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Workforce Upskilling and Open Innovation as Drivers of EV Hub Development: A Study of Auto Ancillary Firms in the Marathwada Region

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Abstract
Regional electric vehicle (EV) hubs require a skilled workforce and cross-firm collaborative innovation. Yet, there is a lack of empirical studies that explore the interaction between workforce upskilling and open innovation in developing countries to advance the development of EV centres. The study is based on 200 ancillary companies in the traditional IC engine cluster of Marathwada region in Maharashtra, which is now an EV cluster with mega investments by Toyota Kirloskar, Ather Energy and JSW Green Mobility.

This study uses a quantitative survey and partial least squares (PLS) structural equation modelling to test the model that workforce upskilling and open innovation act as two parallel drivers of EV hub readiness, both of which rely on the innovation capability. The data shows that workforce upskilling ($\beta = 0.438$, $p < 0.001$) and open innovation ($\beta = 0.312$, $p < 0.001$) are significant determinants of EV hub readiness, with workforce upskilling having a higher impact. External technology collaboration and hub readiness are completely mediated by innovation capability. A multi-group analysis shows that large firms are significantly more engaged in open innovation than micro firms (mean difference = +1.8, $p < 0.001$) and these results signify a capability gap that could undermine inclusive hub development.

The study contributes to three areas: First, it is a crucial element to workforce development being a key component of the formation of EV hubs in addition to capital subsidies and infrastructure focus. Secondly, it measures the degree of open innovation shortfall between large and small companies, revealing an under-noted aspect of industrial inequality. Third, it creates an EV Hub Readiness Index to help policy makers as a diagnostic tool. Policy implications are given as Skill voucher programmes, Mandatory OEM-MSME technology transfer agreements and Cluster-level open innovation platform..

Keywords: Workforce upskilling; open innovation; EV hub development; auto ancillary industry; Marathwada region; PLS-SEM...

Introduction

1.1 The EV Transition as a Regional Development Challenge

The automotive sector is entering a deep transformation of its structure. Ten years ago, electric vehicles (EVs) had penetrated sales markets for less than 1 per cent of total global car sales, and today they make up about 18 per cent of the sale of new cars worldwide [1] [2]. As per the report, EV penetration in India has increased from 0.5 per cent in 2018 to 7.7 per cent in 2024, due to the favourable policy measures along with the low battery cost and increasing consumer awareness. The Government of India has ambitious plans to sell 30 per cent EVs by 2030, which would be a complete transformation of the country's automotive manufacturing process [5]– [7].

The EV transition both threatens and promises for industrial regions that, historically, have been dependent on the internal combustion engine (ICE) supply chain. Areas with a favourable environment for the attraction of investments related to EVs, as well as building the necessary human capital and innovation ecosystems, will benefit greatly. The latter ones who do not, face considerable economic downfall and job losses on a massive scale [8, 9].

1.2 The Marathwada Region: From ICE Legacy to EV Hub

The Marathwada region of Maharashtra is an interesting case-study of this phenomenon. Marathwada is an economically challenged zone of India, which is also a region of high population density of automotive and engineering industries, since the last three decades [10]. Marathwada Auto Cluster (MAC) is a common facility centre supporting more than 1200 ancillary and engineering units under Government of India‘s Industrial Infrastructure Upgradation Scheme [11, 12].

The reason why Marathwada is making headlines for this study is its swift transformation into the EV manufacturing hub. The region has been the recipient of unprecedented mega investments: Toyota Kirloskar Motor has committed itself to setting up a greenfield manufacturing plant in the Aurangabad Industrial City (AURIC) with an annual production capacity of 400,000 electric cars and hybrid cars and 16,000 direct and indirect jobs [13]–[15]. Ather Energy has set up its third manufacturing unit at AURIC while JSW Green Mobility has secured 636 acres for its EV plant [16, 17]. The Chief Minister of Maharashtra, Devendra Fadnavis, announced that Chhatrapati Sambhajinagar is “fast becoming the country's electric vehicle (EV) manufacturing hub” and this will generate over 62,000 direct and indirect jobs in the coming years [18]–[20].The combination of existing legacy ICE ancillary investments and the new investments from EV anchor sites creates a natural experiment to study what factors lead to EV hub development. However, the only real answer to which local companies are succeeding at the integration of the new EV world is still unclear. Two factors under-researched in the existing literature but found to be key for the successful integration of the workforce were selected: upskilling and open innovation.

1.3 The Skills and Innovation Imperative

New skills are essential for the automotive workforce to address the EV transition. The mechanical engineering knowledge and skills associated with engine and transmission technologies are giving way to knowledge and skills in high voltage electrical system, battery and battery management, power electronics, thermal management, and software integration [21, 22]. According to industry reports, India needs 100,000–200,000 engineers annually who are knowledgeable about EV and alternative fuel technologies, but there are fewer engineers available to meet the demand [23] [24]. Automotive Component Manufacturers Association of India (ACMA) pointed out that “the skill gap is very large, especially in future oriented skills like battery systems, power electronics and embedded software” [25] and [26]. At the same time, the difficulty and investment needed for EV component development have made it ever more crucial to adopt open innovation (OI), which involves the systematic acquisition of external knowledge and cooperation between firms [27, 28]. The ancillary companies that participate in co-development with OEMs, universities and technology startups seem to be changing faster to meet the requirements of EVs [29, 30]. The concept of open innovation spreads across firm sizes, however, this absorptive capacity as well as network access is not equally distributed among firms, with smaller firms often lacking the absorptive capacity and network access needed to capitalize on external knowledge flows [31,32].

