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Adoption Drivers of Indigenous Semiconductor chips for IoT in India: An Exploratory Study

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ABSTRACT: India's strategic objective of achieving self-reliance in semiconductor technology has gained urgency following global supply-chain disruptions and the rapid expansion of Internet of Things (IoT) applications. Despite hosting extensive semiconductor design capabilities, India remains dependent on imported microprocessors for most electronic systems. This study examines the factors shaping the acceptance of indigenously developed semiconductor chips for IoT applications in India, with specific reference to the SHAKTI processor ecosystem. Using a quantitatively supported grounded theory approach, data were collected from industry experts, policymakers, manufacturers, and ecosystem stakeholders through interviews, surveys, and document analysis. The findings indicate that acceptance is driven by four interrelated dimensions: design capability, manufacturing readiness, go-to-market strategy, and policy support. While India demonstrates strong design competence and policy intent, gaps persist in manufacturing scale, supply-chain robustness, and market confidence. The study contributes to the limited empirical literature on semiconductor ecosystem development by proposing a holistic, non-technical framework to accelerate adoption of indigenous processors in IoT deployments.

KEYWORDS: Indigenous semiconductors, SHAKTI processor, IoT, RISC-V, semiconductor policy, India

I. INTRODUCTION

Semiconductor chips constitute the foundational infrastructure of modern digital economies, enabling computation, communication, sensing, and control across industries such as automotive, healthcare, energy, defense, and consumer electronics. The rapid growth of IoT applications has further amplified demand for low-power, secure, and cost-efficient processors. Recent global semiconductor shortages exposed vulnerabilities in highly concentrated supply chains, reinforcing the strategic importance of domestic semiconductor capabilities for national economies.

India has articulated a clear ambition to emerge as a global hub for Electronics System Design and Manufacturing (ESDM). The National Policy on Electronics (2019) and subsequent semiconductor initiatives emphasize indigenous design, fabrication, and ecosystem development. However, despite hosting design centers for most major global semiconductor firms, India lacks widespread commercial adoption of domestically developed processors. The disconnect between design capability and market acceptance remains a critical challenge.

The emergence of open-source instruction set architectures such as RISC-V has lowered entry barriers for indigenous processor development. Within this context, the SHAKTI processor initiative represents India's most comprehensive effort to develop an open, scalable, and secure processor ecosystem. While technical feasibility has been demonstrated, adoption in commercial IoT systems remains limited.

This study investigates the factors influencing the acceptance of indigenously developed semiconductor chips for IoT applications in India. Rather than focusing on device-level performance metrics, the research adopts an ecosystem perspective encompassing design capability, manufacturing readiness, market strategy, and policy support.

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II. LITERATURE REVIEW

2.1 Semiconductor Industry and National Ecosystems

The semiconductor industry is widely recognized as one of the most complex and capital-intensive sectors in the global economy. It is characterized by fragmented yet highly interdependent value chains encompassing research and development (R&D), design, fabrication, assembly, testing, and distribution (SIA, 2022). No country operates a fully self-sufficient semiconductor ecosystem; instead, competitiveness depends on specialization, international coordination, and long-term policy alignment (Fuller, 2016). Prior studies emphasize that successful semiconductor nations such as the United States, Taiwan, South Korea, and Japan have relied on sustained public investment, public–private partnerships, and stable regulatory environments to build resilient ecosystems (Mathews & Cho, 2007; Mazzucato, 2018). Government intervention has been particularly critical in mitigating high entry barriers arising from capital costs, technological uncertainty, and long gestation periods (Lee & Lim, 2001). In contrast, emerging economies face structural constraints related to infrastructure, supply-chain dependencies, and skill mismatches (Ernst, 2014). Although India has developed strong competencies in semiconductor design services, its limited manufacturing base has restricted its progression toward end-to-end ecosystem maturity (Chaudhuri & Sanyal, 2021). The literature thus suggests that indigenous semiconductor development must be evaluated not only through technological capability but also through ecosystem readiness and institutional support.

