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QUANTITATIVE ANALYSIS OF AGILE MANUFACTURING 2025

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Executive summary

In this study, we investigated the conditions under which manufacturing firms are likely to adopt agile manufacturing strategies based on pay-per-use (PPU) business models. Drawing on empirical data from a survey of 45 manufacturing firms across multiple manufacturing sectors in Europe and North America, we explored how organizational, technological, and strategic factors—such as innovation priority, research and development (R&D) investment, company age, and customer reach—correlated with openness to PPU adoption. The results revealed that although PPU adoption remains limited, a growing number of mid-sized, innovation-focused firms are ready for change. Firms with mid-to-high revenue, strong innovation cultures, and operational maturity (4–10 years) are particularly receptive. Barriers to PPU adoption include operational risks and misconceptions about the infrastructure required, especially among firms that still rely on traditional models. The findings suggest that adoption of PPU models will unfold gradually, starting with agile firms, whom are using advanced manufacturing technologies and spreading more widely as awareness, case studies, and integration tools expand. This study contributes to the literature by empirically clarifying the make–buy–agile framework, proposing a refined total addressable market (TAM) model for agile manufacturing, and outlining actionable recommendations for suppliers and adopters of PPU models.

Keywords: agile manufacturing, manufacturing as a service, pay-per-use (PPU), traditional production, outsourcing, Industry 4.0

Please view the survey link at:
https://survey.qualtrics.com/jfe/form/SV_8ClaedxvrQnjUZU

See prior paper published on agile manufacturing:
https://www.iese.edu/media/research/pdfs/ST-0660-E

Artificial Intelligence was used as assistance in the creation of this report in respect to data privacy and ethical research practices. Everything has been reviewed by humans.

1. Introduction

Firms can base their manufacturing strategies on any of three primary models: traditional in-house production, outsourcing, or agile manufacturing. Understanding when and why firms adopt particular models necessitates considering their strategic environments and operational readiness. The three models differ significantly in their requirements, benefits, and suitability depending on the firm's strategic goals and external conditions:

- **Traditional in-house production** requires capital expenditure for machinery and basic technology but offers high control of production and operational readiness. It is most suitable for stable environments with predictable demand, long product life cycles, and minimal need for agility. Traditional workforce and organizational systems may remain relatively static.

- **Outsourcing** prioritizes cost reduction and financial flexibility. It requires no capital investment or internal technological capabilities and is most effective when minimal customization is required and supplier networks are dependable. Customer demand is met by leveraging external production capabilities.

- **Agile manufacturing**, in contrast, emphasizes adaptability and responsiveness to dynamic market conditions due to shorter product life cycles, customization, and shifting consumer preferences. Agile systems require firms to have the technological capacity to implement digital infrastructure (e.g., the Internet of Things [IOT], artificial intelligence [AI], and big data), and they demand organizational readiness at both the workforce and managerial levels. Agile manufacturing also supports innovative approaches, such as technology-as-a-service (TaaS) and product-as-a-service (PaaS) models, which reduce financial risk and promote experimentation. However, adopting agile manufacturing depends on having access to physical infrastructure that can support real-time digital tools and smart technologies.

1.1. Conceptual framework

We based this research on a framework that incorporates both firm-level and market-level factors that can influence manufacturing decisions. We assumed that a firm’s choice of in-house production, outsourcing, or agile manufacturing would be shaped by the following variables:

- type of manufacturing technology
- sector characteristics
- risk orientation
- core capabilities
- geographic location
- financial health and access to capital
- physical and technological infrastructure
- customer demand type (e.g., stability, customization, responsiveness)

1.2. Hypotheses

To underpin this study, we formulated the following hypotheses:

1 **Hypothesis one:**
Firms' manufacturing decisions to make (traditionally manufacture), outsource, or implement agile manufacturing (make it agile) are influenced by the following factors:

- manufacturing segment (in-house, hybrid, or outsourced)
- level of R&D investment
- internal ranking of innovation and experimentation as a strategic priority
- annual revenue
- company age

2 **Hypothesis two:**
The TAM for the adoption of agile manufacturing can be estimated as follows:

TAM = global manufacturing market
× (%) using additive, subtractive and automated technologies
× (%) firms which have been running less than ten years
× (%) firms with moderate to high innovation priority
× (%) firms investing > 5% of annual revenue in R&D
× (%) firms with domestic or global customer base.

This equation provides a framework for quantifying firms' adoption potential by analyzing the manufacturing base according to relevant strategic, financial, and market criteria.

We aimed to quantitatively explore how these factors could influence strategic sourcing decisions, specifically the likelihood of adopting agile manufacturing as a third path to supplement traditional make-or-buy decisions.

1.3. Target sample

The target sample consisted of manufacturing firms from various sectors and geographic regions, specifically Germany, the Czech Republic, Poland, Ukraine, Spain, Italy, Switzerland, Austria, France, the United States, and Denmark. These companies varied in size, technological maturity, and organizational structure, and they included start-ups, original equipment manufacturers (OEMs), and contract manufacturers.

The sectors represented were as follows:

- aerospace
- automotive
- biomedical
- machine and tool manufacturing
- construction
- energy and utilities
- metals and mining
- electronics and computing
- power generation

1.3.1. Sample size

We analyzed 45 responses to the agile manufacturing survey. Although the small sample provided meaningful preliminary insights, it limited the generalizability of the results. Therefore, future researchers should replicate and expand the sample to validate the results across broader populations.

1.4. Background

Understanding the decision-making processes underpinning the adoption of agile manufacturing—and, more broadly, PPU models—is increasingly important in the context of Industry 4.0. Technological advances are creating new business models and production strategies, and manufacturers must evolve accordingly.

Simultaneously, global macroeconomic trends, such as decarbonization, sustainability, and customer-centric production, have made agile adaptive systems more relevant than ever. By studying the determinants of agile manufacturing adoption, we contribute to both academic understanding of what drives adoption of such frameworks and practical business strategies.

1.5. Motivation

The primary objective of this study was to investigate how manufacturing organizations make strategic sourcing decisions and, more specifically, what factors influence the adoption of agile manufacturing models. Although make-or-buy decisions have traditionally been analyzed from a cost perspective, the introduction of a third option—make it agile—has received limited empirical attention.

In this study, the objectives were as follows:

- Identify the organizational and market variables that best predict agile manufacturing adoption.
- Provide empirical data to estimate the total addressable market (TAM) for firms likely to adopt agile manufacturing.
- Expand the conceptual understanding of how firms manage innovation, risk, and operational flexibility when experiencing technological and economic transformation.

2. Literature review

Agile manufacturing has emerged as a strategic response to increasing market volatility, rapid technological disruption, and shifting customer expectations. Defined by Yusuf et al. (1999) as an organization's ability to operate effectively in dynamic environments through speed, flexibility, and responsiveness, agility is now regarded as a critical competitive advantage.

Building on this foundation, Gunasekaran (1999) and Sharifi and Zhang (2001) emphasized that the successful implementation of agility depends on the integration of technology, people, and processes, guided by a coherent framework of drivers, enablers, and measurable outcomes. Dove (2002) and Christopher (2000) further expanded this perspective by highlighting the importance of adaptable organizational structures and responsive supply chains. Together, these contributions emphasize the need for agility across both internal operations and external networks.

In our previous theoretical work (ST-0660-E), we applied these principles to the context of strategic sourcing. Specifically, we explored how agile manufacturing redefines traditional make-or-buy decisions by introducing a third, more flexible option centered on modularity and responsiveness. Goehlich (2009) adopted this strategic perspective, arguing that selective outsourcing enhances operational efficiency and enables firms to concentrate on core competencies.

Although these studies offer a robust conceptual foundation, empirical evidence of how agility concretely influences sourcing decisions remains limited. Therefore, we aimed to address the gap in the literature by quantitatively examining the influence of organizational, environmental, and product-level factors on make-or-buy decisions within agile manufacturing environments. In particular, we were interested in how firm-level characteristics, such as innovation strategy, revenue scale, or infrastructure readiness, might predict adoption of PPU models, and we aimed to validate, refine, or challenge existing frameworks of what creates an agile organization based on empirical real-world data.

3. Research design

For this research, we used an empirical survey-based approach and asked manufacturing firms about the organizational, technological, and market-based factors that influenced their production strategies.

To ensure relevance and data quality, we took a structured approach to selecting companies, developing the questionnaire, and distributing it. We identified companies through professional networks, focusing on firms known to be engaged in or transitioning toward agile manufacturing practices. We developed the questionnaire based on established constructs from prior literature on agile manufacturing, organizational readiness, and technological capability. We refined it through a pilot test with a small group of industry experts to ensure clarity and validity. We distributed the questionnaire via email, professional contacts, and professional digital networks, such as LinkedIn. We emphasized the importance of agile manufacturing in the context of current industry trends to encourage participation. Importantly, we carefully selected respondents who held positions with sufficient insight into their firms' manufacturing strategies and practices, typically mid- to senior-level managers in operations, production, or strategic planning. This approach ensured that the collected data was informed and contextually appropriate for evaluating agile manufacturing adoption.

To ensure relevant results given the population size, descriptive statistics were first used to summarize respondent characteristics and identify general trends. For the inferential analysis, binary logistic regression models were used to evaluate the relationship between the likelihood of adopting PPU (the dependent variable) and various categorical predictors, such as industry classification (see **Table 2**), business classification (see **Table 3**), manufacturing type (see **Table 4**), and manufacturing technology (see **Table 6**). Variables were recoded based on clearly defined criteria (e.g., Likert-scale groupings for likelihood of adoption), and diagnostic checks (e.g., convergence and pseudo R^2) were applied to assess model fit and robustness. Cross-tabulations and frequency distributions were used.

We sought to understand the timing of adoption to facilitate a forward-looking analysis of when firms might expect to transition toward agile methods and under what conditions.

3.1. Definition presented to respondents: PPU agile manufacturing models

PPU agile manufacturing models are characterized by low fixed costs and variable expenses based on the actual use of highly versatile manufacturing machinery. Such machines can be deployed across multiple facilities, and they may require service integration, upgrades, maintenance, technical support, and employee training. PPU models incorporate advanced digital technologies with the aim of reducing capital expenditure while facilitating flexibility, experimentation, and scalability.

3.2. PPU model overview

The pay-per-use (PPU) business model is transforming traditional manufacturing by enabling firms to access advanced, versatile equipment and integrated services based on usage. As outlined below, this model is characterized by a flexible cost structure, adaptable machinery, embedded technological capabilities, and comprehensive support services. These features contribute to enhanced operational efficiency and reduced financial risk.

Cost Structure: PPU models feature minimal fixed costs, which typically cover setup and baseline machine availability. Variable costs are based on actual usage, such as operating time, materials consumed, and energy used. This allows manufacturers to pay only for what they use.

Versatile manufacturing machines: The equipment is applicable to various manufacturing processes and can be easily relocated between production facilities, providing substantial operational flexibility.

PaaS (integrated services): These models include built-in support, such as regular software and hardware upgrades; routine and preventive maintenance to reduce downtime; on-demand technical support; and employee training to ensure effective machine operation and maintenance.

Embedded advanced technologies: PPU systems leverage cloud computing for real-time analytics and secure remote access; automation for improved precision and speed; the Internet of Things (IoT) for seamless connectivity across devices; and big data to enable predictive maintenance and continuous efficiency improvements.

Benefits of PPU models: This approach reduces capital expenditure by eliminating the need for large upfront investments in equipment, mitigates financial risk through flexible pilot testing, and supports scalable production based on market demand without the burden of fixed asset ownership.

3.3. Model assumptions

The analytical model underpinning this study was based on several key assumptions, as follows:

- Customer demand trends will continue to emphasize high degrees of customization, flexibility, and short lead times for product development and delivery.
- Early adopters of agile manufacturing will gain competitive advantages by responding more effectively to market dynamics.
- The regulatory environment will remain supportive and stable, facilitating continued investment in agile technologies and digital infrastructure.
- These assumptions reflect prevailing industry trends and policy outlooks but may be subject to change based on broader economic or geopolitical shifts.

3.4. Data visualization and analysis

The findings of this study are based on data collected through an empirical survey administered to manufacturing firms across multiple sectors and regions. We quantitatively analyzed and visualized the data, as shown in **Figures 1-24**, which present the correlations between key factors and the likelihood of PPU adoption.

These visualizations illustrate the influence of organizational, technological, and financial variables on decision-making processes and either support or challenge the previously presented hypotheses.

3.5. Limitations and future research opportunities

Although this study provided meaningful insights, it is important to acknowledge several limitations:

- **Segment-specific variability**
  The significance of each factor may vary across different organizational profiles (e.g., company size, sector, and innovation maturity). Future researchers should explore why certain variables hold more weight for specific firm types, and whether these patterns are consistent across geographies or sectors.

- **Time-frame constraints**
  The data reflect responses collected within a three-month time period. Hence, they may have been influenced by temporary external conditions, such as heightened geopolitical tensions or supply chain disruptions, which may not affect future study periods.

- **Sample size and generalizability**
  Although the sample offered robust initial insights, a larger longitudinal study would allow for greater generalizability and an exploration of how adoption trends evolve over time.

Future researchers should consider longitudinal research designs to track how decision-making evolves with the development of Industry 4.0 tools, shifting regulatory environments, and increasing environmental and social pressures. Such efforts would enhance the predictive power of agile manufacturing models and provide more targeted strategic insights.

4. Results

4.1. Manufacturing sector

Table 1 presents the manufacturing sector clusters and the industries which they include.