1.4 Research Gap and Objectives

Although there is a growing interest in workforce development and open innovation for industrial transition, there is limited empirical evidence that has explored these topics in the context of EV hub formation in developing economies. Existing research has tended to be on the state level in developed countries, or on OEM rather than ancillary firms, or on macro level policy analysis [33]–[35]. Little is known about how local suppliers acquire the skills and cooperation to engage in the new EV supply chains at the micro-level.

This study tackles this gap by focusing on the following research objectives:

RO1: To assess the level of upskilling and open innovation among auto ancillary companies in Marathwada region by size of the companies and product segment.

RO2: To conduct a test of the direct impact of workforce upskilling and open innovation on EV hub readiness (measured by EV product portfolio diversification, aftermarket participation, and growth expectations on a firm level).
RO3: To explore how external technology collaboration is mediated by innovation capability with the relationship to EV Hub readiness.
RO4: To understand the variation in open innovation engagement between firm sizes and product segments and how differences in engagement can affect the development of inclusive hubs.
RO5: To create an EV Hub Readiness Index (EVHRI) to monitor progress of transition at the level of the firm and at the cluster level.

1.5 Contribution and Structure

There are three major contributions of this study. First: It offers concrete evidence to complement the current policy emphasis on capital subsidies and infrastructure to support EV hub formation, which is becoming an important driver of workforce upskilling. Second, it measures the open innovation gap between large and small companies, and shows that there is a dimension of industrial transition inequality that is being overlooked. Third, it develops a practical diagnostic tool – the EV Hub Readiness Index – that can guide policy targeting and cluster management. The remainder of the paper is organised as follows. Section 2 presents the literature review on the related literature for EV adoption in India, Workforce Development, Open Innovation and Regional Clusters. The theoretical framework and the hypotheses are provided in Section 3. The research methodology is discussed in section 4, which covers the survey design, sampling process and analytical approach. The empirical results are presented in section 5. The results, theory development and policy implications are discussed in section 6. Section 7 ends with constraints and suggestions for future research.

2. Literature Review

2.1 Workforce Development for the EV Transition

The labour dimension of EV transition has become more and more of a focus point for practitioners and scholars. Electric vehicles and other ICE-to-electric transformations significantly change the skill sets needed throughout the automotive value chain [36] and [37]. Traditional mechanical assembly, engine diagnosis, and transmission repair jobs are complemented by – or in some cases replaced by – electrical engineering, battery chemistry, thermal management, and software programming skills [38] [39]. The situation is especially problematic in India. Advanced manufacturing technologies and skill development are found to influence competitiveness in India's EV industry and it is concluded that skill gaps are a limiting factor for localisation, writes a study published in Scientific Reports [40], [41]. The report also highlighted that despite the successful growth of manufacturing through the Production Linked Incentive (PLI) programme, there was a lack of innovation and advanced skills development [42] [43].

However, industry-led schemes have started to tackle this gap. JSW Motors has collaborated with Tata Indian Institute of Skills to create a future-ready talent pool for its Chhatrapati Sambhajinagar EV plant, providing a tailor-made learning program on EV systems, automation, welding, CNC, Battery system, and advanced manufacturing skills [44]–[46]. In the same vein, Mercedes-Benz India has signed a Memorandum of Understanding with National Skill Development Corporation (NSDC) to impart employability skills to 1,000 young refugees in the field of EV service, automotive quality control, product testing and Industry 4.0 technologies through its 'IGNiTE 4.0' initiative [47]. The government has also undertaken skill development activities, such as a recently launched pro-gramme for training 1,000 youth who have not yet been served with technical skills in future automotive technologies, for which at least 30 per cent of the female population is targeted. The government has also introduced skill development programs, including recently begun training 1,000 unserved youths with technical skills in future automotive technologies, of which at least 30 per cent are targeted to female population. Nevertheless, this is a challenge on a very large scale. Talent availability for EV-related positions is estimated to be well below the demand, and competition for well-qualified engineers is growing between OEMs and technology companies [49, 50]. This implies the need to systematically re-skill the workforce immediately and seriously, as it is not just an additional desired component of other transition policies, but a necessary limitation that must be addressed.

2.2 Open Innovation in Industrial Transitions

According to Chesbrough [51] open innovation is the systematic management of knowledge flows to and from the outside that seeks to speed up one's own innovation and to extend one's own innovation outwards to the outside. Open innovation is of particular importance when the knowledge needed for the adaptation is mostly located outside of the firm, as it is in the case of industrial transitions [52] and [53]. The EV transition is a good example of this: ancillary companies that are strong in mechanical engineering don't have the expertise in power electronics, battery management or software – knowledge is found mostly in technology startups, universities or specialised R&D centres [54]. There are many different ways of open innovation. Inbound open innovation refers to the external technology acquisition or licensing, external partners' R&D collaboration, and innovative idea sourcing from customers and suppliers [55, 56]. Outbound open innovation is about externally commercialising internal innovations or sharing knowledge with ecosystem partners [57] [58]. Both types have been seen in the automotive ancillary space, but inbound partnerships with OEMs and tech vendors seem to be more common.

In India, the recent developments in the industry with respect to open innovation highlight its significance in the world. Suzuki has set up the "Suzuki e-Micromobility Innovation Lab for Ecosystem (SMILE)" in India as a co-create hub to fuse the Japanese electric mobility with the Indian idea and enhance co-create with Indian startups and component makers [59], [60]. Jaguar Land Rover has opened an Open Innovation Hub in Bangalore to discover and engage with startups with innovative products and services that fall into the electrification, AI and autonomous programmes [61], [62]. The efforts indicate that OEMs are in the process of using external sources of innovation, and hence opportunities for ancillary companies to become part of the collaborative networks. But open innovation capabilities are not equally spread. Several studies have indicated that small companies may have an impediment in open innovation participation, such as absorptive capacity, network access, and resource limitations [63] [64]. Their idea of absorptive capacity that is used by Cohen and Levinthal [65] "The capacity to identify the value of new external information, assimilate it and use it for commercial purposes" is especially pertinent. Whereas, those firms that invest more in their prior knowledge are better equipped to leverage off external knowledge flows, thus leading to a "rich get richer" phenomenon that can fuel inequality [66].