2.2 Open-Source Architectures and RISC-V Adoption

Instruction set architectures (ISAs) play a central role in shaping innovation and market structure within the semiconductor industry. Proprietary ISAs such as x86 and ARM have historically dominated commercial markets but impose licensing costs and strategic dependencies on processor developers (Patterson & Ditzel, 1980). RISC-V, an open-source ISA, has gained increasing attention as a disruptive alternative due to its royalty-free licensing, modular design, and architectural transparency (Waterman & Asanović, 2019). Prior research highlights RISC-V's suitability for embedded systems and IoT devices, where cost sensitivity, power efficiency, and customization are critical (Zhao et al., 2020). The open nature of RISC-V also enables independent security verification, addressing growing concerns over hardware backdoors and cyber vulnerabilities (Chowdhury et al., 2021). However, adoption of open-source hardware is not without challenges. Studies note limitations related to software ecosystem maturity, toolchain availability, and long-term vendor support (Guerreiro et al., 2022). While RISC-V lowers entry barriers at the design level, commercial success depends on complementary assets such as manufacturing access, software stacks, and ecosystem coordination (Teece, 1986).

2.3 Indigenous Processor Development in India and the SHAKTI Initiative

India's engagement with indigenous processor development has historically been fragmented, with limited transition from academic prototypes to commercial products (Kamakoti, 2022). The SHAKTI processor initiative represents a significant departure from earlier efforts by adopting an open-source RISC-V foundation and pursuing scalability across multiple processor classes. Existing literature on SHAKTI primarily focuses on architectural design, performance benchmarks, and security features (Bora & Paily, 2021). Studies demonstrate its applicability to low-power embedded systems, real-time operating systems, and IoT use cases. The transparency afforded by open-source design has been highlighted as a strategic advantage in security-sensitive applications (Chowdhury et al., 2021). Despite these technical strengths, empirical research on market acceptance, manufacturing readiness, and policy effectiveness surrounding SHAKTI remains limited. Most available studies are technical in nature and do not address adoption barriers faced by manufacturers, system integrators, or end users. This gap suggests the need for a broader, ecosystem-oriented analysis of indigenous processor acceptance.

2.4 Internet of Things (IoT) and Semiconductor Demand

The rapid expansion of IoT has significantly reshaped semiconductor demand patterns. IoT devices typically prioritize low power consumption, reliability, security, and cost efficiency over peak computational performance (Atzori et al., 2010). As a result, embedded and microcontroller-class processors dominate this segment. Research indicates that IoT adoption is strongly influenced by supply assurance, lifecycle support, and integration flexibility (Porter & Heppelmann, 2015). For emerging markets, localized manufacturing and customization capabilities further enhance adoption potential by reducing costs and addressing context-specific requirements (Manyika et al., 2015). However, literature on IoT hardware adoption rarely considers the strategic implications of processor origin. The role of indigenous semiconductor solutions in enhancing supply-chain resilience and national security remains underexplored, particularly in developing economies such as India.

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2.5 Policy Support and Semiconductor Adoption

Government policy is widely recognized as a critical enabler of semiconductor ecosystem development. Prior studies emphasize the importance of coordinated policies spanning R&D funding, capital subsidies, procurement preferences, and trade regulations (Rodrik, 2004; Mazzucato, 2018). In the Indian context, policy initiatives such as the National Policy on Electronics and semiconductor incentive schemes reflect strong intent to promote domestic capabilities. However, scholars note challenges related to policy fragmentation, implementation delays, and insufficient alignment between design and manufacturing objectives (Chaudhuri & Sanyal, 2021). Empirical evidence suggests that government procurement can play a decisive role in early-stage adoption of indigenous technologies by creating guaranteed demand and reducing market risk (Edquist & Zabala-Iturriagagoitia, 2012). Nevertheless, limited research has examined how such policies influence acceptance of indigenous semiconductor chips specifically within IoT markets.

2.6 Synthesis and Research Gap

The literature indicates that while India possesses strong semiconductor design capabilities and growing policy support, adoption of indigenous processors is constrained by manufacturing limitations, ecosystem immaturity, and market confidence. Existing research is heavily skewed toward technical performance and architectural innovation, with minimal attention to non-technical adoption drivers. There is a clear gap in empirical studies examining how design capability, manufacturing readiness, go-to-market strategies, and policy support jointly shape acceptance of indigenously developed semiconductor chips. Addressing this gap is particularly important in the context of IoT, where cost sensitivity, supply assurance, and customization are critical decision factors. This study responds to this gap by adopting an ecosystem-level perspective to analyze the acceptance of indigenous semiconductor chips in India, with specific reference to the SHAKTI processor initiative.