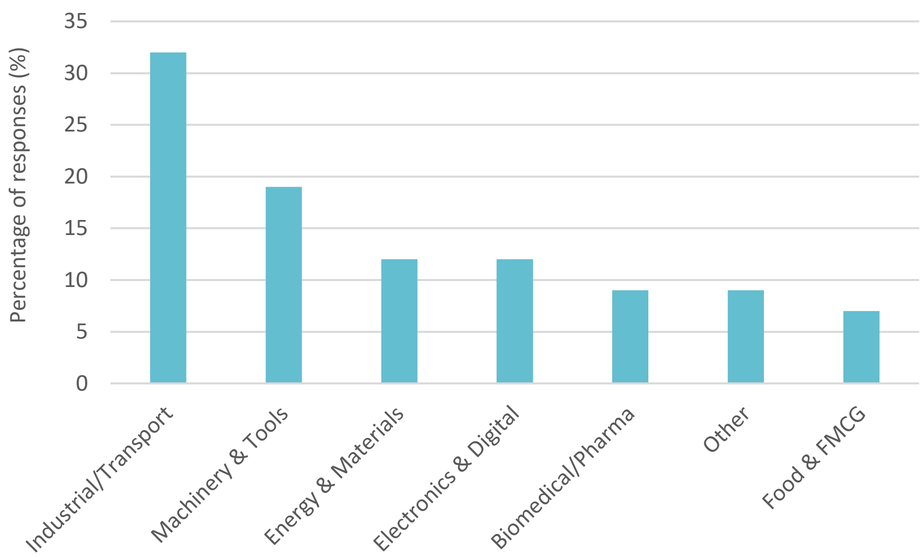
Table 1. Respondents by manufacturing sector

Cluster name	Includes
Biomedical/Pharmaceutical	Pharmaceutical, Biomedical, Medical Devices
Energy & Materials	Energy, Utilities, Mining, Metals
Food & FMCG	Food, Fast-Moving Consumer Goods, Apparel, Footwear
Machinery & Tools	Machinery, Manufacturing Tools, Heavy Equipment
Industrial/Transport	Automotive, Aerospace, Construction
Electronics & Digital	Consumer Electronics, Software, Hardware, Robotics
Other	Other

Cluster distribution of respondents

Following data cleansing and verification, the distribution of responses by industry cluster was as presented in **Figure 1**.

Figure 1. Distribution of responses by cluster



The distribution of survey responses across industry clusters revealed notable patterns in sectoral representation. The industrial and transportation cluster was the largest, driven by strong participation from automotive and aerospace companies. Second was the machinery and tools cluster, primarily composed of equipment and tool production firms. In contrast, the food and fast-moving consumer goods (FMCG) cluster, which included apparel manufacturers, had the fewest responses. The “other” cluster, while substantial, should be interpreted with caution as it encompasses niche industries and cross-sector participants that do not align neatly with the primary categories. It is important to note that, during the data collection process, respondents were permitted to select multiple industry clusters to reflect the multifaceted nature of their operations.

4.2. Analysis: Manufacturing sector and likelihood of PPU adoption

To assess whether companies’ manufacturing sectors (clusters) influenced the likelihood of them adopting PPU business models, we conducted a logistic regression analysis using deviation coding to compare each sector’s adoption tendency to the overall sample average and to provide a neutral reference for detecting deviations.

4.2.1. Model design

The variables used in this model were drawn from a structured survey aimed at assessing companies' attitudes toward adopting the pay-per-use (PPU) model. The dependent variable, likelihood of adoption, was recoded from a 5-point Likert-style survey question. Responses were grouped into two categories: “0” for companies unlikely to adopt (including those who answered “extremely unlikely” or “somewhat unlikely”), and “1” for companies more open to adoption (those who selected “neither likely nor unlikely,” “very likely,” or “extremely likely”). The independent variable, manufacturing sector, was based on self-reported industry classification, in which respondents selected the sector(s) most representative of their business. These sectors were grouped into the following categorical clusters: biomedical/pharmaceutical; energy and materials; machinery and tools; digital electronics; industrial and transportation; and other. This classification enabled comparative analyses across industries that may have differed in technological readiness or structural alignment with PPU models.

Data for both variables originated from a custom-designed survey instrument developed for this study and collected directly from participating manufacturing firms.

- **Dependent variables (likelihood of adoption)**
  - 0 = unlikely to adopt (extremely unlikely or somewhat unlikely)
  - 1 = likely to adopt (neither likely nor unlikely, very likely, extremely likely)
- **Independent variables (manufacturing sectors/categorical clusters)**
  - biomedical/pharma
  - energy and materials
  - machinery and tools
  - digital electronics
  - industrial and transportation
  - other

4.2.2. Regression results

Table 2 presents the regression results for each manufacturing sector cluster, showing the estimated coefficients, p-values, and significance levels in relation to the dependent variable.

Table 2. Regression results from manufacturing sector

Cluster	Coefficient	*p*	Significant?
Biomedical/pharmaceutical	+3.32	.993	No
Electronics and digital	−13.67	.995	No
Energy and materials	+2.62	.995	No
Industrial/transportation	+3.18	.994	No
Machinery and tools	+3.03	.994	No

The regression analysis revealed that none of the industry clusters showed statistically significant deviations from the overall average, with all p-values exceeding .99. While the electronics and digital cluster displayed a large negative coefficient, the result is considered unreliable due to high variance and a small sample size. Additionally, the model's pseudo R^2 was .14 and did not fully converge, indicating limited explanatory power and potential instability, likely stemming from small or unbalanced group sizes.

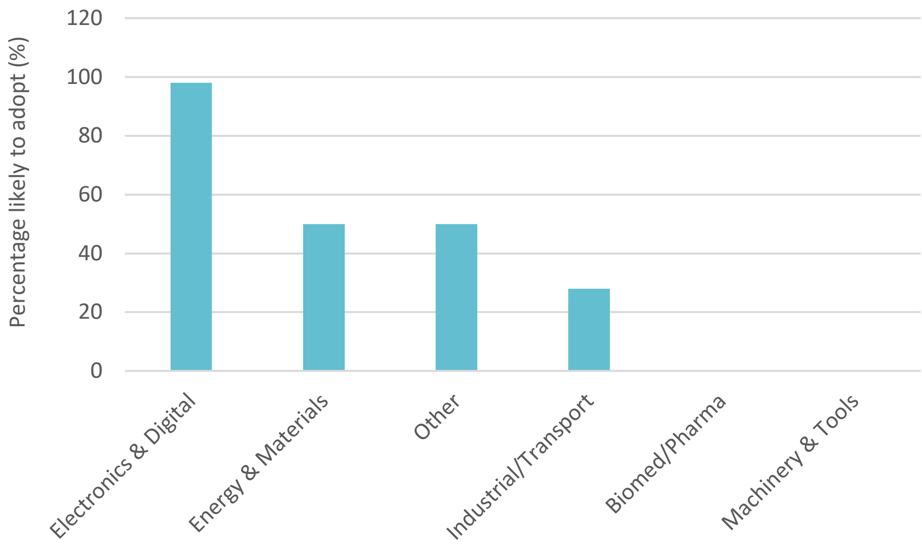
4.2.3. Conclusion

The analysis indicated that the manufacturing sector alone was not a statistically significant predictor of whether a firm adopted a PPU model. Broader organizational, strategic, or structural factors may play a more decisive role in determining PPU adoption.

4.3. Supplementary view: Predicted probability of adoption by sector

Figure 2 displays the percentage of firms in each manufacturing sector (cluster) that self-reported as likely to adopt PPU models.

Figure 2. PPU adoption likelihood by manufacturing sector cluster



To further contextualize adoption trends, reported likelihoods of adopting PPU models were examined across different industry sectors. The electronics and digital sector was the most likely to adopt PPU models, suggesting a strong alignment with flexible, technology-driven business models. In contrast, the biomedical/pharma and machinery and tools sectors showed the lowest likelihood of adoption, which may reflect regulatory constraints or operational rigidity. However, the small sample sizes—particularly within the electronics and digital sector—warrant cautious interpretation of these results. Despite the observed variation in adoption likelihood across sectors, the findings support the regression outcome: industry cluster alone is not a sufficient predictor of PPU adoption behavior. While the adoption likelihood of PPU models of each sector varied, it did not present to be significant enough to influence the manufacturing decisions posed in hypothesis one.

4.3.1. Business classification and the likelihood of adoption

To better interpret adoption patterns, we needed to understand the distribution of respondents by company type. This segmentation was derived from responses to structured questions in the survey, where participants self-identified their organizational role—such as OEM, supplier, start-up, or hybrid entity. Categorizing firms in this way provided a clearer understanding of how structural characteristics might influence attitudes toward adoption of PPU models.

4.3.2. Definitions

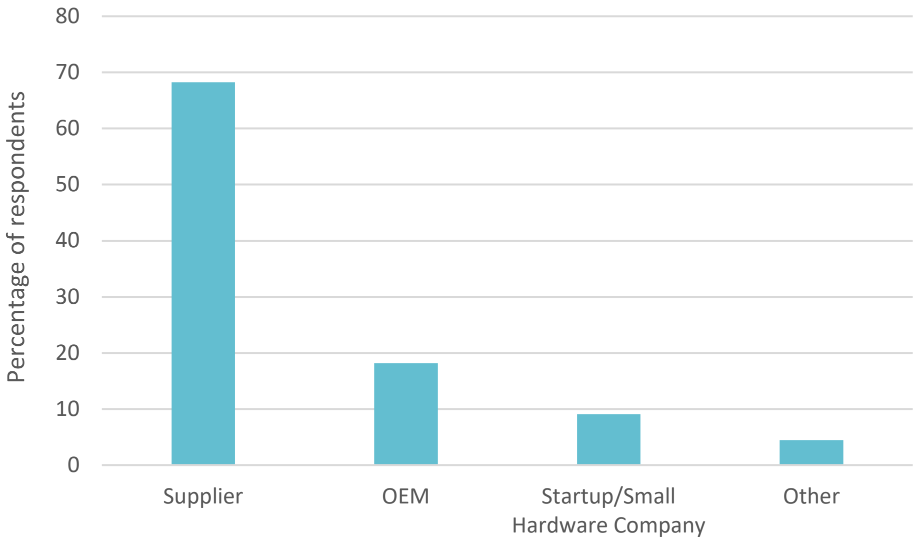
To better understand the potential for technology adoption across the manufacturing landscape, the likelihood of adoption was analyzed by cluster. This analysis spanned start-up hardware firms, original equipment manufacturers (OEMs), Tier 1 and Tier 2 suppliers, and other hybrid or service-oriented companies. The analysis highlighted key differences that can inform strategic decisions and resource allocation. Please see the definitions below:

- start-up/small hardware companies—emerging firms that develop and sell hardware products
- OEMs—firms that produce components for incorporation into other companies' finished products
- Tier 1 suppliers—direct suppliers to OEMs, often producing complex subsystems
- Tier 2 suppliers—suppliers of materials or components to Tier 1 suppliers
- other—companies with hybrid business models, nonmanufacturing actors, and service providers.

4.3.3. Distribution of respondents

Understanding how respondents are distributed by business classification is essential for interpreting adoption trends because different roles in the manufacturing value chain may have distinct perspectives on production innovation. **Figure 3** shows the distribution of survey respondents by business model.

Figure 3. Business model breakdown



The distribution of respondents by business classification revealed meaningful patterns in representation. Suppliers (Tiers 1 and 2) made up most of the sample, likely due to their operational exposure and central role within manufacturing value chains. OEMs accounted for nearly one-fifth of respondents, reflecting their strategic position in the industry. Start-ups represented a smaller, yet agile, portion of the sample, indicating potential for early adoption of innovative models. The “other” category included outliers and hybrid business models, contributing a limited but noteworthy presence.

4.3.4. Interpretation

This distribution suggests that suppliers are the stakeholders most engaged in reshoring and agile transformation discussions. OEMs and start-ups also contribute meaningfully, although in smaller numbers. The relative absence of service-based or hybrid firms may highlight the need for broader outreach or segmentation in future studies.

4.3.5. Predicted probability of likelihood of PPU adoption by business classification

To evaluate whether a company’s business classification influenced its likelihood of adopting a PPU manufacturing model, we conducted a logistic regression analysis based on data from 45 survey respondents.

4.3.6. Variable coding

To support the regression analysis, the survey responses were systematically recoded into categorical and binary variables. The dependent variable, likelihood of PPU adoption, was derived by grouping response categories to reflect meaningful adoption intent. The independent variable, business classification, was treated as an ordinal categorical variable to capture variation across different organizational types. The applied coding scheme is outlined below. The data are sourced directly from the survey results.

- **Dependent variables (likelihood of adoption)**
  - - 1 = likely to adopt (somewhat likely or extremely likely)
  - - 0 = unlikely to adopt (neither likely nor unlikely or extremely unlikely)
- **Independent variables business classification (treated as ordinal categorical variables)**
  - 0 = supplier
  - 1 = OEM
  - 2 = other
  - 3 = start-up/small hardware company

4.3.7. Regression results

Table 3 summarizes the results of a logistic regression model that assesses the relationship between business classification and the predicted probability of adopting a PPU model. It includes estimates of the coefficients, their standard errors, their significance levels, and their confidence intervals.

Table 3. Regression results- Predicted probability of likelihood of PPU adoption by business classification

Variable	Coefficient	Std. Err.	Z-Score	*p*	95% Confidence Interval
Intercept (baseline)	-0.52	0.52	-1.01	.314	(-1.53, 0.49)
Business classification	-0.54	0.64	-0.84	.398	(-1.79, 0.71)

4.3.8. Interpretation

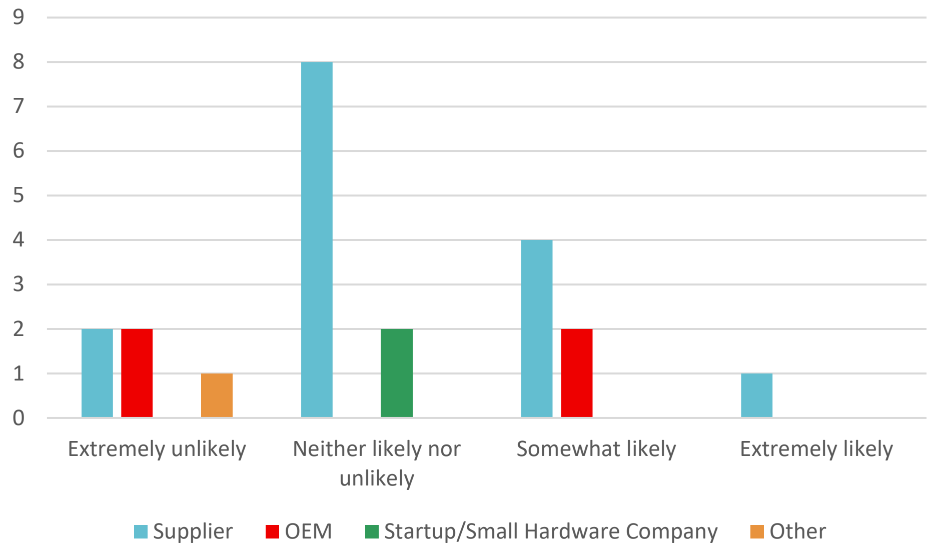
A logistic regression analysis was conducted using refined classification variables to evaluate whether organizational type influences the likelihood of adopting a PPU model. The results showed that business classification did not significantly predict the likelihood of adopting a PPU model ($p = .398$). While the negative coefficient (-0.54) indicated a slight downward trend in adoption from suppliers to OEMs, others, and start-ups, this trend was not statistically significant because the confidence interval included zero. The model offered no reliable evidence that a company's structural classification—such as OEM, supplier, or start-up—meaningfully influenced PPU adoption behavior. These results suggest that organizational structure alone is not a sufficient predictor of adoption and that other factors, such as innovation culture, technological readiness, and capital flexibility, may play a more critical role.