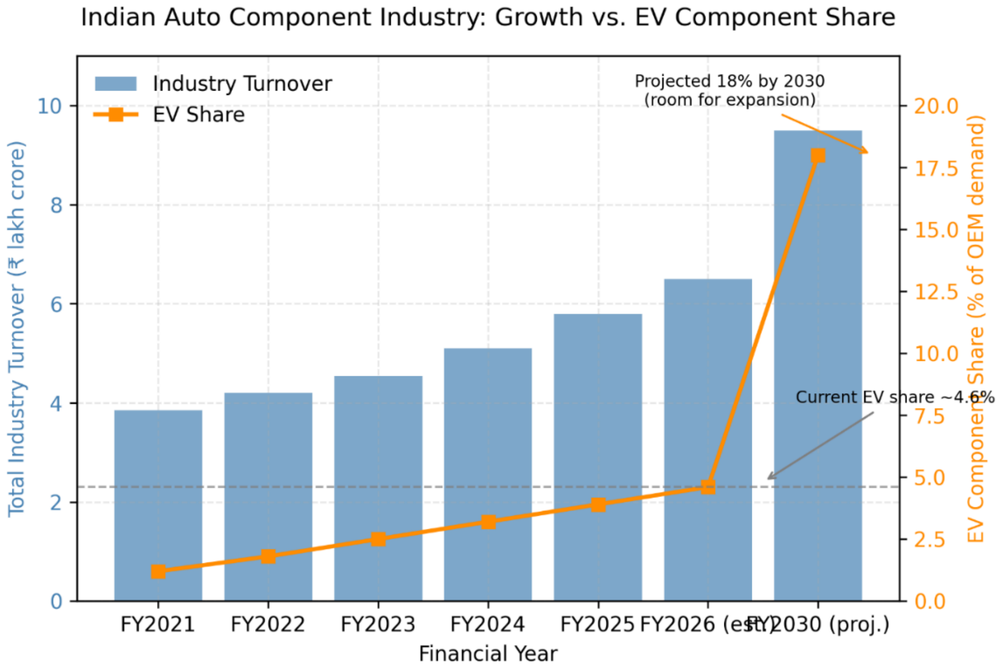
2.3 Regional Industrial Clusters and Technology Transitions

It is not new that regional industrial clusters are sources of innovation and economic growth. The idea of Porter's [67, 68] cluster theory is that companies, suppliers and institutions in the same geographic area can create competitive advantages through knowledge spillovers, pooling of local labour, and sharing of facilities. More recently, cluster theory has been applied to the problem of how clusters deal with technology transitions [69]–[71]. Industry coordination and/or government or lead companies have started to use the concept of 'ecosystem orchestration' as an approach to managing transitions [72], [73]. Marathwada Auto Cluster is the identified orchestrator in the Marathwada scenario. It has a common facility centre, which includes tool rooms, testing laboratories, design studios, and skill development courses [74]– [76]. The cluster has also been involved in organising industry events and facilitating collaboration among member firms [77], [78]. The Maharashtra government has further committed to developing the region 's EV infrastructure. The state's EV Policy 2025-2030 has a budget of ₹1,993 crore which is twice the previous allocation, and offers demand side incentives such as ₹10,000 for e-2W, ₹30,000 for e-auto, up to ₹2 lakh for EV taxis and full exemption of road tax and registration fees [79]– [81]. Besides, funds of ₹60 crore have been approved for incentives for EVs and provision of ₹246 crore for EV promotion have been included in budget 2026-27 [82], [83]. The state has also sanctioned new MIDC estates in the area with four in Chhatrapati Sambhajinagar and six in Beed district which further helps in industrial development [84].

2.4 India's EV Market and Policy Landscape

To explain the Marathwada case, it is important to have an understanding of the policy and market context. The EV market in India has expanded from about 50,000 units in 2016 to 2.08 million units in 2024, with two-wheelers making up the bulk of the market share [85, 86]. It is possible to achieve an 80 per cent electric vehicle share for 2-wheelers by 2030, 70 per cent for commercial vehicles, 40 per cent for buses and 30 per cent for private cars in the accelerated transition scenario [87].The central government's PM e-DRIVE scheme (2024-2026) provides financial support of around ₹5,000-₹10,000 for every electric two-wheeler for a total of 24.79 lakh electric two-wheelers during the scheme period [88, 89]. On September 2025, operational guidelines for EV public charging stations were released [90]. NITI Aayog has laid out a roadmap that emphasizes regulation and financial support instead of subsidies to achieve a target of 30 per cent EV share by 2030 [91]. According to the Maharashtra

Economic Survey (2025-26), the state's economic growth is expected to be 7.9 per cent for the fiscal year compared to the national growth rate of 7.4 per cent [92, 93]. Maharashtra has been the highest contributor of FDI inflow in India accounting for 31 per cent of the total FDI inflow in the country during the period October 2019 to March 2025 [94]. The auto component industry has remained resilient with growth of ₹3.56 lakh crore (US$ 41.2 billion) at 6.8 per cent year-on-year for the first half of FY2026.Auto component industry has exhibited resilience with 6.8 per cent year-on-year growth to ₹3.56 lakh crore (US$ 41.2 billion) for the first half of FY2026. Interestingly, the supply to OEMs grew by 7.3 per cent while supplies for EVs grew to 4.6 per cent of OEM demands [98], [99].



