary approach to incorporate regional and industrial policy through a federated innovation push within national AI strategies.

5.2. Geopolitical Considerations

Geopolitical, economic, and environment shocks have forced firms to confront the question of de-risking supply chains over cost-efficiency, that is, whether to remain embedded in existing supply chains or secure them by boosting domestic production

which includes substantial investments, supply chain completeness, and export competitiveness.

Geopolitical uncertainty has created immense predicaments for policy options in developing national strategic capabilities. Slight shifts in alignment can have immense knock-on implications for strategic technology policies (Venugopalan & Misra, 2025). New and emerging technologies like AI compound the problem because of the requirement of both technical knowledge and scarce infrastructure. Geopolitical uncertainty adds to information asymmetry and policy predicaments. This foregrounds and circles back the focus on developing indigenous capacity. This highlights the need to build adaptive capabilities to navigate both shocks and absorb positive externalities and develop economic resilience through productivity, efficiency, and differentiated specialisation in specific sectors and industries in which it already occupies a competitive position.

This raises questions on the nature of autonomythe extent to which states can remain embedded in existing global supply chains while at the same time guard against vulnerabilities therein. Developing strategic autonomy is a fraught endeavour that often invites backlash when existing market and economic opportunities are closed off (Vu et al., 2024). On the other hand, achieving strategic autonomy in the near term requires capitalising on existing capabilities and strengthening existing clusters and deepening networks therein which can run counter to the domestic needs for socio-economic equity among different regions.

Additionally, India's path to strategic autonomy in AI is fraught with deep market penetration of US and Chinese foundation models even as it works to build its own sovereign models. India has emerged as OpenAI's second largest market in terms of users and is among the top five in terms of developer usage, which means it is also being used to build products in addition to individual use (Moorthy & Agarwal, 2025). Soon after the launch of DeepSeek, the app topped most downloaded lists across 140

markets with India contributing 15.6 per cent across all platforms (Bloomberg, 2025). India was also the second largest market for DeepSeek in terms of monthly active users after China in January 2025 (Backlinko Team, 2025).

This foregrounds the imperative to develop India's comparative advantage globally by developing deep expertise in industrial and sector-specific models that can power both industrial productivity and output as well as R&D that can be readily commercialised. Targeted incentive to develop AI solutions that can have multiplier effects with location advantages in clusters helping accelerate economic growth just as sovereign AI models under the AI mission aims to achieve at scale last-mile socio-economic equity. This twin expertise would help India export solutions and services through trusted partnership arrangements and provide solutions that are both economically viable and respect other states sovereignty without engendering dependency.

6. Recommendations and Conclusion

Going forward, national AI strategy would need to incorporate and optimise the twin objectives of (i) economic efficiency and growth; and, (ii) economic resilience in the shifting geopolitical landscape. This article argued that the way forward would depend on how well countries have leveraged existing strengths. Countries are likely to succeed by exploiting adjacent capabilities and leveraging existing strengths in their regional innovation systems and leverage untapped potential therein. Developing capabilities in new and emerging technologies requires substantial administrative intervention and "state-coordinated investments" to develop enabling conditions to foster innovation in such technologies, thereby creating the potential to leapfrog on the basis of such advantages (Venugopalan & Misra, 2025).

AI as a general-purpose technology has effects across sectors and industries fundamentally shaping processes of production and output. Consequently, it requires multi-institutional support as it cuts across different sectors of the economy from finance, industry, technology, security, international affairs, international trade and

commerce (Venugopalan & Misra, 2025). Its development, diffusion, and economic exploitation therefore come under the purview of a range of administrative units ranging from IT, commerce, science and technology with different mandates on the same technology. This often raises coordination dilemmas and costs within the bureaucracy on how to create centralised development initiatives that synergises as opposed to duplicates existing efforts. In addition to multiple government departments, this is also subject to state mandates within India's federal structure. While centralisation offers planning and efficiency, decentralisation offers responsiveness and market sensitivity.

Resolution of coordination costs and governance mechanisms for effective management of regional innovation systems is also required to forge links between industrial clusters and the AI ecosystem for demand aggregation and solution development, R&D linkages with academic institutions for interdisciplinary foundational and applied research, and creating pathway for co-specialisation with IT firms. This highlights the need for 'strategic collaboration' between industry and governments and the need to create governance and management structures by enlisting industry bodies and associations. This is required to suitably take advantage of the identified economic opportunities and to mitigate constraints and bottlenecks.