4.4. Supplementary visualization: Adoption likelihood by business classification

The stacked bar chart in **Figure 4** shows the distribution of adoption likelihood across business classification according to four response categories:

- extremely likely
- somewhat likely
- neither likely nor unlikely
- extremely unlikely

Figure 4. Likelihood of PPU adoption by business classification



4.3.1. Key insights

To better understand how adoption sentiment varied across business classifications, the responses of the participants were analyzed by group. Suppliers represented the majority of the responses, and their views spanned a wide range. Most fell into the "neither likely nor unlikely" or "somewhat likely" categories, while a few expressed more extreme positions. This suggests moderate optimism tempered by uncertainty. OEMs were divided between being "extremely unlikely" and "somewhat likely" to adopt PPU models, reflecting a mixed or cautious sentiment that may stem from the need for greater clarity on cost-benefit outcomes. Start-ups and small hardware companies mostly selected "neither likely nor unlikely," indicating indecision or limited awareness of how a PPU model might apply to their scale or operations. Only one respondent fell into the "other" category, and they were extremely unlikely to adopt a PPU model, probably due to model misalignment or unfamiliarity.

4.3.1. Conclusion

Although suppliers appeared to be the most engaged stakeholders, their adoption outlook was not uniformly positive. OEMs remained split, and start-ups were hesitant or uncertain. These insights indicate that business type alone is not a strong predictor of PPU adoption, reinforcing earlier regression findings.

For stakeholders aiming to promote adoption, this analysis highlights the importance of targeted engagement, education, and financial incentives—particularly for start-ups and OEMs that may need clearer value propositions or reduced perceived risk.

While the adoption likelihood of PPU models of each business classification varied, it did not present to be significant enough to influence the manufacturing decisions posed in hypothesis one.

4.5. Manufacturing type: In-house, hybrid, and outsourced models

We categorized manufacturing companies into three core types based on how they organized and executed their production, as follows:

1. **In-house manufacturing**
   All production activities are carried out within the company's own facilities using its own labor, equipment, and resources (e.g., a car manufacturer that builds and assembles all vehicle components in its own factory).
2. **Hybrid manufacturing**
   A mix of in-house and outsourced production. Some processes are completed internally, while others are delegated to external suppliers or third-party manufacturers (e.g., a smartphone manufacturer that assembles phones in-house but outsources chip production).
3. **Outsourced manufacturing**
   Most or all production activities are managed externally, often by international suppliers or contract manufacturers (e.g., a fashion brand that designs clothing internally but outsources all production overseas).

Figure 5. Composition of the 45 companies by manufacturing type

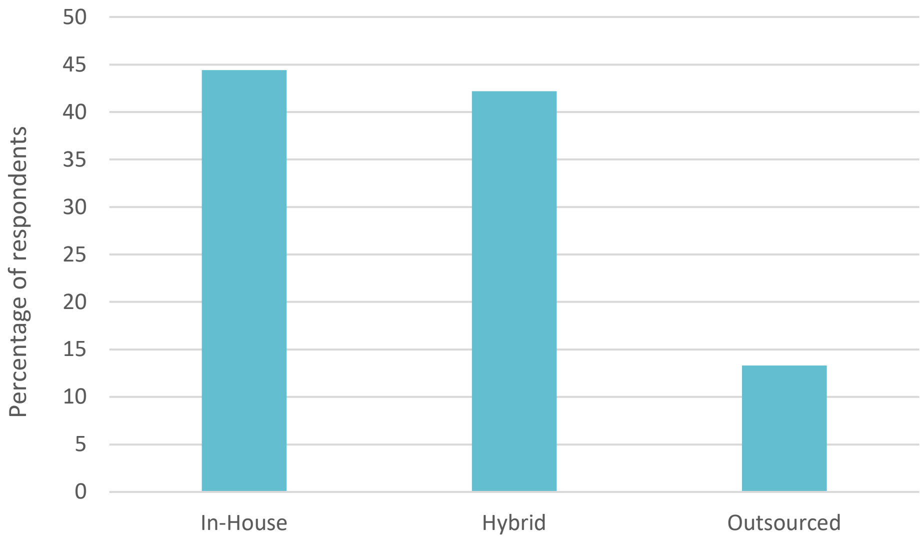


Figure 5 shows how manufacturing types are distributed among respondents. It highlights the relative prevalence of in-house, hybrid, and outsourced production approaches.

4.5.1. Relationship between manufacturing type and adoption of PPU manufacturing models

To explore whether a company's manufacturing type influenced its likelihood of adopting a PPU model, we conducted ordinary least squares (OLS) regression analysis.

4.5.2. Model design

A regression model was constructed to assess the influence of the manufacturing approach on PPU adoption, with adoption likelihood as the dependent variable and manufacturing type as the independent variable. These variables were selected to test whether differences in operational structure, such as in-house control, outsourcing, or hybrid models, correlate with differing levels of adoption intent. The data was sourced directly from the survey results.

- **Dependent variables**
  - 1 = likely to adopt
  - 0 = unlikely to adopt
- **Independent variables**
  - hybrid manufacturers (baseline category)
  - in-house manufacturers
  - outsourcers

4.5.3. Regression results

Table 4 shows the results of the regression analysis examining the relationship between manufacturing type and the likelihood of PPU adoption. Hybrid manufacturers are used as the baseline category.

Table 4. Regression results – manufacturing type and PPU adoption

Segment	Coefficient	Std. Err.	*p*	Interpretation
Hybrid (const)	0.684	0.112	< .001	Baseline adoption probability (68%)
Outsourced	-0.351	0.228	.132	Slightly less likely than hybrid firms; not significant
In-house	-0.034	0.156	.828	Nearly identical to hybrid firms; not significant

4.5.4. Interpretation

To examine the relationship between manufacturing structure and PPU adoption, the predicted probabilities were compared across the hybrid, outsourced, and in-house segments. Hybrid manufacturers had the highest predicted likelihood of adoption at 68% and served as the baseline category in the regression model. Outsourced manufacturers were approximately 35 percentage points less likely to adopt PPU models than hybrid firms. However, this difference was not statistically significant ($p = .132$). Similarly, in-house manufacturers showed no meaningful difference from hybrid firms, with a nearly zero coefficient and a high p-value of .828, indicating no significant relationship between in-house structure and adoption likelihood.

These results suggest that manufacturing type alone does not significantly influence PPU adoption behavior. Although hybrid firms had a marginally higher baseline likelihood of adoption, the differences between all groups were statistically insignificant.

4.6. Real-world examples of hybrid manufacturing models

Despite the lack of statistically significant findings, qualitative insights from respondent companies illustrated that hybrid models may support operational flexibility and innovation. Examples are as follows:

- **Arkadia Space (aerospace sector)**
  This company maintains in-house expertise in propulsion system development while outsourcing manufacturing, testing, and integration. This allows the company to retain control over core technologies while scaling efficiently.
- **Mikron (machinery manufacturing)**
  This company combines in-house engineering and production with external partnerships for specialized components. The hybrid architecture maintains high-precision capabilities internally while supporting scalable deployment.
- **Viega Schweiz AG (HVAC & plumbing)**
  This company uses in-house production for key plumbing, heating, ventilation and air conditioning (HVAC) systems while outsourcing specific product lines or regional manufacturing. This dual strategy helps the company maintain product quality and innovation while operating globally.

These examples highlight that hybrid models enable firms to balance quality control, innovation, and scalability, but the type of manufacturing model alone is not a reliable predictor of PPU adoption behavior.

4.6.1. Conclusion

The regression analysis confirmed that manufacturing segmentation—whether in-house, outsourced, or hybrid—does not have a statistically significant impact on the likelihood of companies adopting PPU models. Although hybrid manufacturers had a slightly higher predicted likelihood of adoption, organizational strategy, technological readiness, and innovation orientation possibly played a more influential role in adoption decisions. While the adoption likelihood of PPU models of each manufacturing type varied, it did not present to be significant enough to influence the manufacturing decisions posed in hypothesis one.

4.7. Manufacturing technology breakdown

Figure 6 illustrates the distribution of manufacturing technologies across the sample according to four categories: traditional, subtractive, automated, and additive manufacturing. This categorization helped highlight prevailing production capabilities and technological advances.

4.7.1. Technology categories and definitions

The following classification (see **Table 5**) outlines the key types of manufacturing, along with the representative technologies commonly associated with each type.

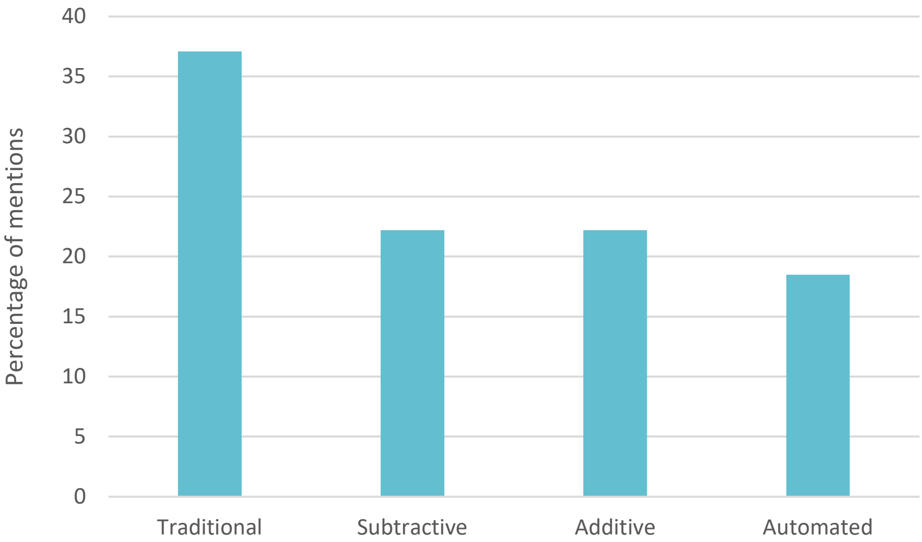
Table 5. Manufacturing technology categories

Manufacturing type	Examples of technologies
Traditional	Tooling, injection molding, welding, casting, plastics fabrication, sheet metal fabrication, manual assembly, chemical processing, surface treatment
Subtractive	Drilling, laser cutting, milling, CNC machining, turning
Automated	Automated assembly, electronics assembly, robotics-assisted manufacturing, semiconductor processing
Additive	Additive manufacturing (3D Printing)

4.7.2. Technology distribution analysis

Figure 6 illustrates the distribution of manufacturing technologies used by respondents based on the number of mentions across traditional, subtractive, additive, and automated processes.

Figure 6. Distribution of manufacturing technology types used



To understand the technological landscape of the participating firms, the respondents were asked to identify the types of manufacturing technologies that they use. Traditional technologies accounted for 37.1% of all mentions, reflecting an ongoing reliance on fundamental processes such as tooling, injection molding, welding, and manual assembly. These methods remain dominant due to their cost-effectiveness, scalability, and broad applicability across sectors. Subtractive and additive technologies were equally represented at 22.2% each. Subtractive methods, such as CNC machining and laser cutting, are essential for high-precision, high-volume production. Meanwhile, additive manufacturing reflects growing interest in the flexibility, customization, and rapid prototyping made possible by 3D printing. Automated technologies, including robotics-assisted manufacturing and semiconductor processing, accounted for 18.5% of mentions. Though fewer firms reported using these technologies, their presence indicates a shift toward digitized, low-touch, scalable manufacturing environments. Overall, this distribution shows that, although emerging technologies are gaining ground, traditional processes still form the operational backbone of many firms, underscoring the need for hybrid capabilities and transitional strategies in the face of digital transformation.

4.7.3. Implications for strategy

Understanding the distribution of manufacturing technologies is critical for aligning the following:

- investment priorities (e.g., upgrading legacy processes or scaling advanced systems)
- workforce development efforts (e.g., training in robotics or 3D printing)
- infrastructure planning (e.g., integrating cloud-based platforms or smart sensors)

This segmentation helped us identify where modernization is most needed, particularly in traditional heavy industries that may benefit from targeted automation or digital upgrades.

4.7.4. Glossary of technologies referenced

The following glossary defines the key manufacturing technologies referenced throughout the report. Understanding these terms is essential for interpreting the analysis, as each technology type reflects distinct capabilities, constraints, and implications for PPU adoption and operational flexibility.

Traditional manufacturing methods

- tooling (design and creation of tools and fixtures used in production)
- injection molding (molding plastics by injecting molten material into a mold)
- welding (joining materials using heat or pressure)
- casting (pouring molten material into molds to create complex parts)
- plastic fabrication (shaping plastic materials via bending, forming, or joining)
- sheet metal fabrication (manipulating metal sheets into parts using cutting, punching, or bending)
- manual assembly (human-performed component assembly)
- chemical processing (using chemical reactions to transform raw materials, e.g., pharmaceuticals, and chemicals)
- surface treatment (altering the surface of materials for performance or appearance, e.g., coatings and anodizing).