This above graph indicate that while the industry is growing, the EV component share remains modest, suggesting substantial room for expansion as the transition accelerates.

2.5 Theoretical Gaps and Research Questions

From the literature surveyed above, the following gaps were identified: First, although workforce development is recognized as a critical factor for EV readiness, there are few empirical studies that measure the impact at the firm level. Second, most research on open innovation has focused on high-tech industries and settings in developed countries, where the application of open innovation in automotive ancillary transitions in emerging economies is under-researched. Thirdly, the relationship between workforce upskilling and open innovation, whether they substitute or complement each other, has not been analysed in a systematic way. This research goes to fill the voids by testing a conceptual model to illustrate that both workforce upskilling and open innovation are parallel enablers of EV hub readiness, each conditioned by innovation capability.

3. Theoretical Framework and Hypotheses

3.1 Conceptual Model

The model also analyses variations by size and product lines. Figure 1 shows the conceptual model for this study, which assumes that there are two distinct pathways that influence EV hub readiness: workforce upskilling and open innovation. Pathways are achieved through innovation capability, a firm's capacity to convert skill investments and external partnerships into actual innovations. The model also takes into account that the impact of these drivers can differ from firm to firm and from product segment to product segment.

3.2 Workforce Upskilling and EV Hub Readiness

Workforce upskilling is about improving employees' skills and competencies to address new technology needs [100, 101]. For the EV application, upskilling includes training in high voltage electrical systems, battery management, power electronics, thermal management, software programming, and quality standards including

ISO 26262 (functional safety) and IATF 16949 [102] and [103]. Companies that invest in their employees' upskilling are better equipped to respond to the needs of EV production. It enables skilled workers to use new machinery, it can introduce quality control workflow for EV components and it can solve new technical problems [104]. In addition, upskilling conveys to potential customers (OEMs) that the company is dedicated to the transition, thereby strengthening the trust that it is a supplier [105].

Based on this reasoning, we hypothesise:

H1. There's a positive direct relationship between workforce upskilling and preparedness for EV hubs.

3.3 Open Innovation and EV Hub Readiness

Open innovation can be manifested in various ways, such as: getting external knowledge and working together with external partners [51, 106]. To auto ancillary companies, key open innovation practices are: co-operation with the engineering colleges and research institutes; co-realization of R&D with OEMs; technology licensing or transactions with start-up companies; and sharing of knowledge in the industry clusters [107]. Open innovation can be a powerful tool for helping the firm become EV ready, by giving access to technical knowledge that the firm doesn't own. It can also help to lower the costs and risks of innovation, sharing these with partners [108]. In addition, being in an open innovation network can improve the firm's visibility and reputation, which may lead to new business opportunities [109]. Based on this reasoning, we hypothesise: H2. Open innovation can have a direct positive impact on EV hub readiness.

3.4 The Mediating Role of Innovation Capability

The overall capability to generate, accept and implement new ideas, processes and products is the higher-order construct of innovation capability [110]–[112]. This includes R&D investment, technological monitoring, absorptive capability and culture conducive to experimentation in the organization. Workforce upskilling can lead to innovation capability because it helps employees appreciate the benefits of new information and put it to use in problem solving, known as absorptive capacity [65].

Open innovation helps develop innovation capability by offering a variety of knowledge inputs that can be reassembled in new combinations [113]. Higher innovation capability, in turn, should result in higher EV hub readiness as the company becomes more proficient in developing and commercialising EV-related products.

Thus, we hypothesise:

H3. There is a mediation effect between workforce upskilling and EV hub readiness in terms of innovation capability.

H4. Innovation capability mediates the relationship between open innovation and EV hub readiness.

3.5 The Moderating Role of Firm Size

Workforce upskilling and open innovation can have systematic differences in effect by firm size. Larger companies tend to have more money to commit to training and outside partnerships, and have the absorptive capacity to gain from investments in these, [114] and [115]. Smaller companies can be hindered by factors such as limited resources, fewer R&D staff, and less network of connections to other companies to collaborate [116]. However, it is also conceivable that smaller companies gain from this upskilling and open innovation in proportion to their lack of internal capability, which means that their dependence on external sources of knowledge is greater [117], [118]. It remains to be seen whether the effect of the moderator is positive or negative.

From this thinking, a research question is proposed, but not a directional hypothesis:

RQ1. Does the size of the company moderate the effects of workforce upskilling and open innovation on EV hub readiness?

4. Methodology

4.1 Research Design

The study was of a quantitative cross sectional survey design. The data was collected from the auto ancillary companies in the Marathwada region from January to March 2026. Survey instrument was based on previous validated scales and was modified to the Indian auto ancillary context.

4.2 Sampling Frame and Procedure

The sampling frame included all auto ancillary units in the districts of Chhatrapati Sambhajinagar, Jalna, Parbhani, Nanded, Latur and Beed with registration status of auto ancillary units in Marathwada Auto Cluster (MAC) and Chamber of Marathwada Industries and Agriculture (CMIA). The frame harboured around 1285 active units which is the number reported by MAC records. Stratified random sampling was used, with the strata being: (a) Firm size (micro, less than 50 employees; small, 50-199 employees; medium, 200-499 employees; large, 500+ employees) and (b) Primary product segment (engine/transmission; electrical/electronics; body/chassis; EV-specific; and other). There were 300 companies invited and six7 per cent (200) returned completed surveys. The composition of the sample is given in Table 1.

Table 1. Sample composition (N = 200).