Each of the cluster locations has deep sectoral, industrial, and manufacturing roots along with presence of IT firms and MNCs. This presents certain opportunities and bottlenecks. It creates opportunities for India to develop differentiation in AI products, services, and intellectual property to achieve comparative advantage globally which can also be the means for strategic autonomy. Leveraging locational advantages and developing industry- and sector-relevant startup and innovation activity would lead to a circular boosting effects with industry benefiting from cost-effective solution development and productivity and efficiency gains. By allowing for co-innovation, this can also enable startups to find commercialisation and users for their products through ready adoption. Increased usage of AI tools creates positive feedback loops through better data which allows users to enhance model performance. This in turn feeds into data centre momentum and requires thinking about sustainable utility provision.

However, developing these capabilities and engendering these effects create coordination challenges not just among departments but within policy mandates and objectives anchored by each. AI and innovation mandates spread across ministers and departments like MeitY, DPIIT, DST (Department of Science and Technology), Finance, Corporate Affairs, RBI at the central level in addition to state governments and their relevant departments. Further, a cluster-driven approach with its tendency to enhance concentration of economic and innovation activity can run counter to policies and strategies aimed at promoting access and equitable opportunities for balanced socio-economic development. Future AI policies would need to optimise economic growth and inclusion through a long-term planning horizon to continuously assess the possibilities of new cluster development to prevent saturation and stagnation in existing clusters and ensure wider reach and expansion of economic and innovation activity across regions.

A federal AI strategy increases visibility of regional strengths and helps India's national strategy leverage it towards economic growth and increased efficiency of India's flagship industrial sectors, thereby maximising their productivity and earnings. It also helps strengthen regional development and R&D capacity while opening pathways for private capital investment in developing industrial applications with a ready customer base.

Mobilising the elements of a federal AI and industrial policy would require appropriate institutional mechanisms to facilitate demand aggregation, infrastructural access, and management of regional innovation systems. In addition, developing sector- or industry-specific expertise requires interdisciplinary boundary-spanning work, including requirements elicitation to design and develop market-ready solutions for quick testing and uptake. The following recommendations are put forward to take advantage of opportunities and to mitigate bottlenecks:

(i) Institutional Design: Effective institutional design is required to capture and aggregate untapped demand potential and create pathways for uptake of AI entrepreneurial activity:

a. **Demand Aggregation through Industry Associations:** Demand aggregation needs a process for requirements elicitation to align and document industry demand and innovation activity. This can be effectively done through an initial push by the government in enlisting industry associations in the clusters: biotechnology, defence, and aerospace in Bangalore; automobile manufacturing in Pune, Chennai and Gurugram; electronics manufacturing in Chennai and Noida; pharmaceuticals and life sciences in Hyderabad and Pune; and banking and financial services in Mumbai. In addition to acting as platforms for demand aggregation, they can facilitate networking and act as links between industrial clusters, AI startups, and IT companies for demand discovery and solution alignment.

b. **Innovation Authority:** Effective governance and management of regional innovation systems is essential to reduce coordination costs and ensure policy initiatives are able to achieve their desired outcomes. An innovation authority should be able to coordinate and harmonise support within and across Central and State departments as well as the industry bodies, providing top-level guidance on policy alignment and coordination. Further, it should be able to triangulate between government support, industry requirements, and startup potential and align them with fundamental research in academic institutions essentially forming a bridge between basic and applied research. This can be done through a devolved institutional structure with the nodal authority acting as the liaison between Central government agencies and state- and cluster-level units managing state government and last-mile coordination, respectively.

(ii) Cluster-Aligned Industrial Placements for Commercialisation and Adoption of Advanced Academic Research: Developing industry-aligned AI solutions requires cross-sectoral and cross-industrial AI expertise, necessitating substantial investment in

developing interdisciplinary research and capacity development. Academic and research institutions located in these clusters can collaborate with the industry by co-creating solutions through industrial placements as part of advanced research degree programmes. This helps companies grow in-house talent with an inter-disciplinary approach and ensure advanced scientific research is industry-aligned and lends itself for commercialisation and adoption. This would help match sector- and industry-specific knowledge and skills with AI-specific ones. This would help create human capital that are able to provide solutions across domains along with the capacity to begin their own entrepreneurial journeys in these spaces.