Subtractive manufacturing

- drilling (creating holes using rotating cutting tools)
- laser cutting (cutting or engraving with focused laser beams)
- milling (shaping materials using rotating cutting tools)
- CNC machining (precision machining controlled by computer programs)
- turning (shaping materials by rotating them against a cutting tool)

Automated manufacturing

- automated assembly (machine-based assembly with minimal human input)
- electronics assembly (automated assembly of electronic components onto circuit boards)
- robotics-assisted manufacturing (use of robots in processes such as material handling, welding, or inspection)
- semiconductor processing (high-precision cleanroom fabrication of chips, including photolithography and etching)

Additive Manufacturing

- 3D printing (building objects layer by layer from digital models using plastic, metal, or resin materials)

4.8. Manufacturing technology and likelihood of adoption of the PPU model

To assess whether the type of manufacturing technology used influenced a company's likelihood of adopting a PPU business model, we conducted a multinomial logistic regression analysis, grouping technologies into four categories, as follows:

- additive (e.g., 3D Printing)
- automated (e.g., robotics, semiconductor processing)
- subtractive (e.g., CNC machining, milling, drilling)
- traditional (e.g., tooling, welding, casting, injection molding)

We measured the dependent variable using a five-point scale (1–5) for the likelihood of adopting a PPU model, with higher values indicating greater likelihood.

4.8.1. Regression model overview

The additive cluster was used as the baseline category (intercept) for comparison, with an average adoption score of 3.67—indicating a position between neutral and somewhat likely.

4.8.2. Regression results summary

Table 6 shows the results of the regression analysis examining the relationship between the type of manufacturing technology and the likelihood of adopting the PPU model. The analysis uses additive manufacturing as the baseline category.

Table 6. Regression results - manufacturing technology and likelihood of adoption of the PPU model

Cluster	Coefficient	*p*	Interpretation
Additive (baseline)	–	–	Average score of 3.67
Automated	-0.47	.451	Slightly lower adoption likelihood than additive manufacturing; not statistically significant
Subtractive	-0.67	.272	Moderately lower likelihood; not statistically significant
Traditional	-1.17	.064	Largest negative effect; marginally significant (suggesting greater resistance)

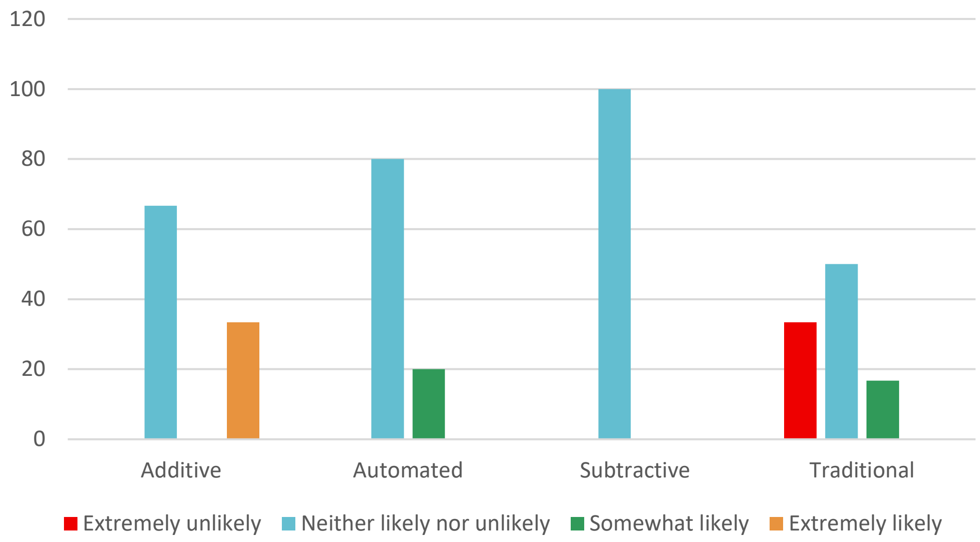
4.8.3. Interpretation

Although the overall regression model was not statistically significant ($p = .259$), several notable patterns emerged. The traditional manufacturing cluster showed the strongest negative association with PPU adoption likelihood (coefficient = –1.17, $p \approx .064$), suggesting greater resistance to adoption among firms using legacy processes. The automated and subtractive clusters also demonstrated lower likelihoods of adoption compared to additive manufacturing, although these differences were not statistically significant. The model's pseudo R^2 was .217, indicating that approximately 22% of the variation in adoption likelihood was explained, leaving 78% unexplained—likely due to other unmeasured organizational or strategic factors. Additionally, the model failed to converge robustly, suggesting limited statistical power, possibly due to small or unbalanced sample sizes across technology groups.

4.9. Visual analysis: Adoption likelihood by technology cluster

The bar chart in **Figure 7** illustrates the distribution of adoption likelihood across the four technology clusters, divided into the following categories: extremely likely, somewhat likely, neither likely nor unlikely, and extremely unlikely.

Figure 7. Distribution of PPU adoption likelihood by technology cluster



4.9.1. Key observations

The analysis of adoption sentiment across manufacturing technology clusters revealed several key observations. The additive cluster had the highest proportion of "extremely likely" responses, indicating a high level of openness to innovation and flexibility. This group consisted primarily of early adopters, making it a promising target for initial PPU pilot programs. This aligns with the strategic role of additive technologies, which are often integrated with Industry 4.0 tools for rapid prototyping, customization, and complex design applications. In contrast, the traditional cluster showed a notable concentration of "extremely unlikely" responses, indicating strong resistance to changing business models. Barriers mentioned included entrenched workflows, low digital maturity, and a preference for ownership-based systems. Targeted strategies, such as financial incentives, pilot programs, and peer-led case studies, may be necessary to reduce their resistance to adoption. The automated and subtractive clusters were mostly concentrated around "neither likely nor unlikely," suggesting ambivalence or uncertainty. This neutral stance may reflect moderate readiness, unclear applicability, or uncertainty about the return on investment when considering a shift to PPU models.

4.9.2. Conclusion

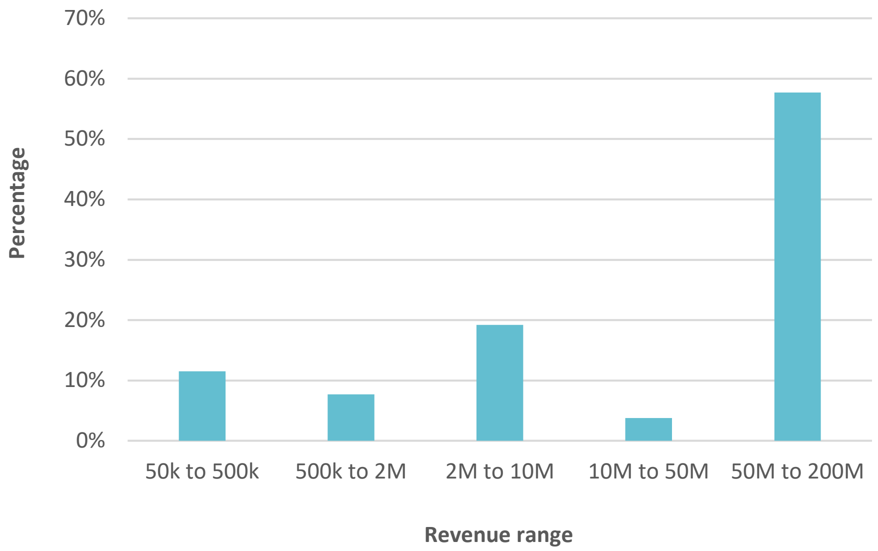
Although the regression results were not statistically significant, the analysis provided valuable insights into the directional influence of manufacturing technology on attitudes toward PPU adoption. Firms that use additive manufacturing were the most open to adopting PPU models, making them ideal candidates for pilot programs and initial expansion efforts. In contrast, traditional manufacturers were the least likely to adopt PPU, which highlights the importance of risk-mitigation strategies, targeted education, and tailored communication to address resistance. Automated and subtractive manufacturers were undecided, suggesting that their adoption may depend on clearer value propositions and stronger evidence of compatibility with existing systems. While technology type may not definitively predict PPU adoption, these findings suggest that it influences innovation orientation, offering useful guidance for go-to-market segmentation and strategic messaging. Despite the statistical insignificance of technology type, the interpretive analysis of technology type in relation to PPU model adoptability suggests that active users of automated, subtractive, and additive technologies are part of the total addressable market, thus confirming hypothesis two.

4.10. Annual revenue

We divided the respondent companies into different revenue categories to assess whether annual revenue influenced a manufacturer's likelihood of adopting a PPU manufacturing model.

Figure 8 shows how annual revenue is distributed among the survey's respondents. This provides insight into the financial scale and diversity of the firms represented.

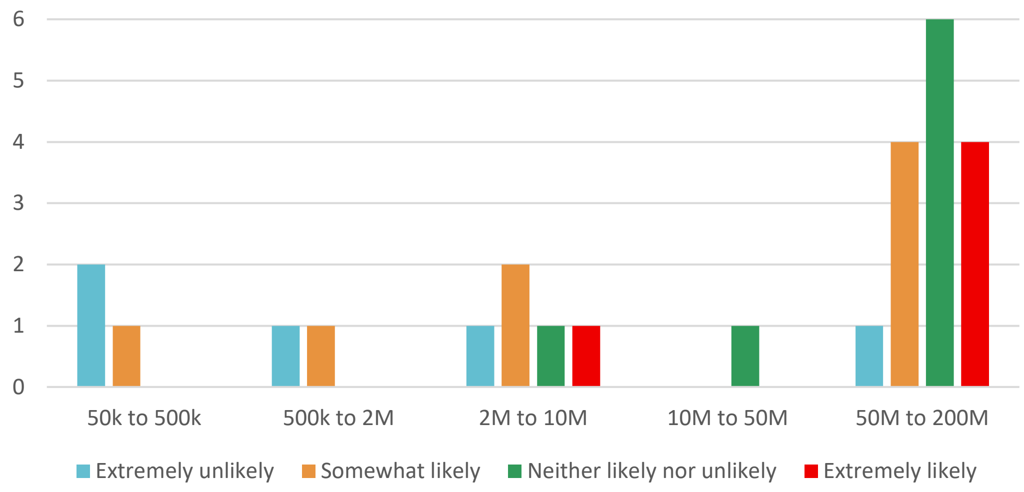
Figure 8. Annual revenue per respondent company (in dollars)



4.10.1. Annual revenue and adoption distribution

Figure 9 offers insight into how annual revenue may influence adoption of PPU models. The analysis reveals a strong correlation between company revenue and the likelihood of adopting new technology. The majority of respondents (57.7%) come from organizations that earn between $50 million and $200 million annually. This group shows the highest openness to adoption, with the majority of respondents being at least somewhat likely to adopt new technology, including four who are extremely likely to do so. In contrast, smaller firms earning under $2 million exhibit greater hesitation, with multiple responses marked as extremely unlikely and none marked as extremely likely. Companies in the $2 million to $10 million range display a balanced distribution across all likelihood categories, indicating mixed views and a potentially persuadable segment. Firms in the $10 million to $50 million bracket are notably underrepresented and contribute little to the overall trends. These findings suggest that high-revenue companies are the most promising targets for adoption efforts. Smaller firms, however, may require more targeted education or support to overcome barriers. Mid-tier companies should be approached strategically, as they present a blend of interest and uncertainty.

Figure 9. Distribution of adoption likelihood by revenue bracket



4.10.2. Interpretation and future enquiry

Although higher-revenue firms—particularly those in the $50–$200 million range—demonstrated the greatest overall openness to adopting PPU models, a significant portion reported neither being likely nor unlikely to adopt them. Specifically, six out of fifteen respondents in this revenue bracket selected a neutral stance. This suggests that, although these firms have the capacity and potential interest, many remain undecided and likely require clearer demonstrations of value, targeted use cases, or reassurance about how PPU models would align with their current operations.

This observation raises opportunities for researchers to answer questions such as the following:

- What organizational or psychological factors cause firms to remain undecided about PPU adoption?
- What interventions (e.g., education, case studies, or pilot programs) would shift companies from neutrality to willingness to adopt PPU models?

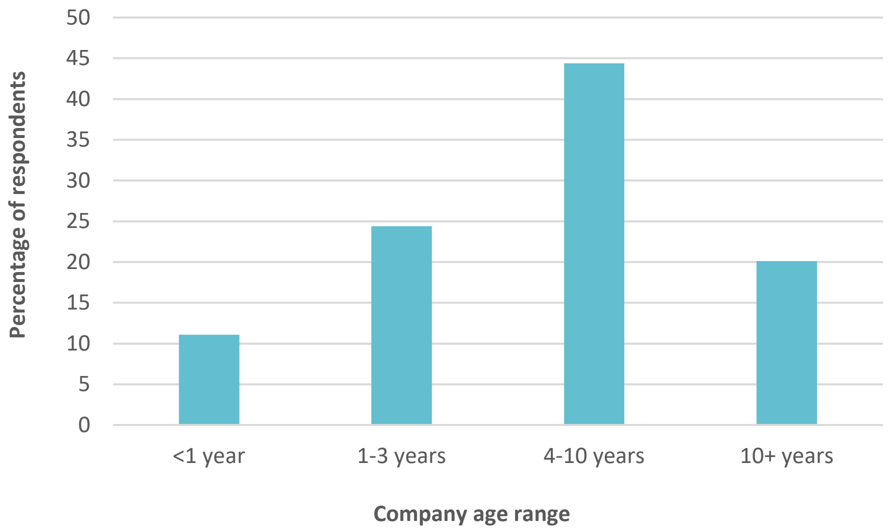
4.10.3. Conclusion

The analysis confirms a positive relationship between annual revenue and readiness to adopt PPU models. Not only did companies in the highest revenue bracket ($50–$200 million) make up the majority of the sample, but they also showed the strongest intent to adopt, with most indicating at least some likelihood. In contrast, firms with less than $2 million in revenue demonstrated more reluctance and provided the only "extremely unlikely" responses, suggesting potential barriers such as limited resources or risk sensitivity. Mid-revenue companies, especially those with revenues between $2 million and $10 million, displayed a balanced mix of responses, including interest, neutrality, and hesitation. This highlights them as a key segment for strategic engagement and education to accelerate adoption. Despite the limited sample size, the analysis of annual revenue in relation to the adoptability of PPU models suggests that firms with more than two million dollars in annual revenue are part of the total addressable market and the manufacturing decision-making process. Thus, hypothesis one is confirmed.