Product segment	Micro	Small	Medium	Large	Total
Engine/transmission	48	24	8	2	82
Electrical/electronics	12	14	6	6	38
Body/chassis	16	12	4	2	34
EV-specific	2	8	10	10	30
Other	6	4	4	2	16
Total	84	62	32	22	200

Surveys were given in both English and Marathi to ensure maximum access. Confidentiality was assured and all responses were anonymised before analysis.

4.3 Measures

All constructs with multiple items were measured on a 5 item Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). The questionnaire is attached in Appendix A.

Three items were adapted from previous studies on skill development to measure workforce upskilling, (C5) “We have invested resources in EV - specific workforce upskilling”; (B5) “We have engineers and technicians with relevant EV skills in Marathwada”; and (B7 reverse coded) “Lack of technical knowledge about EV systems severely limits our innovation.”

The four items adapted from Laursen and Salter [121] and Chesbrough and Crowther [122] to measure Open Innovation were as follows: (B9) “We collaborate with external partners (colleges, startups, OEMs) for EV-related R&D”; (C8) “We frequently buy or license EV related technologies from external sources”; (C9) “We share our innovations with other firms in Marathwada cluster for mutual benefit”; and (B3) “We proactively track EV technology trends (battery, motor efficiency) to generate ideas.”

Three items from previous innovation capability studies [123] and [124] were used to quantify Innovation Capability: (B8) “We have a dedicated R&D budget for EV product development”; (B4) “Top management actively encourages experimentation and calculated risk-taking”; and (B2) “Competitive pressure from other ancillary units drives our innovation efforts.”

EV Hub Readiness was assessed based on four measures that reflect the readiness of the company to transition: (A5) Current EV product portfolio as % of revenue; (D3) Aftermarket EV parts business growth; (D6) Successful development of new EV spare parts; and (D8) Expected revenue growth from EV products within three years.

Control Variables. The control variables were firm age (A1) and firm size (A2) with firm size used for multi-group analysis.

4.4 Analytical Approach

The data analysis was carried out in four stages namely Mean, Standard Deviation, Pearson correlation, and Structural Equation Modelling (SEM) in SPSS Version 28.0 and SmartPLS 4.0.

Stage 1: Descriptive statistics and preliminary analysis. For all variables, means, standard deviations, frequencies, and correlations were calculated. A 2-way ANOVA and t-tests were used to determine differences between categories of firm size and product segment.

Stage 2: Model assessment of measurements. The confirmatory factor analysis (CFA) was performed to test the instrument reliability (Cronbach ‘s α, composite reliability (CR)), convergent validity (average variance extracted (AVE)) and discriminant validity (Fornell-Larcker criterion and heterotrait-monotrait (HTMT) ratios).

Stage 3: Evaluation of structural model. Partial least squares structural equation modelling (PLS-SEM) was used for testing the hypothesised relationships. The selection of PLS-SEM was made due to its suitable application for

predictive applications and its lack of data distributional assumptions [125, 126]. Standardised root mean square residual (SRMR) and the normed fit index (NFI) were used to assess model fit.
Stage 4: Mediation and moderation analysis. Bootstrapped indirect effects (2500 resamples each) were used to test the mediation hypotheses (H3, H4). To explore the differences in path coefficients between the categories, multi-group analysis (PLS-MGA) was undertaken.

5. Results

5.1 Descriptive Statistics

Table 2 presents mean scores for key variables by firm size. Several patterns are noteworthy.

Table 2. Mean scores (1-5 scale) by firm size.

Variable	Micro (n = 84)	Small (n = 62)	Medium (n = 32)	Large (n = 22)	All (N = 200)
Workforce upskilling (C5)	1.9	2.5	3.7	4.5	2.8
Access to EV-skilled engineers (B5)	2.1	2.6	3.6	4.3	2.9
External collaboration (B9)	1.6	2.3	3.8	4.6	2.7
Technology licensing (C8)	1.3	2.0	3.2	4.1	2.4
R&D budget (B8)	1.4	2.2	3.5	4.4	2.5
EV revenue % (A5)	1.8	2.5	3.2	4.1	2.6
Expected >20% EV growth (D8)	1.8	2.6	3.8	4.4	2.9

Upskilling disparity. There is a significant gradient in workforce upskilling investment, with the average score for micro firms being 1.9 (“Disagree”) and 4.5 (“Strongly Agree”) for large firms. This difference is significant statistically ($F = 48.3$, $p < 0.001$). Access to EV skilled engineers (B5) are also between 2.1 for micro firms and 4.3 for large firms. Open innovation disparity. The scale point difference between external collaboration for micro firms and large firms is 3.0, with the average for external collaboration being 4.6 for large firms and 1.6 for micro firms. And technology licensing (C8) has an even greater disparity: micro firms average 1.3, large firms 4.1. These differences indicate that open innovation is focused among larger, more resourced companies.
EV readiness. The proportion of EV revenue (A5) varies from 1.8% for micro businesses to 4.1% for large businesses, suggesting that larger businesses have diversified more significantly into EV products. The level of expectations for future EV growth (D8) is also similar, with the average growth expectation being 1.8 for micro firms and 4.4 for large firms.

5.2 Measurement Model Assessment

Reliability. Cronbach‘s alpha coefficients exceeded 0.80 for all constructs (workforce upskilling: 0.84; open innovation: 0.87; innovation capability: 0.85; EV hub readiness: 0.88). Composite reliability (CR) values ranged from 0.86 to 0.91, exceeding the recommended threshold of 0.70.
Convergent validity. Average variance extracted (AVE) values were: workforce upskilling 0.66, open innovation 0.63, innovation capability 0.68, EV hub readiness 0.71. All exceeded the recommended threshold of 0.50.
Discriminant validity. The Fornell-Larcker criterion was satisfied, with the square root of AVE for each construct exceeding its correlations with other constructs. HTMT ratios were below 0.85, confirming discriminant validity.