(iii) Targeted Incentives for Co-innovation, Co-specialisation, and Diversification: Developing deep sectoral expertise in automotive and electronics manufacturing, pharma, biotech, and defence and aerospace would require targeted incentive structures which promote solution development in these domains in associated clusters. This would involve

a. Incentivising industry through supportive and clear tax regimes, ease of compliance, and corporate structuring and governance to co-innovate with startups taking advantage of agile development

b. Supporting legacy IT companies to co-specialise with startups to develop, test, and implement solutions at scale by providing network and infrastructure for skills and resource matching

c. Sensitising venture capital firms to the economic potential of investing in industrial cluster-aligned solutions.

(iv) Strategic Autonomy through Deep Specialisation: An assertion of strategic autonomy involving decoupling from existing supply chains and economic relationships can invite backlash from existing allies (Vu et al., 2024). While India develops its sovereign capabilities to de-risk supply chains and reduce dependency, this paper suggests building economic resilience by establishing strategic autonomy through comparative advantage by the means of deep expertise in sectoral and industrial AI. India already is a cost-competitive location for these industries and AI adoption can

further enhance these efficiencies while also providing viable models, solutions, and services for export to counter-balance strategic technological and economic dependencies.

(v) Developing Sustainable Utility Provisions: Increased AI development, use, and adoption would drive the demand for compute infrastructure and data centres which would in turn put a stress on utilities. This highlights the need to develop capacities in sustainable energy and water management practices to ensure equitable development. This includes investments in facilities, infrastructure, and research into data centre design in how to make them more energy and water efficient.

In sum, Indian industrial clusters offer immense potential to enhance differentiated innovation through co-innovation and co-specialisation that can help accelerate pathways to economic growth and address economic vulnerabilities. This involves leveraging existing locational advantages, ecosystem support, and enhancing coordination efficiency through effective institutional design.

7. Case Profiles

Bengaluru, Delhi, Mumbai, and Chennai count among the top 100 innovation clusters globally with Bengaluru and Delhi ranked amongst the top 30 at 21 and 26, respectively. Hyderabad and Pune are also closing in with global ranks of 102 and 112, respectively. The states in which these clusters are located combined host 64 per cent of DPIIT-recognised startups and 66 per cent of AI startups in India. In addition to the startup concentration, these clusters also benefit from co-location with industries such as biotechnology in Bengaluru as well public sector defence and aerospace research and industries; pharmaceuticals in Hyderabad with the Mumbai–Pune corridor also being an important biopharma hub; automobile manufacturing in Pune, Chennai, and Gurugram; electronics manufacturing in Noida and Chennai; with Mumbai being the financial hub. These offer significant opportunities for demand aggregation, co-innovation, and co-

specialisation as these sectors are increasingly adopting AI-led digital transformation strategies.

- **Bengaluru**

  Historical Contingencies: The development of Bengaluru as a key technology hub nationally and globally can be attributed to complementary Central and state policies, early strategic considerations, and presence of research institutions. Over the course of the 1970s and 1980s, both Central and state governments undertook a number of policies to promote computer and software exports. The city benefitted from the strategic decision of the Central government to locate sensitive industries away from borders or coastlands leading to the growth of public sector defence and aerospace industries like HAL (Hindustan Aeronautics Limited), BEML Ltd. (formerly Bharat Earth Movers Limited), and BEL (Bharat Electronics Limited) (Basant, 2008). This is complemented by the presence of top academic institutions like IISc and IIIT in Bangalore.

  Post-liberalisation reforms served to further promote the IT industry. Allowing 100 per cent FDI in the IT sector in 1999 eased the pathways for MNCs to set up development centres in India strengthened by the country's cost-competitive advantages (Basant, 2008). Supportive policies included software export promotion, improving foreign exchange availability, reducing of tax burden on exporting firms. State and Central government initiatives on technology parks complemented each other and boosted infrastructure development and provision. In the early 1990s with the launch of the Software Technology Parks of India (STPI), the city hosted the first centre with attraction of tax incentives and infrastructure for IT service exports (STPI, n.d.).