III. THEORETICAL FRAMEWORK

The study is grounded in innovation diffusion and ecosystem theory, viewing semiconductor adoption as a systemic outcome rather than a purely technological decision. Acceptance of indigenous processors is conceptualized as a function of four interrelated dimensions:

1. **Design Capability** – Availability of skilled talent, IP ownership, scalability, and generational continuity.
2. **Manufacturing Readiness** – Access to fabrication, assembly, testing infrastructure, materials, utilities, and logistics.
3. **Go-to-Market Strategy** – Cost competitiveness, supply assurance, customization capability, and vendor credibility.
4. **Policy Support** – R&D incentives, capital subsidies, procurement preferences, and regulatory alignment.

These dimensions collectively influence stakeholder confidence and adoption decisions in IoT deployments.

IV. RESEARCH METHODOLOGY

4.1 Research Design

A quantitatively supported grounded theory approach was adopted. Initial qualitative exploration was conducted to identify key constructs, followed by quantitative validation through structured surveys.

4.2 Data Collection

Data were collected from multiple sources:

- Semi-structured interviews with industry experts, manufacturers, policymakers, and investors
- Survey responses from ecosystem stakeholders
- Observations from industry and academic conferences
- Analysis of policy documents, industry reports, and academic publications

This multi-source approach enabled triangulation and enhanced validity.

4.3 Data Analysis

Qualitative data were coded thematically to identify recurring patterns and relationships. Quantitative data were analyzed using descriptive statistics and hypothesis testing to assess ecosystem favorability and acceptance drivers.

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V. HYPOTHESES

The study tested the following hypotheses:

- **H1:** India's ecosystem is favorable for developing indigenous microprocessors for IoT.
- **H2:** Identified ecosystem factors positively influence acceptance of indigenous IoT processors.
- **H3:** Existing strategies favor adoption of indigenous processors.
- **H4:** Government policies support indigenous semiconductor acceptance.
- **H5:** India's supply chain favors indigenous processor deployment.
- **H6:** Marketing and positioning significantly influence acceptance.

VI. FINDINGS AND DISCUSSION

This section presents and interprets the empirical findings of the study, focusing on the factors shaping acceptance of indigenously developed semiconductor chips for IoT applications in India. The analysis integrates quantitative survey outcomes with qualitative insights from industry experts, policymakers, and ecosystem stakeholders. Findings are organized around the four core dimensions of the conceptual framework: design capability, manufacturing readiness, go-to-market strategy, and policy support.

6.1 Overview of Respondent Profile

The study collected responses from stakeholders across the semiconductor and IoT ecosystem, including device manufacturers, design engineers, policymakers, academic researchers, and investors. This diversity ensured that acceptance-related factors were examined from multiple decision-making perspectives.

Table 6.1. Respondent Profile

Category	Percentage (%)
Semiconductor design professionals	28
IoT device manufacturers/system integrators	24
Policy and government officials	14
Academic and research institutions	18
Investors and industry consultants	16

The respondent composition reflects a balanced ecosystem view, strengthening the validity of findings related to adoption barriers and enablers.

6.2 Design Capability and Acceptance of Indigenous Processors

Design capability emerged as the strongest positive driver influencing acceptance of indigenous semiconductor chips. Respondents consistently expressed confidence in India's availability of skilled talent, particularly in VLSI design, embedded systems, and processor architecture

Table 6.2. Perceived Strength of Design Capability Factors

Design Factor	Mean Score (5-point scale)
Availability of skilled design talent	4.42
Scalability across processor generations	4.08
Access to open-source IP (RISC-V)	4.35
Security and auditability	4.18

High scores indicate strong agreement that India possesses the intellectual and human capital required for indigenous processor development. The open-source nature of RISC-V-based designs was repeatedly highlighted as a trust-enhancing feature, particularly for security-sensitive IoT deployments.

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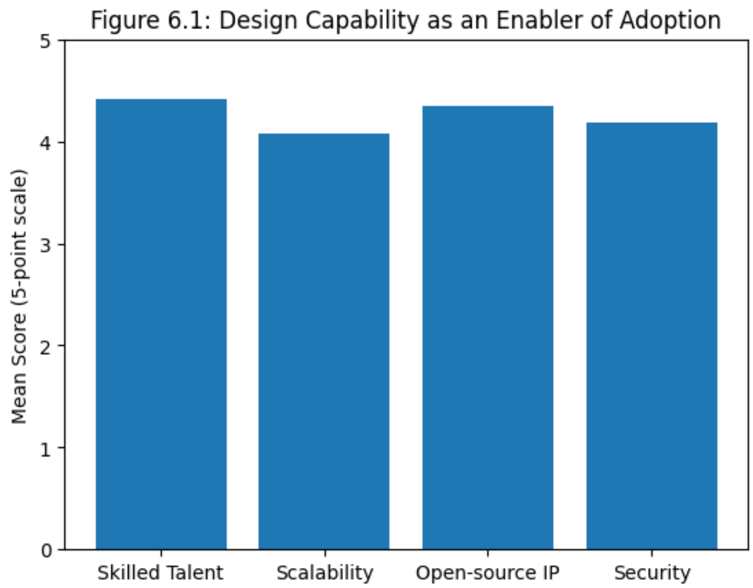