4.11. Company age distribution

Figure 10 presents the distribution of respondent companies by age, offering insights into the life-cycle stages of manufacturers represented in the dataset.

Figure 10. Company age (business longevity)



4.11.1. Key observations

To explore the relationship between organizational maturity and the adoption of PPU models, the respondents were categorized by company age. The largest proportion (44.4%) were 4–10 years old, representing mid-stage firms that are likely focused on scaling, market positioning, and strategic innovation after overcoming early operational challenges. A significant 24.4% of firms were one to three years old, indicating strong participation from young, growth-oriented businesses, many of which may be drawn to flexible models like PPU due to their emphasis on capital efficiency and agility. Only 11.1% of respondents were from companies that were less than a year old. This suggests that early-stage start-ups may participate less, possibly due to limited access, awareness, or a more cautious stance toward emerging models. Meanwhile, 20.1% of respondents represented companies that were 10 years or older. While these mature firms may benefit from resource stability, they could face internal resistance to adopting new models due to entrenched systems or legacy operations.

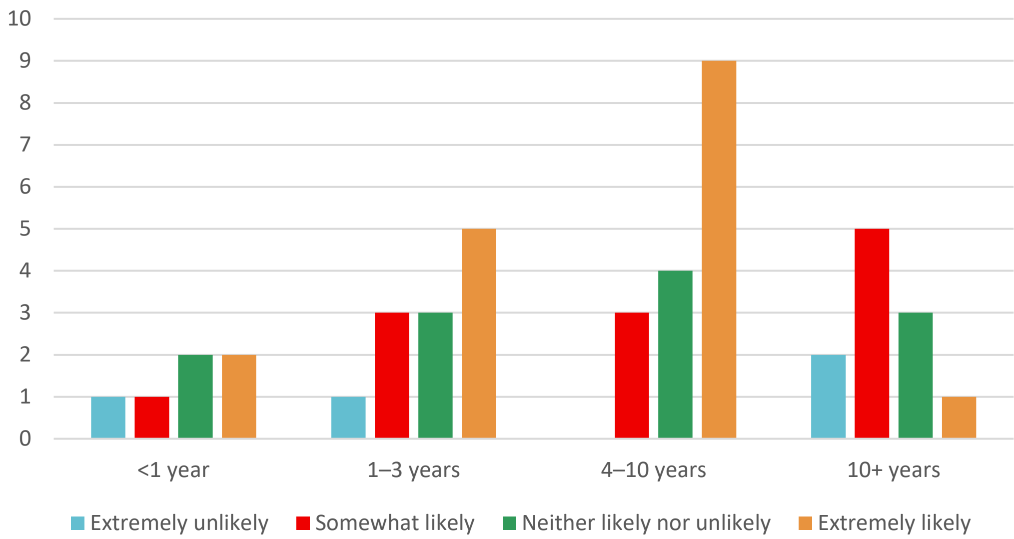
4.11.2. Conclusion

The dataset was skewed toward companies in the middle stages of development (4–10 years)—mature enough to consider innovation, but still agile enough to pursue change. This group represents a critical adoption segment for new models, including PPU models.

4.12. Company age and adoption distribution

The stacked bar chart in **Figure 11** shows how company age influenced the likelihood of adopting PPU manufacturing models. Each bar represents an age group segmented according to adoption sentiment: extremely unlikely, somewhat unlikely, neither likely nor unlikely, somewhat likely, or extremely likely.

Figure 11. Distribution of PPU adoption likelihood by company age



4.12.1. Key insights

To assess the influence of company age on openness to adopting PPU models, responses were analyzed by organizational maturity. Firms aged 4–10 years showed the highest overall enthusiasm for adoption, with a significant proportion indicating that they were extremely likely to adopt PPU models. This indicates a strong appetite for innovation and business model transformation, likely fueled by operational stability, the need to scale, and the desire to differentiate. Firms aged one to three years also demonstrated notable openness, with many respondents reporting that they were somewhat or extremely likely to adopt PPU. These younger firms appear to be proactively seeking capital-efficient, flexible, and scalable growth strategies. In contrast, companies younger than one year old displayed a more evenly distributed range of responses, reflecting the uncertainty typical of businesses in the early stages of developing their strategic direction. Lastly, companies older than 10 years tended to lean toward somewhat likely or neutral responses, with fewer indicating strong enthusiasm. This more cautious posture may stem from reliance on established systems, longer decision-making timelines, or a lower perceived urgency for change.

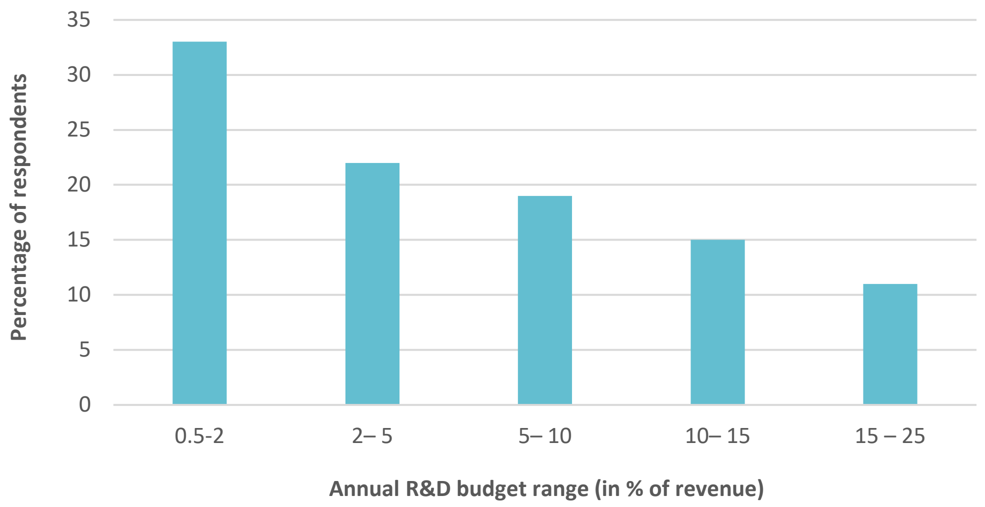
4.12.2. Conclusion

The data revealed a compelling correlation between company age and attitude toward PPU adoption. Mid-aged firms (4–10 years old) were the most enthusiastic adopters, reflecting a balance of innovation readiness and operational resilience. Younger companies (1–3 years old) showed moderate optimism and are likely still in the exploration phase, evaluating strategic fit and feasibility. Meanwhile, very young companies (under one year) had varied responses, indicating openness but not complete optimism. Mature firms (10+ years), in contrast, appeared more reserved or divided in their responses, suggesting that they may require more targeted outreach, education, or incentive structures to support adoption. This age-based segmentation offers a useful roadmap for stakeholders aiming to engage with firms at different stages of their lifecycle, highlighting that timing, maturity, and organizational agility are key factors that influence a company's readiness for business model transformation. Despite the limited sample size, the interpretive analysis of company age in relation to the adoption of PPU models suggests that firms operating for less than ten years are part of the total addressable market and the manufacturing decision-making process. Thus, hypothesis one is confirmed.

4.13. Annual budget allocation for R&D activities

Figure 12 shows how the companies allocated their annual revenue regarding R&D—a key indicator of innovation intensity and future readiness.

Figure 12. Annual budget allocated to R&D



4.13.1. Key observations

To better understand firms' innovation priorities, respondents were asked to report the percentage of their revenue allocated to research and development (R&D). The largest proportion of companies (33%) reported allocating only 0.5%-2% of their revenue to R&D, suggesting a conservative investment approach likely shaped by limited budgets or a preference for incremental innovation. Mid-level spenders were more evenly distributed: 22% invested 2%-5%, and 19% invested 5%-10%. These firms may demonstrate stronger innovation awareness and invest more deliberately in product development, efficiency improvements, or market differentiation. At the higher end, 15% of companies reported spending 10%-15% of their revenue on R&D, and 11% allocated 15%-25% or more. These high-investment firms likely operate in innovation-intensive industries, such as technology, biotechnology, and advanced manufacturing, where R&D is essential for maintaining a competitive edge.

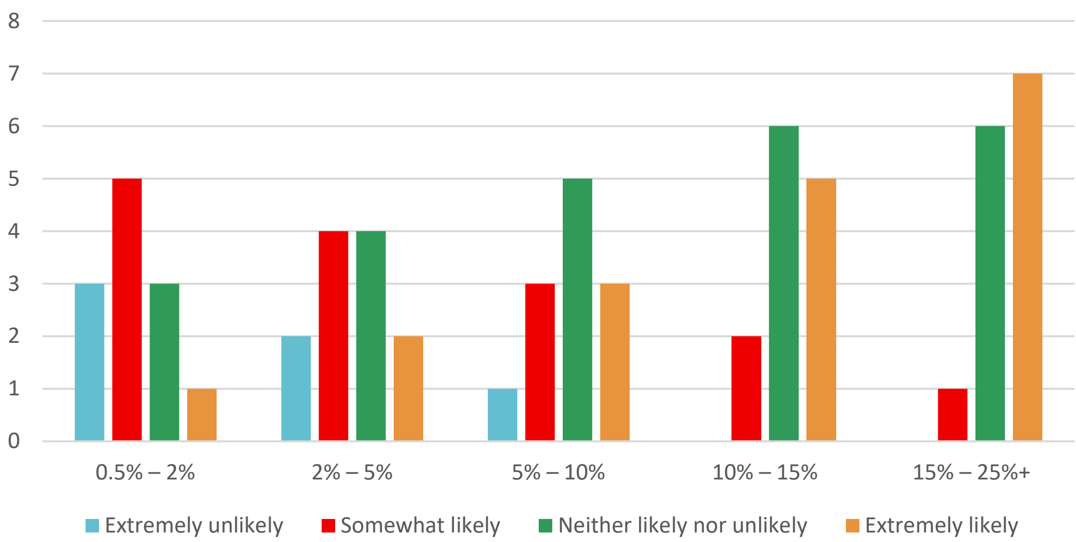
4.13.2. Conclusion

The distribution of R&D investment among the respondents was heavily skewed toward the lower end. Nearly three-quarters of the companies allocated less than 10% of their revenue to research and development. While some firms demonstrated a strong commitment to innovation by spending more, most appeared to favor risk-managed, cost-controlled approaches. This trend suggests an opportunity for breakthrough innovation, particularly among moderate-spending firms, which could benefit from more strategic investments. It also highlights the potential need for external incentives, such as grants, tax credits, or policy support, to encourage greater investment in innovation across the broader manufacturing ecosystem.

4.14. R&D investment and adoption distribution

The stacked bar chart in **Figure 13** shows how R&D intensity correlated with the likelihood of adopting PPU manufacturing models. The relationship was strong and directional: higher R&D spending corresponded with a higher adoption likelihood.

Figure 13. Distribution of PPU adoption likelihood by R&D budget



4.14.1. Detailed trends

To better understand the correlation between R&D investment levels and openness to PPU adoption, detailed trends were examined across spending categories. Companies that invested between 0.5% and 2% of their revenue in R&D were the most hesitant. Many respondents indicated that they were only somewhat likely or neutral toward adoption. A notable share reported that they were extremely unlikely to adopt. This pattern suggests a generally risk-averse stance, limited innovation infrastructure, or uncertainty around the value proposition of the PPU model. In contrast, firms that allocated 2–5% and 5–10% of their revenue to R&D showed more evenly distributed responses across the likelihood spectrum. This indicates a more strategic and exploratory approach to adoption, balancing perceived benefits with implementation risks. The shift became most pronounced among companies investing 10%-15% or more than 15% in R&D. These respondents were heavily concentrated in the “extremely likely to adopt” category, suggesting a high degree of confidence, stronger innovation capabilities, and greater structural readiness to implement new business models like PPU.

4.14.2. Conclusion

Companies that allocated more than 10% of their revenue to R&D had the strongest adoption intentions, reinforcing the connection between innovative investment and strategic agility. Conversely, firms with minimal R&D budgets appear to be more resistant to transformation.

Despite the limited sample size, the interpretive analysis of R&D investment in relation to the adoptability of PPU models suggests that firms that invest more than 5% of their annual revenue in R&D are part of the total addressable market and are actively involved in the decision to manufacture and adopt PPU models. This finding supports both of the proposed hypotheses.

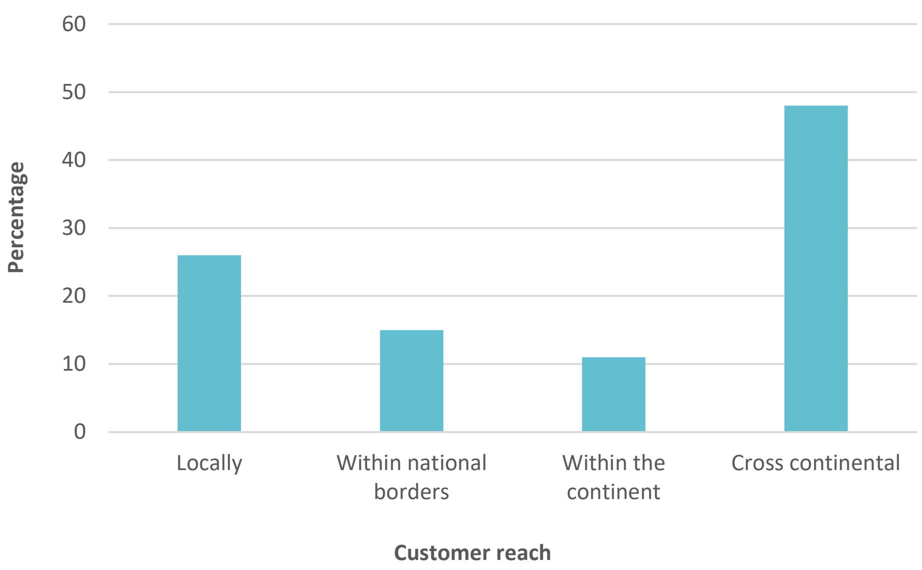
These findings suggest that R&D intensity is a reliable predictor of readiness for business model innovation. For stakeholders promoting PPU adoption, targeting high-R&D firms may yield better traction, while lower-investing firms may require additional education, de-risking measures, or financial incentives to stimulate engagement.