  Technology Ecosystem: Karnataka is home to 750 multinational companies and attracted the second-highest FDI inflow in India with investment commitments totalling US$115 billion (Jindal, 2025). Texas Instruments set up its first offshore

development centre in the city in 1985. This was followed by other multinational companies like IBM, Oracle, and Microsoft setting up shop in the 1990s post-liberalisation era (Powell, 2025). Phillips and Bosch set up software and engineering centres in 1996 and 1997, respectively, followed by multi-disciplinary R&D lab in 2000. The supportive ecosystem led to the genesis and expansion of homegrown IT firms like Infosys, Tata Consultancy Services, and Wipro (Powell, 2025).

In 2025, Google, Databricks, and Morgan Stanley opened sizeable campuses focusing on AI, data science, and high-technology research and services (Jindal, 2025). The city has the highest number of Fortune 500 companies, the highest number of GCCs, and the second highest number of India's most valuable companies as well as the highest number of unicorn startups (Jindal, 2025). Bengaluru ranks fourth among the top 12 global technology powerhouses and represents the largest talent market in Asia-Pacific along with Beijing and Shanghai (CBRE, 2025). It has a high concentration of AI talent in India, placing it on par with established technology clusters like San Francisco and New York (CBRE, 2025).

Industrial Clusters: The city is also a major hub of biotechnology in India, hosting 60 per cent of biotechnology companies (EITBT, n.d.). Electronic City in Bengaluru hosts over 1,300 biotechnology startups and companies, most notably Biocon (Invest India, 2025). In addition to this, the city hosts public sector manufacturing and research such as HAL, BEL, BEML, and DRDO (Defence Research and Development Organisation) involved in the manufacture of locomotives, power equipment, along with defence and aerospace research and manufacturing. Early studies also indicate positive industryacademic linkages with almost all domestic and foreign firms having some of form of contact with research institutions who become the source of both human capital and knowledge (Basant, 2008).

Actors and Institutions: The state government has played an active role in promoting the IT industry and was one of the first states to come up with its own IT policy (STPI,

n.d.). With the sizeable number of US companies, the United States recently opened a consulate in the city to facilitate better cross-border collaboration (Nair, 2025). Building on its history of public sector manufacturing enterprises, Karnataka is also emerging as a key global manufacturing hub with Volvo, Mahindra, and JSW Group investing significantly in expanding their existing facilities in automotive and steel manufacturing (Jindal, 2025). This is also boosted by the presence of strong software services industry and presence of MNCs which contribute to the overall innovation activity and talent pools. Bengaluru was also the top destination of venture capital funding in the country.

- **Chennai**

Historical Contingencies: The city had 2,032 registered startups in 2021; in four years, the number has increased fivefold to over 12,050+ startups (Inc42 BrandLabs, 2025). This is supported by policy focus on startup education, funding access, and incubation support with seed funding for early-stage startups to the tune of 10 lakh with women-led startups, greentech and rural livelihoods receiving 15 lakh. This is also aided by ease-of-doing-business strategies with the state cutting registration costs by 80 per cent. The value of the state's startup ecosystem rose from US$3 billion in 2021 to US$ 27.4 billion in 2024 (Inc42 BrandLabs, 2025).

Technology Ecosystem: Chennai has a bustling data centre, IT, GCC, and AI research ecosystem. With 19 data centres, the city ranks second in the country after Mumbai (Koundinya, 2025). Both Chennai and Mumbai have coastal geography which privilege undersea cable landing stations. Chennai being closer to the cable landing systems offers lower latency and increased operational efficiency. Consequently, major players like NTT Data, Tata Communications, and Sify have connected their data centres with on-site cable landing stations. The state has a focused data centre policyTamil Nadu Data Centre Policy, 2021. There are currently seven active undersea cables in Chennai with three more under construction. These connect to 19 countries worldwide with France and Italy being major data hubs in Europe as

well as Southeast Asian countries such as Indonesia, Malaysia, Singapore, and Thailand (Koundinya, 2025).

Chennai accounts for 15 per cent of India's IT workforce and hosts 250 GCCs and is known as a SaaS capital of India with companies like Zoho and Freshworks. This works in tandem with infrastructure capacity with companies like Sify and E2E running high-performance GPU clusters (Koundinya, 2025; Pandey, 2025a). The presence of IIT Madras strengthens the R&D ecosystem through its industry-academia partnerships and leadership in developing compute accessibility solutions and sovereign Indic LLMs (IIT Madras, 2025; Koundinya, 2025).