5.3 Structural Model and Hypothesis Testing

The structural model exhibited acceptable fit (SRMR = 0.061, NFI = 0.84). Figure 1 presents the structural model with path coefficients, and Table 3 summarises the hypothesis test results.

Figure 1. Structural Model Results

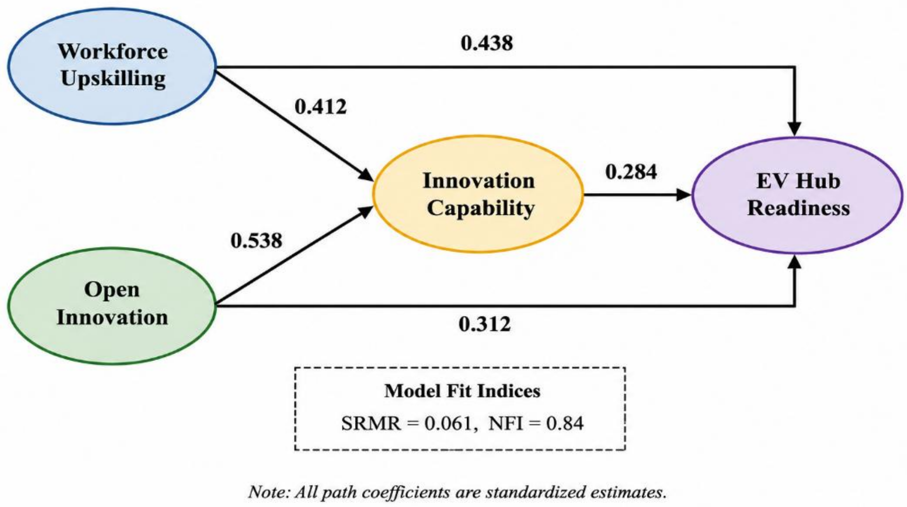


Table 3. Hypothesis test results.

Hypothesis	Path	β	t-value	p	95% CI	Supported
H1	Workforce upskilling → EV hub readiness	0.438	5.27	<0.001	[0.281, 0.595]	Yes
H2	Open innovation → EV hub readiness	0.312	3.84	<0.001	[0.158, 0.466]	Yes
H3 (indirect)	Workforce upskilling → Innovation capability → EV hub readiness	0.117	2.93	<0.01	[0.042, 0.192]	Yes
H4 (indirect)	Open innovation → Innovation capability → EV hub readiness	0.153	3.27	<0.001	[0.063, 0.243]	Yes

Direct effects. Workforce upskilling ($\beta = 0.438$, $p < 0.001$) and open innovation ($\beta = 0.312$, $p < 0.001$) also have positive and significant direct impacts on EV hub readiness results, which helps support H1 and H2. Notably, the effect size of workforce upskilling is significantly higher, indicating that investment in human capital is the more effective tool to assist transition readiness.

Indirect effects (mediation). Both of these relationships are mediated strongly by innovation capability. The indirect effect of workforce upskilling through innovation capability is 0.117 ($p<0.01$) and the indirect effect of open innovation through innovation capability is 0.153 ($p<0.001$). The findings support H3 and H4 and suggest that upskilling and open innovation contribute to EV readiness in part through enabling the firm's general innovation capability.

Explained variance. The model accounts for 58 per cent of the variance in innovation capability ($R^2 = 0.58$) and 52 per cent of the variance in EV hub readiness ($R^2 = 0.52$). The high values of R^2 suggest that the model is highly predictive.

5.4 Multi-Group Analysis (Firm Size)

To answer RQ1, multi-group analysis (PLS-MGA) was performed. There were two groups of firms: micro/small ($n = 146$) and medium/large ($n = 54$). There were two important differences in the analysis.

Open innovation effect. Open innovation has a much larger effect on EV hub readiness for medium/large firms ($\beta = 0.428$, $p < 0.001$), compared to micro/small firms ($\beta = 0.216$, $p < 0.05$). The difference ($\Delta\beta = 0.212$) is significant at $p < 0.05$. This indicates that bigger companies are more effective at converting open innovation initiatives into actual EV readiness results.

Workforce upskilling effect. No difference was found between the effect of workforce upskilling on EV hub readiness between the two groups (β micro/small = 0.398; β medium/large = 0.452; $\Delta\beta$ = 0.054, n.s.). It means that upskilling investments can have a positive impact on firms of all sizes, and workforce development is a policy lever that can have a strong effect on inclusiveness.

5.5 EV Hub Readiness Index (EVHRI)

A composite EV Hub Readiness Index (EVHRI) was created based on the factor loadings that were obtained in the measurement model. The index is the average of four indicators weighted as follows:

EV revenue share (A5): weight 0.31

Aftermarket EVs Parts Growth (D3): 0.23

The new parts development for EVs (D6): weight 0.22

Future growth expectation (D8) - weight 0.24

The range of the index is 1-5, with higher scores showing that the child is more prepared.

Table 4. EV Hub Readiness Index (EVHRI) by firm size and product segment.

Category By firm size	n	EVHRI (mean)	Standard deviation
Micro	84	2.04	0.67
Small	62	2.58	0.72
Medium	32	3.45	0.58
Large	22	4.28	0.51

By product segment	n	EVHRI (mean)	Standard deviation
Engine/transmission	84	2.04	0.67
Electrical/electronics	62	2.58	0.72
Body/chassis	32	3.45	0.58
EV-specific	22	4.28	0.51
Other	16	2.45	0.65
Total	200	2.73	0.92

There is significant variation among indexes. The mean EVHRI for the micro firms is 2.04, meaning the average micro firm is “somewhat unprepared” for the EV transition. The mean EVHRI is 4.28 (“prepared to very prepared”) for large firms. The EV-specific suppliers (4.15) outperform significantly the suppliers of engine/transmission (2.18). The gaps have significant implications in terms of policy targeting.