4.15. Customer distribution: Geographic reach of respondent companies

Figure 14 illustrates how the companies categorized their customer bases by geographic scope:

- locally
- within national borders
- cross-continental
- within the continent

Figure 14. Geographic reach and customer distribution of respondents



4.15.1. Key insights

The distribution of customer reach among the surveyed firms reveals an obvious international focus in their business operations. A significant proportion—48%—reported serving a cross-continental customer base, indicating substantial engagement with markets beyond their own continent. This suggests the capacity to navigate diverse regulatory, cultural, and logistical environments, as well as a strategic emphasis on global market integration.

In contrast, only 11% of firms operate primarily within their own continent, suggesting a limited regional focus. Similarly, 15% concentrate their activities within national borders, reflecting the modest presence of nationally bounded business models. Notably, 26% serve a local customer base, suggesting that, although globalization dominates, a significant minority still prioritizes proximity-based strategies due to the nature of their goods or services, regulatory constraints, or the advantages of local market knowledge.

Collectively, these figures suggest a shift away from local and regional market dependence, as nearly half of the firms operate across continents. This trend highlights the growing importance of global customer engagement and may reflect broader patterns of digital connectivity, supply chain internationalization, and the strategic pursuit of diversified markets.

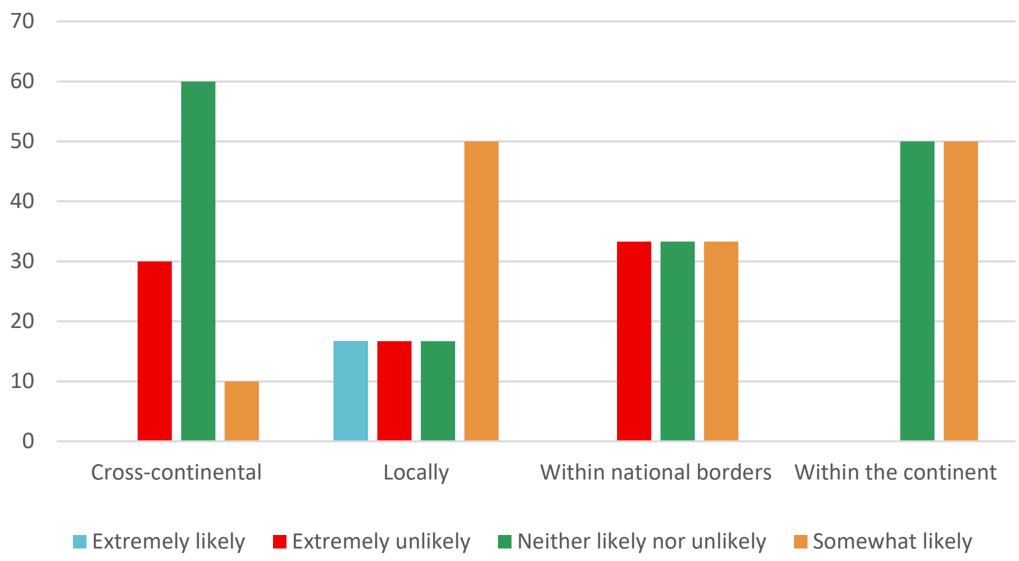
4.15.2. Conclusion

In sum, the data illustrates a clear movement toward internationalization among the surveyed firms. Cross-continental engagement has emerged as the predominant mode for reaching customers. This trend reflects broader shifts in the global economy, where competitive advantage increasingly depends on accessing and serving dispersed markets. However, the persistence of local and national orientations among some firms indicates that globalization is uneven and context-dependent. It is shaped by industry-specific factors, resource constraints, and strategic choices.

4.16. Customer distribution and likelihood of PPU adoption

The stacked bar chart in **Figure 15** hows the companies' customer reaches relative to their likelihood of adopting PPU models based on geographic distribution.

Figure 15. Distribution of PPU adoption likelihood by customer base



An analysis of adoption sentiment across customer reach categories reveals clear patterns in how geographic scope influences openness to PPU models. Firms with **cross-continental reach** show the strongest reluctance: 60% report being "neither likely nor unlikely" to adopt, and 30% are "extremely unlikely," with only 10% indicating they are "somewhat likely." Notably, none in this group are "extremely likely" to adopt, suggesting that while these firms may benefit from global exposure, they also face higher levels of complexity, coordination challenges, or risk sensitivity that dampen enthusiasm for adopting new models.

In contrast, **locally focused firms** appear far more open to PPU adoption. Half of these firms are "somewhat likely" to adopt, and 16.7% are "extremely likely," indicating a strong positive lean. The remaining responses are split evenly between neutral and extremely unlikely, suggesting that while not universally ready, many local firms are more agile and perceive clearer benefits or fewer barriers when adopting new operational approaches.

Firms operating within national borders present a perfectly even distribution of sentiment: 33.3% fall into each of the "somewhat likely," "neutral," and "extremely unlikely" categories. This points to a mixed outlook, with no dominant stance emerging—these firms may be weighing potential benefits but remain divided in their readiness to act.

Finally, **firms operating within a single continent** exhibit a moderate but consistent posture. Half of these firms are "somewhat likely" to adopt PPU, while the other half are neutral. None express strong reluctance or strong intent, indicating that this group may be open to change but lacks the conviction or urgency seen in local adopters.

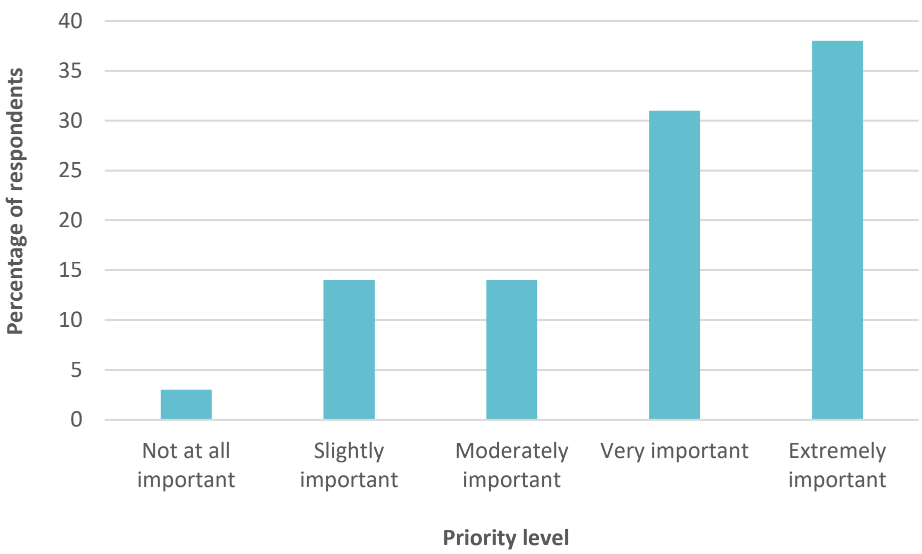
Overall, the data suggests that **customer reach is a meaningful factor in shaping innovation posture**. Global firms tend to proceed more cautiously—likely due to scale, coordination demands, or regulatory diversity—while locally and regionally focused firms are more optimistic and prepared to explore new operational models like PPU.

In conclusion, while the interpretive analysis of customer reach offers useful context, it does not significantly impact the adoptability of PPU models or define their total addressable market.

4.17. Priority of innovation and experimentation as a business goal

The chart in **Figure 16** shows how the companies ranked the importance of innovation and experimentation within their broader strategic priorities. The data reflected a strong overall emphasis on innovation among the respondents.

Figure 16. Priority of innovation and experimentation as a business goal



4.17.1. Key findings

To understand how companies prioritize innovation within their strategic agendas, respondents were asked to rate its importance. Of the companies surveyed, 38% rated innovation as extremely important, followed by 31% who considered it very important. Together, nearly 70% of respondents placed innovation in the top two tiers of strategic priority, indicating a strong consensus that continuous experimentation and advancement are essential for long-term success. Another 14% rated innovation as moderately important, and an equal percentage viewed it as slightly important. This suggests that, while these firms recognize innovation's value, they may face constraints, such as limited resources, rigid industry norms, or a heavier focus on operational execution. Only 3% considered innovation unimportant, likely representing businesses operating in stable or niche markets where traditional approaches still deliver acceptable performance.

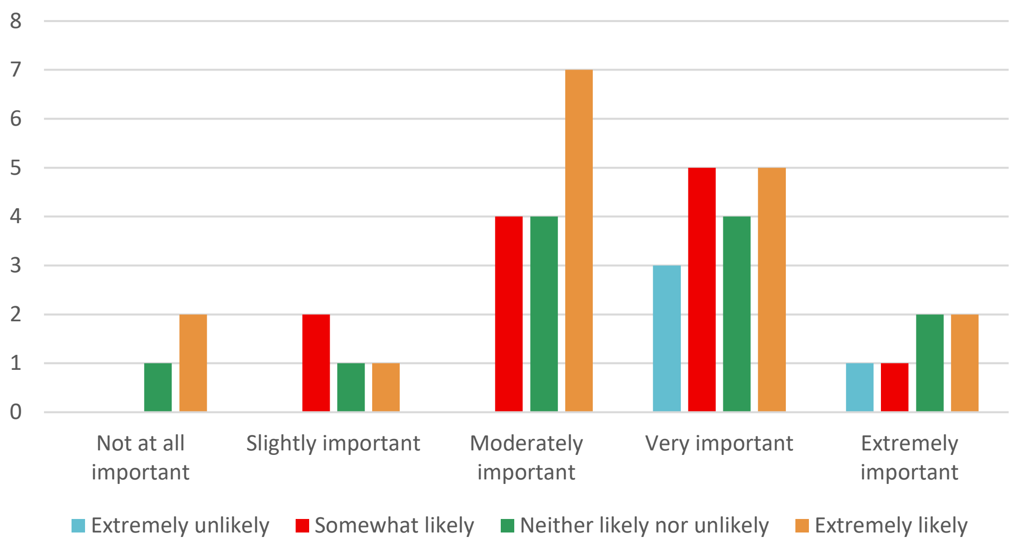
4.17.2. Conclusion

The data affirmed that innovation is a dominant strategic priority for most manufacturers. The majority of respondents viewed it as central to competitiveness, resilience, and adaptability—especially in a landscape increasingly shaped by Industry 4.0 and agile operating models. This underscores the need for firms not only to prioritize innovation in theory but also to support it through investment, culture, and leadership commitment.

4.18. Innovation priority and the likelihood of adopting PPU models

The stacked bar chart in **Figure 17** shows the relationships between the companies' stated innovation priorities and their likelihood of adopting new business models, specifically PPU models.

Figure 17. Distribution of PPU adoption likelihood by innovation priority



4.18.1. Key trends

To explore the relationship between strategic emphasis on innovation and openness toward PPU adoption, responses were grouped by self-reported innovation priority levels. The majority of responses came from companies in the high and moderate innovation priority groups, and these companies showed strong adoption signals, particularly in the “extremely likely” and “somewhat likely” categories. These firms appeared more willing to experiment with new operational models and embrace structural change. The high-priority group, in particular, demonstrated the most balanced distribution, with a clear bias toward high adoption likelihood. In contrast, companies with low or very low innovation priorities had fewer total responses and a flatter distribution, with limited representation in the “extremely likely” category. This suggests a more cautious or indifferent stance likely tied to limited risk tolerance or reliance on established processes. Interestingly, a few respondents with very low innovation priorities still indicated a high likelihood of adoption, suggesting that an innovation mindset is not the sole driver of openness to change. Finally, the group with very high innovation priorities—though smaller in size—showed a neutral-to-positive distribution, hinting at a niche, highly experimental segment already engaged in disruptive strategic thinking.

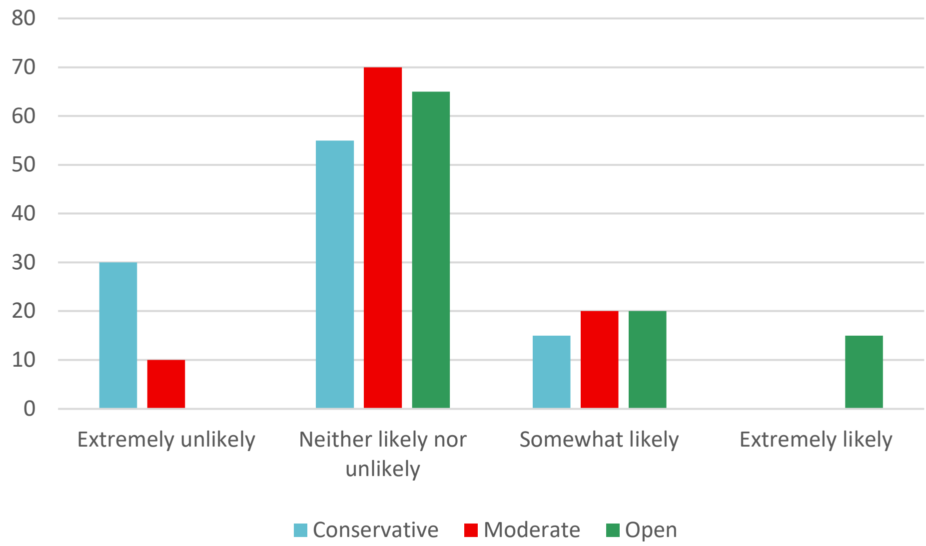
4.18.2. Conclusion

To explore the relationship between a strategic emphasis on innovation and an openness to PPU adoption, the responses were grouped by the self-reported innovation priority levels. Most responses came from companies in the high and moderate innovation priority groups. These companies showed strong adoption signals, particularly in the “extremely likely” and “somewhat likely” categories. These firms appeared more willing to experiment with new operational models and embrace structural change. The high-priority group demonstrated the most balanced distribution, with a clear bias toward high adoption likelihood. In contrast, companies with low or very low innovation priorities had fewer total responses and a flatter distribution, with limited representation in the “extremely likely” category. This suggests a more cautious or indifferent stance, likely tied to limited risk tolerance or reliance on established processes. Interestingly, a few respondents with very low innovation priorities indicated a high likelihood of adoption, suggesting that an innovation mindset is not the sole driver of openness to change. Finally, the group with very high innovation priorities—though smaller in size—showed a neutral-to-positive distribution, hinting at a niche, highly experimental segment already engaged in disruptive strategic thinking.