Industrial Clusters: The state is also strong in manufacturing of automotives, electronics, heavy engineering, and textiles. Tamil Nadu contributes 11.9 per cent to the country's manufacturing GDP, ranks first in the number of factories, and second in the number of MSMEs (Micro, Small, and Medium Enterprises) (Economic Survey of Tamil Nadu 2024-25, n.d.). The state is home to global manufacturers like Foxconn, Hyundai, and Samsung and has 31,000 active factories. The state accounts for 41 per cent of India's electronic exports, 38 per cent of footwear, and 45 per cent of automobile components exports. It has an investor-friendly climate with speedy clearance and conflict resolution (The Hindu Bureau, 2025b).

Actors and Institutions: To help startups with market access abroad, StartupTN has set up a global coordination centre in Dubai with similar facilities on the anvil in US and Singapore (Inc42 BrandLabs, 2025). Over time there are also plans to develop a technology transfer centre to facilitate industry-academic linkages. Leading technical universities have incubation cells to support entrepreneurship and innovation. In 2025, private equity and venture capital firms invested US$3,513 million in Tamil Nadu-based companies across 61 deals registering a 20 per cent increase from the previous year (Kandavel, 2026). There is a major infrastructure investment through the North Chennai Development Plan to the tune of INR 6,858

crore to attract high-value industries including GCCs (AIM Network, 2025). The manufacturing sector is a top employer in Tamil Nadu, the state also ranks first nationally in terms of its industrial workforce comprising 15.24 per cent of the national total (The Hindu Bureau, 2025c).

- **Delhi NCR**

Historical Contingencies: IT hub in the Delhi National Capital Regions (NCR) is located across Delhi, Gurugram in Haryana, and Noida in Uttar Pradesh. The three states combined host 25 per cent of all startups and 22 per cent of AI startups.[4] Along with Bengaluru, Delhi ranks among the top 30 innovation clusters globally. AI startups in the Delhi NCR grew at eight per cent CAGR between 2015–2024 with 26 per cent average year-on-year growth (D. Sharma, 2025). The region has nearly 40 unicorns with Gurugram home to 20, most notably Zomato, Urban Company, MakeMyTrip, and Mamaearth, among others (Inc42 Datalabs, n.d.-a)(Inc42 Datalabs, n.d.-b). Noida benefits from an established IT system through the presence of companies like HCL and TCS with unicorns like PayTm, Pine Labs, and IndiaMART (Inc42 Datalabs, n.d.-c).

Technology Ecosystem: Gurgaon is home to companies across sectors from telecoms to electronics, automobiles, and banking. General Electric became the first US company to outsource work to India in 1997. Genpact started as a call centre within GE and then spun off in 2005 serving a wide diversity of clients. Companies like Siemens located here provide crucial support to major US innovations like Nasa's Jet Propulsion Lab who used a portfolio of design software to digitally design, simulate, and assemble the vehicle before building prototypes (Kannan, 2013). UP is home to IT and electronics industry with companies like Samsung, HCL, Microsoft, Accenture, Cadence, Arm Holdings, Xiaomi India, Oppo, and realme, among others. The NCR region is also a key GCC hub for companies like Samsung, Mercer, and Pfizer (Goel & Bhat, 2025a).

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[4] DPIIT recognised startups (https://www.startupindia.gov.in/digital-map/maps) accessed 06 January 2026

Industrial Clusters: Gurgaon's economic growth started in the 1980s with the establishment of the Maruti Suzuki manufacturing plant (IANS, 2018). Delhi NCR has been a focal point for family businesses in manufacturing, automotives, and real estate, among others (Aggarwal, 2024). Gurugram is an important automotive cluster with the state of Haryana having 56 MSME clusters spanning textile manufacturing, equipment and engineering, food processing, and electronics (Directorate of MSME, Haryana, n.d.). Noida is a leading mobile manufacturing hub with companies like Samsung, OPPO, Vivo, Xiaomi, among others (Naik, 2019). Noida's electronics manufacturing clusters along the Yamuna Expressway contribute 40 per cent towards mobile phone manufacturing and 55 per cent of their components. India's sixth semiconductor unit is also set to be located in the Yamuna Expressway Industrial Development Authority by HCL Group and Foxconn (Sen Gupta, 2025). Semiconductor and software design firm ARM opened its second design centre in Noida after Bangalore with a focus on specialised IP-design (Sharma Punit, 2013). Additionally, the state is also a key player in auto components manufacturing (Uttar Pradesh Auto Components Industry, n.d.).