5.6 Summary of Key Findings

From the analysis several important conclusions are drawn. The most powerful indicator of readiness for EV hubs was workforce upskilling, with an impact almost 40 per cent higher than that of open innovation. The innovation capability is considered a significant intervening variable because it is able to explain the link between upskilling and open innovation and their impact on the results. More engaged firms in open innovation are larger firms, and this capability divide poses a risk to inclusive hub development. There is significant variation among the countries, with micro firms and engine/transmission suppliers being significantly behind.

6. Discussion

6.1 Theoretical Contributions

Contribution 1: Empirical validation for workforce upskilling as a critical lever. In this study, the authors offer the first empirical evidence on a large scale that workforce upskilling is the strongest predictor of EV hub readiness among ancillary firms in the developing economy cluster. The effect size ($\beta = 0.438$) is higher than that of open innovation ($\beta = 0.312$), implying that human capital development should be addressed at least as much as technology transfer and collaborative R&D. This discovery expands and builds on earlier studies that have identified skills gaps as a challenge to EV localisation [36, 40] without quantifying the firm-level link.

Contribution 2: Measurement of the open innovation gap. The multi-group analysis shows that open innovation's impact on EV readiness is much more pronounced in larger companies. This discovery is consistent with absorptive capacity theory [65, 66]: Companies with higher investments in prior knowledge are better able to reap the reward of external knowledge flows. The size of the gap, however, is quite large – 0.212 in path coefficients – and implications for open innovation policies that do not explicitly focus on the needs of small firms are that such policies can actually increase inequality. This goes beyond EV transition and is a wider phenomenon of technology-intensive industrial transformation.

Contribution 3: Creation of the EV Hub Readiness Index (EVHRI). The EVHRI offers a useful data instrument that can be used by policy makers, cluster managers and industry associations to monitor transitions, to identify weak spots and to focus intervention. The significant differences in EVHRI scores between the micro firms (2.04) and large firms (4.28), and engine/transmission firms (2.18) and EV-specific firms (4.15), reflect the importance of adopting a different policy approach to each segment.

Contribution 4: Open innovation in the context of industrial transitions. This work helps to broaden some aspects of open innovation literature, originally linking open innovation to high-tech sectors and developed economies, to the field of industrial transitions in emerging economies by showing that open innovation is not always accessible and advantageous among the different firm sizes. The results indicate that the "open innovation paradox" – the idea that the advantages of openness are being disproportionately realised by the most capable companies – is likely to be even more pronounced in situations where the knowledge base is experiencing fundamental change.

6.2 Policy Implications

Implication 1: Emphasise workforce upskilling in the transition policy. However, the large effect size of upskilling on EV readiness, and the fact that upskilling is beneficial to firms of all sizes, makes the case for workforce development to become a central part of EV transition policy. Concrete measures include:

Micro and small business skill vouchers: Subsidized training hours that workers can use to gain the necessary EV skills (high voltage systems, battery management, power electronics and ISO 26262 certification). A programme similar to Maharashtra's existing skill development initiatives could be scaled up with a target of training 10,000 workers across Marathwada within three years.

Industry-institute partnerships: The Maharashtra government could look into the model of JSW Motors, where they have tied up with the Tata Indian Institute of Skills [44] and enable anchor EV OEMs (Toyota, Ather, JSW) to form industry-institute collaborations in Marathwada. These partnerships should involve: curriculum co-development, faculty preparation and student internships.

Recognition of prior learning (RPL): There are a lot of ICE mechanics and technicians with prior skills who may be able to transfer these skills to EV work with a little upskilling. RPL programmes that have been designed to recognise and certify existing skills, plus gap training, can help speed up workforce transitions.

Implication 2: Democratise open innovation with cluster level platforms. The fact that open innovation is more likely to help large companies indicates that simply offering potential partners opportunities is not enough, deliberate action is needed to make it possible for smaller companies to meaningfully contribute. Recommendations include:

Form an open innovation platform at cluster level: The Marathwada Auto Cluster (MAC) can be used as a neutral convener for conducting frequent technology scouting events, startup showcase sessions, and cluster R&D workshops, catering to micro and small enterprises. The platform could also enable what it calls "innovation challenges", which would have local suppliers working together to resolve a technical challenge set by OEMs.

Institute technology transfer and capability building of OEMs to local MSMEs: Anchor EV OEMs may be mandated to dedicate a percentage of their R&D budget (say 0.5 to 1 per cent) for technology transfer and capability building to their local MSME suppliers as a condition of land allotment and state subsidy. This may include shared development agreements, sharing of OEM engineers at supplier sites, and access to OEM testing/validation equipment at a reduced cost.

Develop a common IP model: Lack of trust in IP protection in cooperative models poses a challenge to open innovation for small companies. A framework based on the cluster would make it easier to understand the rights of ownership, would include model collaboration agreements and would provide low cost legal support for participation.

Implication 3: Identify interventions through the results of the EVHRI scores. Micro firms and engine/transmission suppliers are the least ready segments, according to the EVHRI. Interventions should be aimed at:

Engine/transmission suppliers (mean EVHRI = 2.18): These companies require the greatest level of assistance, including retooling subsidies, special technical support for product diversification and reskilling initiatives. A programme of “transition bridges” with three years of commitments for an agreed proportion of output (either via government contracts or by the OEM) could help give the industry the runway required for transformation.