Figure 6.1. Design Capability as an Enabler of Adoption
(Conceptual bar chart showing design capability as the highest-rated factor among adoption drivers)

From a discussion standpoint, these findings align with India's established role as a global semiconductor design hub. However, respondents noted that design strength alone does not translate automatically into market acceptance, reinforcing the need to evaluate downstream ecosystem factors.

6.3 Manufacturing Readiness: The Primary Bottleneck

Manufacturing readiness was identified as the most significant constraint affecting acceptance. While prototype fabrication and small-volume production were viewed as feasible, large-scale, reliable manufacturing was perceived as inadequate.

Table 6.3. Manufacturing Readiness Assessment

Manufacturing Dimension	Mean Score
Access to advanced fabrication nodes	2.31
Assembly and testing infrastructure	2.78
Availability of materials and chemicals	2.45
Reliability of utilities (water, power)	2.62
Scalability for mass production	2.18

The low scores indicate skepticism regarding India's ability to deliver consistent, high-volume semiconductor output. Respondents emphasized that IoT device manufacturers prioritize supply continuity over marginal cost advantages, particularly for products with long operational lifecycles

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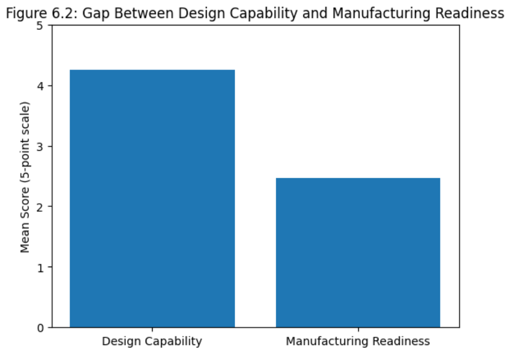

Figure 6.2. Gap Between Design Capability and Manufacturing Readiness
(Conceptual figure showing a sharp divergence between high design readiness and low manufacturing readiness)

This gap creates a "confidence deficit" in indigenous processors. Even when technical specifications are adequate, manufacturers hesitate to commit due to uncertainty regarding future availability, yield consistency, and turnaround times.

6.4 Go-to-Market Strategy and Industry Acceptance

The go-to-market dimension revealed that cost advantage alone is insufficient to drive adoption of indigenous processors. Instead, acceptance is shaped by a combination of reliability, vendor credibility, customization support, and ecosystem maturity.

Table 6.4. Go-to-Market Factors Influencing Acceptance

Factor	Mean Score
Long-term supply assurance	4.21
Customization and local support	4.05
Cost competitiveness	3.62
Brand credibility	3.89
Software and toolchain support	3.74

Long-term supply assurance ranked higher than cost competitiveness, underscoring that manufacturers are risk-averse when integrating processors into IoT products. Indigenous chips were viewed favorably in government-backed, cost-sensitive, and low-power IoT applications, such as smart meters, energy-efficient appliances, and industrial sensors.

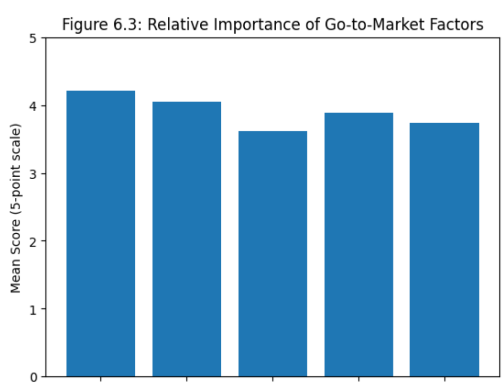

Figure 6.3. Relative Importance of Go-to-Market Factors
(Conceptual stacked bar chart showing supply assurance and support outweighing price)

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The discussion highlights that indigenous processors currently lack the ecosystem signaling mechanisms—such as proven large-scale deployments—that global vendors possess. Strategic partnerships, reference designs, and anchor customers were identified as critical to overcoming this barrier.