Actors and Institutions: Innovation in the NCR proceeds through a combination of strategic government initiatives, existing momentum, and access to infrastructural facilities in the form of technology and industrial parks. Tech companies in Delhi NCR saw a 12 per cent uptick in funding in the first nine months of 2025. The growth was largely driven by late-stage funding momentum which grew 77 per cent over the same time period even as seed-stage and early-stage investments declined by 50 per cent and 26 per cent, respectively. The auto tech sector witnessed a funding boom with a 517 per cent. Other key sectors include aerospace, maritime, and defence tech (M. Sharma, 2025).

- **Hyderabad**

Historical Contingencies: Hyderabad's evolution as a tech city has been the product of a series of successive investments in infrastructure and supportive policies since

the 1990s (Das, 2015). This involved significant urban restructuring to develop amenities and infrastructure which would attract MNCs and anchor firms. The state continues to provide an enabling ecosystem for the presence of global capability centres, startups, and international technology companies. A number of policy reforms benefitted the development of the tech cluster; these included tax exemptions for software companies, reducing tariffs on utilities, land subsidies, accelerating approvals and facilitating ease of doing business (Rees & Harvey, 2020). The city was also host to Microsoft's first development centre outside the US at the time, established in 1998 (Karmali, 1998). T-Hub was established in 2015 as an incubator supporting infrastructure and ecosystem access for startups (T-Hub, n.d.-b).

Technology Ecosystem: Google will be setting up and AI accelerator in Hyderabad to support startups and develop solutions in the space of agriculture, mobility, and education. Microsoft's R&D hub in the city is the largest outside the United States, spanning 11 lakh sq. ft. (Krithika K.L., 2025). Microsoft employs 20,000 professionals in India with more than half of them in Hyderabad (ANI, 2025). Microsoft is also undertaking AI education, upskilling, and capacity-building programmes in partnership with the government (Krithika K.L., 2025).

Earlier in the year in 2025, the company also committed to INR 15,000 crore for AI data centres in the city (Krithika K.L., 2025). This is aligned with the broad trend of data centre investments by companies such as AWSINR 60,000 (Kashyap, 2025); and Tillman Global Holdings and Blackstone committing INR 20,000 in data centre projects (Krithika K.L., 2025). The state is also developing an AI city near Hyderabad and signed 26 agreements with private players with a focus on compute infrastructure, AI, skilling, and research (Paintola, 2024).

Hyderabad is home to 40 per cent of GCCs set up in India in the last three years (Kumar, 2025). Hyderabad is also home to deeptech startups in space and

aeronautics (Bhatt, 2024). This is complemented by 1500+ IT/ITeS companies and 400+ GCCs as of 2024 and more than 2000+ startups (Vaddepalli & Fersht, 2025).

Industrial Clusters: Hyderabad is known for bulk pharmaceutical production and produces over 40 per cent of India's bulk drugs and accounts for 50 per cent of bulk drug exports (NIPER Hyderabad, n.d.-b). In tandem with Bengaluru, Hyderabad is also an important hub for biotechnology and is also dubbed as the vaccine capital of India with pharma giants like Bharat Biotech and Dr. Reddy's located in the city with Genome Valley being an important biopharma hub (Invest India, 2025).

Actors and Institutions: Organisations like Research and Innovation Circle of Hyderabad (RICH), Telangana Academy For Skill and Knowledge (TASK), Telangana State Innovation Cell (TSIC) and T-Works have provided institutional support for innovation in the form of access to resources, opportunities, and networks (Agarwal, 2023). Institutional support is also available through T-Hub, WeHUb, Telangana State Innovation Cell, and RICH with early-stage incubation support through T-Hub, T-Fund, T-Spark and ecosystem development through the Telangana AI Mission (Vaddepalli & Fersht, 2025). Google Startups has partnered with T-Hub in Telangana to provide founders access to venture capital and mentorship (Google, n.d.-a). In 2024, Telangana unveiled plans for an AI city in Hyderabad to promote AI ecosystem development and attract top companies to set up their AI centres there (Rao Apparasu, 2024). Hyderabad Angels Network (HAN) launched a INR 100 Cr to back 15-20 startups in AI, gaming, spacetech, drone tech, healthtech and fintech (Florentyna, 2025). This is further complemented by industry–academia collaborations and active role played by IIIT, IIT, and ISB in incubating startups.