4.19. Technology openness and PPU model adoption

Figure 18 illustrates the relationship between respondents’ level of technology openness and their reported likelihood of adopting PPU models, highlighting how openness to new technologies may influence adoption sentiment.

Figure 18. Impact of openness to technology on the likelihood of PPU adoption



4.19.1. Key observations

To better understand how openness to technology influences PPU adoption sentiment, the respondents were grouped into three categories based on their primary manufacturing technologies: conservative, moderate, and open. Of the conservative group, which consists primarily of traditional manufacturing users, 30% of companies were extremely unlikely to adopt new technologies, and 55% were neutral, indicating a strong hesitancy toward change. Only a small fraction were somewhat likely to adopt, and none were extremely likely. Among the moderate group, which included subtractive technology users, the percentage of extremely unlikely responses decreased to 10%, though neutrality still dominated at 70%. Responses indicating some likelihood of adoption were comparable to those in the conservative group, and responses indicating extreme likelihood of adoption remained minimal. In contrast, the open group, consisting of automated and additive manufacturing users, showed no extremely unlikely responses. While 65% were still neutral, the percentage of somewhat likely responses increased. Notably, this group was the only one with a significant proportion (15%) who reported being extremely likely to adopt new technologies. This progression suggests that greater technological openness correlates with a higher willingness to explore and adopt innovative models like PPU.

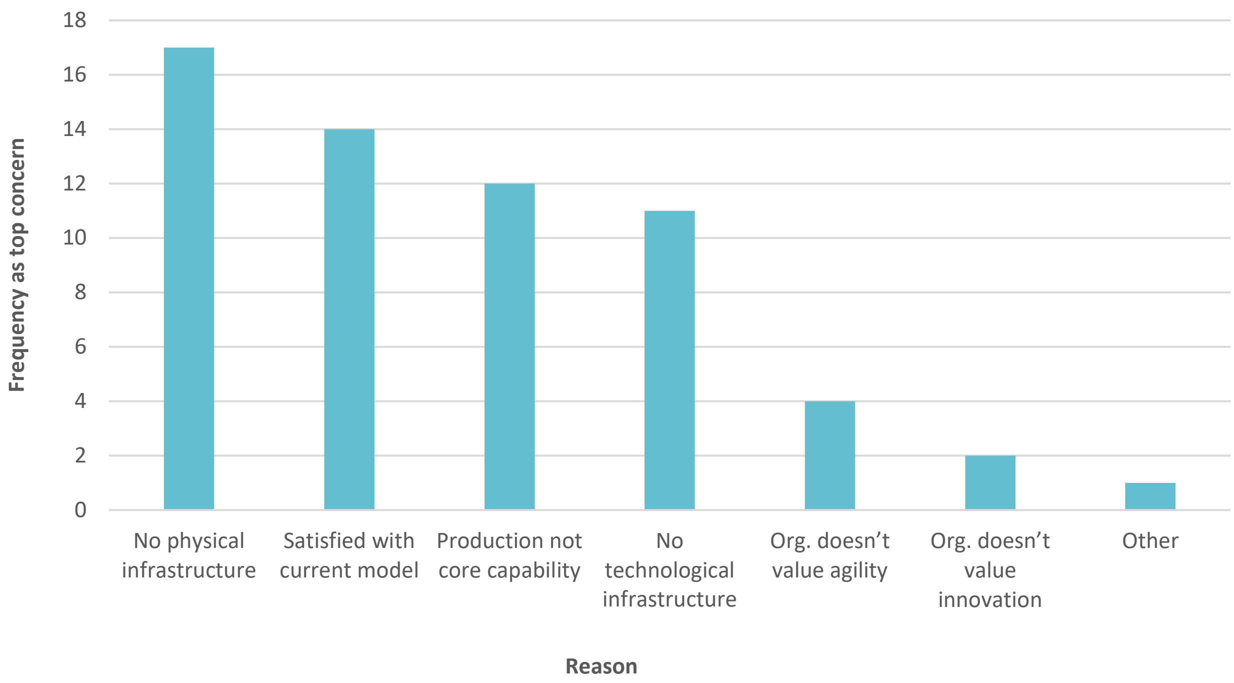
4.19.2. Conclusion

Overall, the progression across technology adoption groups reveals a clear link between openness to manufacturing technology and sentiment toward PPU adoption. Firms that rely on advanced technologies, such as automation and additive manufacturing, exhibited significantly less resistance and had a higher proportion of high adoption intent. These firms also had the only meaningful proportion of "extremely likely" responses. In contrast, companies using traditional or moderately advanced methods were far more hesitant, exhibiting high levels of neutrality and notable resistance, particularly in the conservative group. These results suggest that openness to manufacturing innovation is a strong indicator of readiness for PPU adoption. This reinforces the idea that technological maturity plays a key role in shaping a firm's willingness to engage with new operational models. These results support the conclusion in Section 4H, "Manufacturing Technology Cluster and Likelihood of Adoption of the PPU Model." Specifically, they confirm that firms utilizing more advanced manufacturing technologies are more open to adopting PPU models, thus reinforcing both hypotheses.

4.20. Top constraints preventing the adoption of PPU manufacturing models

The chart in **Figure 19** highlights the primary barriers preventing companies from adopting PPU manufacturing models based on the most frequently ranked constraints (1st or 2nd place) from a list of seven options.

Figure 19. Barriers to adoption of PPU models



4.20.1. Key findings

To better understand the challenges that companies face when adopting PPU models, respondents were asked to identify the main barriers to adoption. The most frequently cited barrier was a "lack of physical infrastructure." Three constraints followed in second place: lack of technological infrastructure, satisfaction with the current manufacturing type, and production not being a core organizational capability. These data present a clear opportunity for providers of PPU manufacturing services to address common misconceptions and reframe model value propositions for prospective adopters.

4.20.2. Analysis of main barriers

The following section outlines the most reported barriers to PPU adoption and provides practical solutions to address each challenge. These solutions are intended to support more informed and confident decision-making among potential adopters.

1. **Lack of physical infrastructure**
   Many companies assume that adopting the PPU model will require the same capital-intensive infrastructure as traditional ownership-based manufacturing. The reality is that PPU models dramatically reduce up-front investment requirements by shifting the focus from ownership to access.
   Solutions
   - Deliver targeted education and awareness campaigns.
   - Share real-world case studies and demonstrations.
   - Highlight financial flexibility and the reduced risk associated with PPU adoption.
2. **Satisfaction with the current model**
   Some firms see no need for change due to perceived operational efficiency or stability.
   Solutions
   - Use real-world transitions to PPU to demonstrate enhanced performance.
   - Highlight hidden inefficiencies (e.g., idle assets, underutilized capacity, and/or high maintenance costs).
   - Show how PPU models can improve adaptability, service differentiation, and Environmental Social Governance alignment.
3. **Production is not a core capability**
   Organizations that outsource or have no internal manufacturing often dismiss PPU as irrelevant.
   Solutions
   - Position PPU as a low-risk entry point into internal production.
   - Offer access to scalable technology and training.
   - Emphasize that PPU allows testing, learning, and strategic capability development without operational disruption.
4. **Lack of technological infrastructure**
   This barrier stems from the belief that significant internal technologies are needed to adopt PPU.
   Solutions
   - Clarify that PPU models come with integrated IoT, automation, and machine analytics.
   - Provide training and support for seamless onboarding.
   - Share examples of plug-and-play integration and cloud-managed operations.

4.20.3. Conclusion: Addressing perception gaps

The leading constraints preventing adoption reflect perception gaps rather than actual limitations. Many businesses mistakenly assume that PPU models require ownership-style investment, deep in-house expertise, or advanced infrastructure.

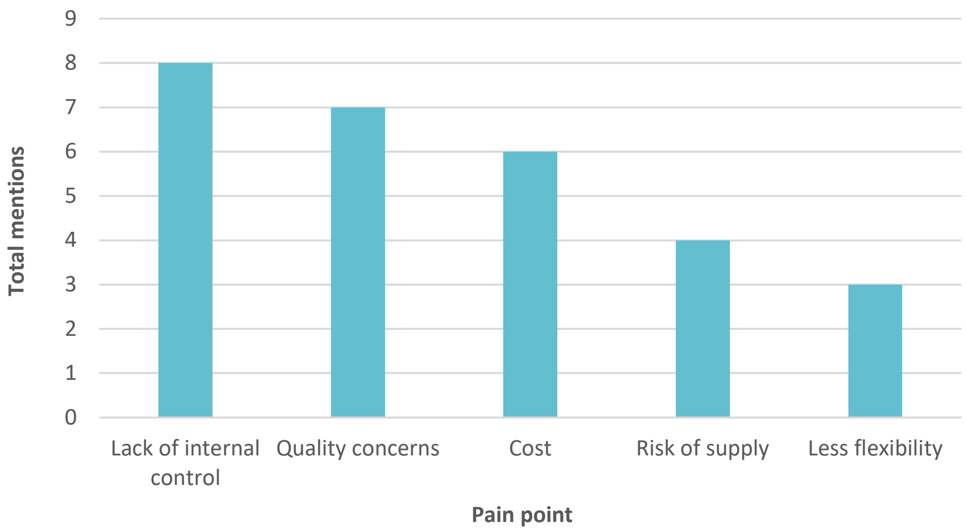
To overcome these barriers:

- Targeted education, pilot demonstrations, and real-world case studies should be provided to bridge the knowledge gap.
- Reframing PPU as an enabler of innovation, rather than a disruption, could resonate with hesitant firms.
- Providers must emphasize flexibility, scalability, and reduced risk—especially for small- and mid-sized businesses wary of change.

4.21. Pain points of outsourcing

The chart in **Figure 20** ranks the most frequently cited pain points associated with outsourcing, based on respondent prioritization.

Figure 20. Pain points of outsourcing (ranked 1st or 2nd)



To address broader adoption barriers, respondents were asked to identify their primary concerns related to the PPU model. The top-ranked issues were a lack of internal control and quality concerns. This indicates that firms are highly sensitive to the potential loss of operational oversight and the risk of compromised product or process standards. Secondary concerns included cost uncertainty and the risk of supply disruption. These issues reflect a growing awareness of hidden costs and the vulnerability associated with relying on external suppliers, especially in volatile or unpredictable market conditions. While these findings do not directly confirm or contradict the hypotheses, they are relevant to understanding the broader context of adoption behavior and highlight areas for future exploration.

4.21.1. Noteworthy insight

"Less flexibility" ranked as the least significant concern, suggesting that most firms do not view outsourcing as inflexible, or that flexibility is adequately managed.

4.21.2. Deeper insight: Supply risks may be underestimated

Although supply risks were ranked relatively low, this may reflect the respondents' narrow definitions of supply risk. In reality, supply risks include the following:

- supplier financial instability
- geopolitical disruption
- environmental vulnerability
- inflexible supplier responses to demand shocks

A broader understanding of supply risks may shift their perceived importance in future assessments.

4.21.3. How PPU addresses outsourcing concerns

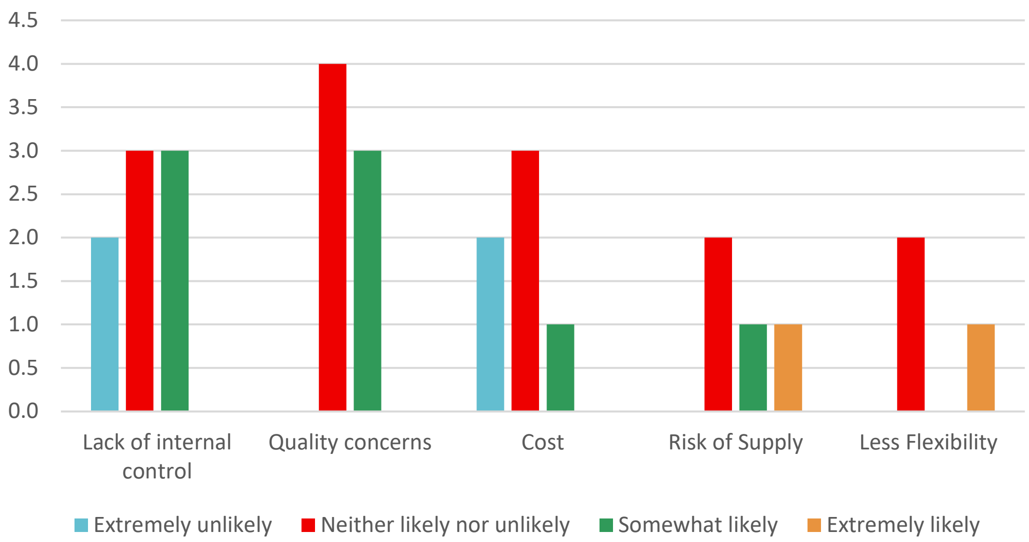
PPU models directly address key outsourcing pain points, as follows:

- **Control:** granular usage reporting, service-level transparency, and customizable Service Level Agreements restore visibility and governance.
- **Quality:** providers are financially incentivized to maintain high standards due to usage-linked revenue.
- **Cost:** payments are tied to outputs, eliminating sunk costs and idle capacity expenses.
- **Flexibility:** on-demand scaling enables firms to adjust operations based on real-time needs.
- **Supply risks:** PPU partners typically hold redundant inventory and operate with high service reliability, reducing exposure to disruption.

4.22. Outsourcing pain points and likelihood of PPU adoption

The chart in **Figure 21** shows how each identified pain point correlated with the likelihood of adopting PPU models.