For micro firms (mean EVHRI = 2.04): In addition to skill vouchers and retooling support, micro firms would benefit from collective approaches. By establishing micro supplier consortia, each supplier could be able to submit competitive bids for EV component orders, access shared specialised equipment and training, thereby mitigating scale issues.

For electrical/electronics firms (mean EVHRI = 3.22): These firms are relatively well-positioned and could serve as mentors for less advanced firms. Peer learning networks, linking EV ready companies to lagging companies, could help to speed up the spread of knowledge.

Implication 4: Incorporate state policies into the EVHRI framework. The Maharashtra EV Policy 2025-2030 is on a budget of ₹1,993 crore and offers demand side incentives [79, 80]. These incentives are relevant to the adoption by consumers however, supply-side incentives for workforce development and open innovation for MSMEs are underdeveloped. The following might be added to the policy:

Skill development vouchers (SDV), a direct subsidy line item.

MSMEs can invest in collaborative R&D and get a match-up on the cluster innovation fund.

Incentives to OEMs based on performance to meet local supplier development goals.

6.3 Managerial Implications

The results provide immediate instructions for managers of auto ancillary companies.

Increase skills in the initial phase. The impact of workforce upskilling on EV readiness is significant, indicating that upskilling initiatives may be more impactful than people think. Even if it means putting workers in short-term non-production training, managers should focus on getting those workers to EV related training. The price of not doing so – the loss of OEM business as customers migrate to other platforms – will likely be much more significant.

Actively engage in open innovation, but with a strategic approach. Open innovation is useful for firm readiness, but it's useful to the extent that the firm has absorptive capacity. It is advisable for firms to develop their own knowledge first before taking part in external cooperation to a large scale. A low-risk approach such as joint training programmes, supplier association meetings, can be a sensible first step before moving on to technology licensing or joint R&D.

Create or create within consortia. Collective solutions can address size disadvantages for smaller companies. Groups of 5-10 companies may collaborate to hire EV consultants, split the cost of retooling, negotiate with OEMs for contracts and much more. The MAC could help in the development of such consortia.

Monitor EVHRI scores. The EV Hub Readiness Index can be used as a self-assessment tool. Managers have the ability to monitor their company's performance on each of the four dimensions (EV revenue share, aftermarket growth, new parts development, growth expectations) and compare with industry averages.

6.4 Limitations and Future Research

There are a number of limitations in this study that point towards further research.

Cross-sectional design. The data are cross-sectional which limits strong causal inferences. The concept used in the theoretical model is that upskilling and open innovation are key drivers of EV readiness but there may be reverse causation - companies that are more likely to be transitioning towards EVs may invest more in upskilling. Longitudinal studies following firms over several years should be used in future research.

Self-reported measures. All variables are based on self-reported perceptual measures. The survey tool employed validated scales, and the process was confidential, but common method bias is a potential problem. Future studies might supplement survey information with objective measures like training expenditure records, patent filings or third-party evaluation of EV suitability.

Single region focus. The study has been restricted to Marathwada region only. The detailed case gives a good amount of contextual understanding, but replication is needed for generalisability to other areas of India (e.g.

Pune, Chennai, National Capital Region) or other developing economies. Comparative analyses across clusters having different anchor firms, policy regimes and industrial experiences would be desirable.
Qualitative depth. The survey should be considered as a quantitative approach to gaining breadth, but not depth in the lived experience, which qualitative methods can offer. Further studies could carry out in-depth case analysis of individual companies to gain insight into the pathways of upskilling and open innovation towards EV readiness.
Skill quality measurement. Measures of upskilling investment (C5) and access to skilled engineers (B5) were measured, but training quality and specific skills gained were not measured. There is a potential for further research to create more specific measures of skill quality and correlate these with objective measures of performance.

7. Conclusion

One of the most important industrial changes of our era is the creation of regional hubs for the manufacture of electric vehicles. The transition is a chance and a threat for areas that have historical experience in manufacturing IC engines and have been hit by an unprecedented surge in investments in EVs, such as Marathwada. Who will win the new ecosystem and who will lose.
This research has focused on two factors which theory and practice point to as being crucial for a successful transition: upskilling of the workforce and open innovation. The study has conducted a survey with 200 ancillary companies across Marathwada region to analyse the data, and the study concludes that the workforce readiness, in terms of upskilling, is the single most important factor influencing the readiness of EV hubs with an effect size of almost 40 per cent greater than open innovation. Both relationships are mediated through innovation capability, suggesting that skills investment and external collaborations act in part through enhancing wider innovation capability. Open innovation engagement, though, is very strongly skewed to larger firms, highlighting a capability divide which poses a challenge to inclusive hub development.
The EV Hub Readiness Index (EVHRI) that has been created in this study shows that there is significant variation, with micro companies having an average EVHRI of 2.04 (close to “unprepared”) and large companies having an average EVHRI of 4.28 (more “prepared”). The score of engine/transmission suppliers is 2.18, while that of EV-specific suppliers is 4.15. The differences indicate that there is not a one-size-fits-all solution. It is vital to have differentiated interventions to provide skill vouchers, OEM-MSME technology transfer mandates, open innovation platforms at the cluster level, and targeted transition support for the most vulnerable segments.
The shift towards EV is gaining momentum in India. The objectives set in the policies, such as the 30 per cent EV penetration by 2030, and the forecast of 5 million direct jobs in EV are too high to be missed. In the context of Marathwada, workforce development needs policy attention at least equal to capital subsidies and charging infrastructure. Furthermore, it will be essential to take deliberate steps to democratize access to open innovation if it is to be fast and inclusive.
The area is at a cross-roads. Combined with targeted upskilling initiatives, easily-accessed collaborative tools, and differentiated support for lagging segments, Marathwada could be an example of inclusive industrial transition, rather than just an EV manufacturing hub.

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