6.5 Policy Support and Institutional Influence

Policy support was perceived as directionally strong but operationally fragmented. Respondents acknowledged the intent behind semiconductor incentive schemes, but questioned execution speed and coordination across agencies.

Table 6.5. Policy Effectiveness Perception

Policy Instrument	Mean Score
R&D subsidies	4.12
Capital expenditure incentives	3.85
Government procurement preference	3.98
Import restrictions on low-end chips	3.41
Policy coordination and execution	2.96

Government procurement emerged as a potentially powerful lever for early adoption. Respondents emphasized that **anchor demand from public-sector projects** could significantly reduce market risk for indigenous processors.

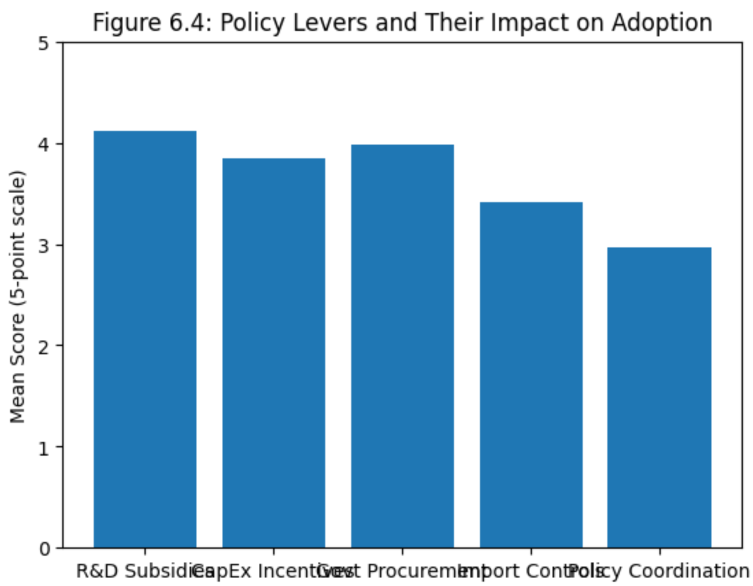

Figure 6.4. Policy Levers and Their Impact on Adoption
(Conceptual diagram mapping policy tools to adoption outcomes)

The findings suggest that while policy intent is clear, ecosystem synchronization—linking design, fabrication, procurement, and standards—is essential to translate policy into sustained adoption.

6.6 Hypothesis Testing Summary

Based on quantitative analysis and triangulated qualitative evidence, the hypotheses were evaluated as follows:

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Table 6.6. Summary of Hypothesis Results

Hypothesis	Result
H1: Ecosystem favorable for development	Supported
H2: Factors favor acceptance	Partially supported
H3: Strategies favor adoption	Partially supported
H4: Policies favor acceptance	Supported
H5: Supply chain favors adoption	Not supported
H6: Marketing influences acceptance	Supported

The partial or non-support of several hypotheses highlights that acceptance is uneven across ecosystem dimensions. Strong design and policy support are offset by weaknesses in manufacturing and supply chains.

6.7 Integrated Discussion

The findings collectively indicate that acceptance of indigenous semiconductor chips for IoT in India is not constrained by technological feasibility but by ecosystem confidence. Design capability acts as a necessary but insufficient condition for adoption. Manufacturing readiness and supply-chain reliability emerge as decisive constraints, while policy support and go-to-market strategies function as moderators.

The results reinforce the view that semiconductor adoption decisions are strategic and risk-driven, particularly in IoT markets where device lifecycles are long and margins are thin. Indigenous processors are more likely to succeed in controlled, policy-supported environments before expanding into competitive global markets.

VII. IMPLICATIONS

7.1 Academic Implications

The study extends semiconductor research by integrating ecosystem and policy perspectives into adoption analysis, moving beyond device-centric evaluations.

7.2 Managerial Implications

IoT device manufacturers can leverage indigenous processors in low-power, security-sensitive applications by emphasizing customization, supply assurance, and local support.

7.3 Policy Implications

A coordinated policy framework linking R&D, fabrication, procurement, and standards is critical for accelerating adoption beyond pilot projects.

VIII. CONCLUSION

Acceptance of indigenously developed semiconductor chips for IoT in India is shaped by a complex interaction of design capability, manufacturing readiness, market strategy, and policy support. While initiatives such as SHAKTI demonstrate strong technical potential, ecosystem-level gaps constrain large-scale adoption. Strengthening manufacturing infrastructure, supply-chain resilience, and market confidence will be essential for India's transition from a design hub to a semiconductor product nation.

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