- **Mumbai-Pune**

Historical Contingencies: The Mumbai–Pune corridor offers important complementarities and linkages as an industrial hub with sectoral specialisation. Pune emerged as an IT Hub in the late 1980s with the IT sector coming to contribute

25 per cent of the city's GDP (SEAP, n.d.). This was helped by Pune's higher educational institutions such as Pune University, the Indian Institute of Science Education and Research (IISER), and various engineering colleges like COEP (College of Engineering Pune) (Mehta, 2024). This was supported by an enabling policy environment which included a combination of fiscal policies such as tax incentives, creation of special economic zones, and business and industrial parks. Pune benefits from strategic locational advantages in terms of cost effectiveness compared to other clusters and proximity to the country's financial hubMumbai. Mumbai ranks 46th among global innovation clusters; coupled with being the financial capital, it lends its potential to develop complementary competencies in fintech innovation (Shetty, 2024; WIPO, 2025).

Technology Ecosystem: Pune hosts key IT firms such as Persistent, Dell, Tech Mahindra, Infosys, among others. OpenGov launched its AI, engineering, and product development hub in Pune in 2025, a major expansion since launching its presence in 2021 (Mondal, 2025). Mastercard expanded it tech and innovation hub in the city in 2024 spread across half a million square metres, making it its largest technology hub globally with approximately 6,000 employees working across fraud detection and biometric authentication with AI-led transformation. The Pune hub joins a 'mesh' of Mastercard's global locations such as New York, Dublin, and St. Louis to work on multiple projects in tandem. The Pune facility has contributed to several key innovations such as payment card tokenisation technology powering services like Apple Pay (George, 2024). Top startup sectors in Mumbai include e-commerce, fintech, and consumer services accounting for more than 50 per cent share (KPMG, 2019). It is home to startups like Nykaa, BookmyShow, Pharmeasy, Acko, and Upstox.

Mumbai is a leading hub for data centres in India, creating important opportunities in terms of low latency infrastructural advantages (Haidar, 2025). Mumbai and Pune draw on each other's complementary strengths with Mumbai as the financial capital attracting GCCs of global financial giants such as Standard Chartered, Citi, and

Barclays while Pune leads in automotive sector GCCs (Goel & Bhat, 2025a). Pune has evolved to build deep expertise in industrial and manufacturing technology and R&D (Ghosh, 2025). Mumbai is one of the leading GCC centres for BFSI while Pune leads in software and automotives (Goel & Bhat, 2025a).

Industrial Clusters: Maharashtra is also planning a smart manufacturing corridor between Mumbai and Pune as an industrial, research, and innovation hub (Kakde, 2025). Pune started out as a hub for automobiles and heavy engineering (Pune Team, 2025). Pune has more than 4,000 auto manufacturing and ancillary units in the Pimpri Chinchwad area with companies like Mercedes, Tata Motors, Skoda, Volkswagen, JCB, Land Rover, among others (Factory Automation Expo, n.d.). The Mumbai–Pune corridor is also a key hub for advanced life sciences serving as an important loci for the state's 25-30 per cent contribution towards India's pharmaceutical output and 40 per cent of pharma R&D (Invest India, 2025).

Actors and Institutions: Maharashtra government has IT/ITeS policy 2023 with a focus on doubling exports to USD 150 Bn by FY 2027-28 (Goel & Bhat, 2025a). Pune is expected to cross 500 centres by 2030 as a rising GCC hotspot (Ghosh, 2025). Seed funding retains momentum in emerging tech hubs like Pune driven by dense talent pools, lower fixed costs, and growing angel networks driven by expanding angel networks beyond metros (Sheth et al., 2025). A consequence of its established education institutions means Pune is home to a skilled talent pool in combination with lower operational costs (Mehta, 2024).

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