Figure 21. Likelihood of adopting a PPU model by outsourcing pain point (ranked 1st or 2nd)



4.22.1. Key relationships

To explore how specific concerns relate to adoption sentiment, companies were analyzed based on their prioritized issues. Those that identified supply risks and a lack of flexibility as the main outsourcing concerns were often extremely likely to adopt PPU models, possibly viewing them as direct solutions to their current operational vulnerabilities. In contrast, firms that cited quality concerns and a lack of internal control made up the largest proportion of those somewhat likely to adopt, indicating cautious optimism and a desire for greater assurance regarding service quality and oversight before committing fully. Meanwhile, companies that listed costs and lack of control were the most likely to be extremely unlikely to adopt. These companies may require clearer communication regarding pricing models, cost transparency, and the operational safeguards embedded in PPU offerings.

4.22.2. Strategic recommendations

To address varying levels of adoption readiness, communication strategies should be tailored to the specific concerns and mindsets of different groups of respondents. For the group that is extremely unlikely to adopt, it is important to provide cost comparisons with traditional outsourcing models and emphasize the benefits of value-based payment, the absence of sunk costs, and the scalability of PPU. Messaging for the neutral group should focus on the flexibility of on-demand access, using seasonal or project-based examples. It should also showcase available training and assure output quality. For the group most likely to adopt, campaigns and onboarding efforts should address present-day operational challenges and highlight how PPU models can enhance continuity and responsiveness and mitigate supply chain bottlenecks.

4.22.3. Conclusion

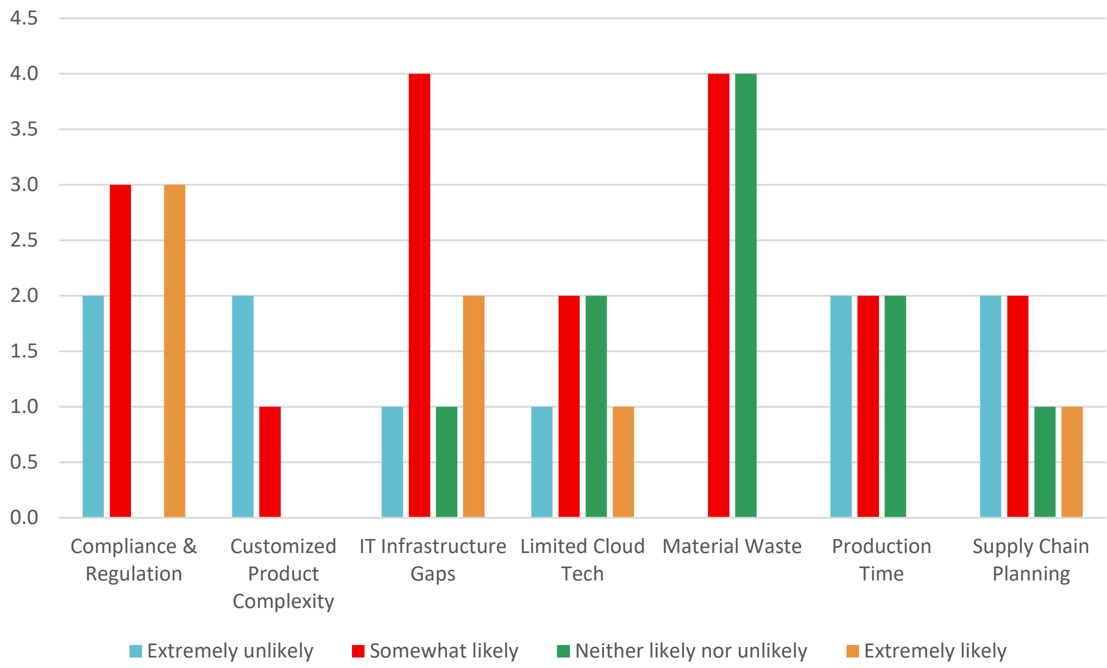
PPU adoption is most promising among firms struggling with supply instability and rigid procurement systems. A PPU model’s flexibility, cost efficiency, and control mechanisms offer a compelling alternative to traditional outsourcing—especially when targeted at the right pain points.

Providers can maximize the adoption of PPU models by aligning their outreach strategy with the specific concerns and priorities of prospective clients. This involves tailoring messages to address distinct pain points related to cost, control, or operational risk experienced by different segments. Additionally, offering trial programs, cost-benefit analyses, and integration support can reduce perceived barriers and build confidence in the models' feasibility. It is important for providers to frame PPU models as performance-enhancing evolutions rather than replacements for internal control. They should position the models as flexible, value-driven solutions that complement existing operations rather than disrupt them. While these findings do not directly confirm or contradict the hypotheses, they are relevant to understanding the broader context of adoption behavior and highlight areas for future exploration.

4.23. Pain points of in-house manufacturing and the likelihood of PPU adoption

The chart in **Figure 22** shows how specific in-house manufacturing pain points correlated with the companies’ likelihood of adopting PPU models.

Figure 22. Likelihood of PPU adoption according to main in-house manufacturing pain points



4.23.1. Key findings

To better understand how specific operational challenges influence adoption readiness, companies were analyzed based on their primary issues. Those citing compliance and regulatory burdens or IT infrastructure gaps as their main challenges demonstrated the highest likelihood of adopting PPU models. Many respondents indicated that they were extremely likely to transition. Compliance and regulatory concerns often involve navigating complex and evolving certifications, such as Good Manufacturing Practices (GMP) in the pharmaceutical industry, AS9100 in the aerospace industry—an internationally recognized quality standard based on ISO 9001 with added aerospace-specific requirements—and IATF 16949 in the automotive industry, a technical specification aligned with ISO 9001 that is tailored to ensure consistent quality and improvement in automotive production processes. These companies also manage broader risks related to legal liability, labor laws, emissions regulations, and data privacy or cybersecurity standards. These risks contribute to increased operational complexity and cost. In contrast, firms that identified custom product complexity or supply chain planning as their primary challenges were more reluctant to adopt PPU, with a noticeable concentration of responses in the "somewhat likely" and "extremely unlikely" categories.

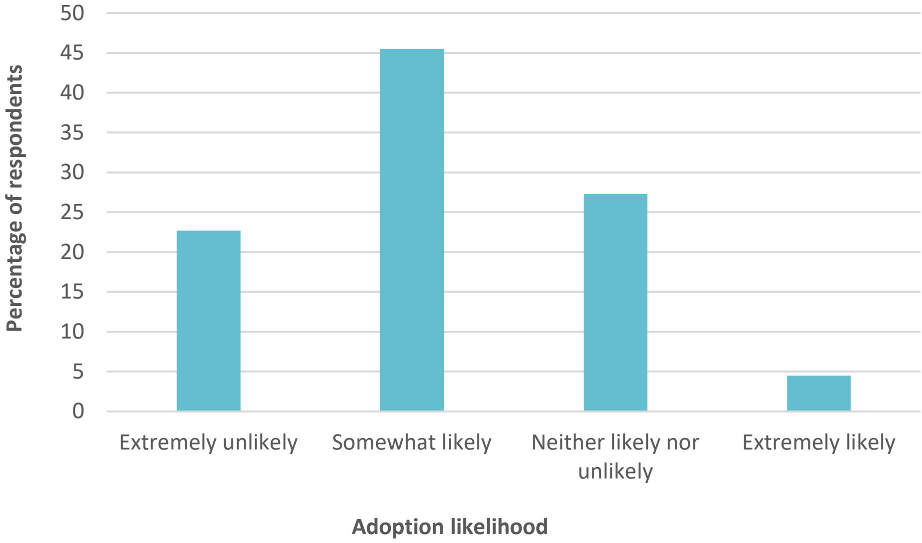
4.23.2. Interpretation

Firms facing regulatory and technology-related burdens may see PPU as a path to de-risk and simplify compliance, especially when inclusive of service support and shared infrastructure. In contrast, companies managing high product complexity or logistical coordination may perceive PPU models as potential risks or misfits for their intricate operations. While these findings do not directly confirm or contradict the hypotheses, they are relevant to understanding the broader context of adoption behavior and highlight areas for future exploration.

4.24. Overall likelihood of PPU adoption

The chart in **Figure 23** provides a high-level snapshot of the companies' overall willingness to adopt PPU manufacturing models.

Figure 23. Likelihood of adopting PPU manufacturing models (percentage distributions)



4.24.1. Key results

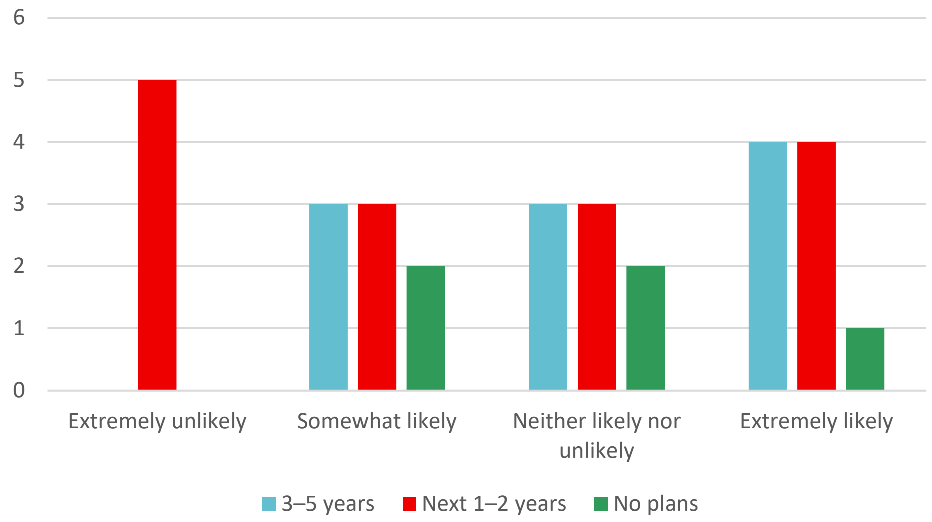
To gauge overall sentiment toward the adoption of the Pay-Per-Use (PPU) model, companies were asked to rate their likelihood of adopting it. A plurality of respondents (45.5%) indicated that they were somewhat likely to adopt the model, suggesting a broad base of cautious interest or early-stage exploration. In contrast, only 4.5% reported being extremely likely to adopt the model, indicating a significant discrepancy between curiosity and commitment. At the other end of the spectrum, 22.7% of companies reported being extremely unlikely to adopt the model, signaling strong resistance among certain segments. Additionally, 27.3% of respondents were neutral, indicating hesitation or a need for greater clarity, confidence, and support before considering a transition to the PPU model.

4.24.2. Conclusion

Although there was moderate interest in PPU models, widespread adoption was hesitant. To bridge this gap, companies must provide stronger evidence of return on investment, clearer technical integration pathways, and greater reassurance regarding risk mitigation and operational impact. Addressing these key areas could help convert interest into action and enable more confident decision-making among potential adopters. While these findings neither confirm nor contradict the hypotheses directly, they are relevant to understanding the broader context of adoption behavior and highlight areas for future exploration.

4.25. Adoption timeline outlook: Planned transitions to PPU

Figure 24. PPU adoption by planned transition timeline (excluding companies that had already adopted)



4.25.1. Key trends

An analysis of the timelines for adopting the PPU model reveals distinct attitudes toward implementing advanced technology, each with implications for readiness and engagement. Firms planning to adopt the model within the next one to two years exhibited the widest range of responses, from "extremely unlikely" to "extremely likely." This polarization suggests that, while some near-term planners are confident and prepared, others are uncertain, potentially due to concerns about cost, infrastructure readiness, or strategic fit. Companies planning a transition within the next 3–5 years were more concentrated in the "somewhat likely" and "extremely likely" categories, indicating a more measured but optimistic approach. These firms may be preparing by investing in digital infrastructure or refining internal processes before committing fully. In contrast, firms with no current adoption plans showed limited engagement, with responses clustering around neutrality or unlikelihood. This group may reflect a lack of awareness, perceived relevance, or immediate strategic priority, underscoring the need for broader outreach and education.

4.25.2. Conclusion

The adoption of PPU model timelines significantly shapes firms' outlooks on advanced technologies. Companies with near-term plans tend to have more polarized attitudes—some are highly motivated, while others are hesitant—while those with longer-term plans are generally more optimistic, but more cautious. Firms without concrete plans remain largely disengaged, suggesting persistent barriers or uncertainty. For stakeholders aiming to promote PPU models, this variation calls for targeted strategies. Early adopters should be supported with tailored onboarding, educational resources, and ROI tools. Mid-term planners should be offered pilot programs, phased rollouts, and infrastructure support. Late-stage or uncertain firms may benefit most from awareness-building initiatives and efforts to mitigate perceived risks. While these findings do not directly confirm or contradict the hypotheses, they are relevant to understanding the broader context of adoption behavior and highlight areas for future exploration.

5. Discussion

5.1. Key findings

In this study, we investigated the organizational, technological, and strategic factors influencing the adoption of PPU manufacturing models. Although widespread adoption remains in the early stages, the results suggest a growing cohort of firms showing cautious but measurable intentions to explore alternative business models that support agility, flexibility, and financial efficiency.

Only 4.5% of the companies in this study reported being extremely likely to adopt PPU in the near term; however, 45.5% described themselves as somewhat likely to adopt PPU, indicating a sizable pool of firms in the exploratory phase. Adoption intentions were most positively associated with firms that had the following characteristics:

- moderate-to-high prioritization of innovation
- R&D investment exceeding 5% of annual budget
- revenue in the mid-to-high bracket
- organizational age under ten years
- organizations using automated, subtractive or additive technologies

Conversely, organizations citing outsourcing-related concerns—particularly regarding quality control, cost and the loss of internal governance—demonstrated greater resistance or hesitance to adopt PPU models. Among in-house manufacturers, respondents who identified compliance complexity, and IT infrastructure limitations, as key challenges were more inclined to adopt PPU, suggesting that these firms perceive it as a viable solution to operational bottlenecks.

Furthermore, since the lack of physical infrastructure was the most frequently cited primary barrier to adopting PPU models, PPU providers could play a critical role in raising awareness of practical solutions to this challenge.

Hypothesis one, which proposed that manufacturing make, buy, or make agile decisions are significantly influenced by firms' manufacturing types, R&D investments, innovation orientations, revenues, and ages, was not **statistically supported**. However, a qualitative analysis of the data indicated that these factors still correlated with increased openness to PPU adoption.

Firms younger than ten years old—particularly those in the four-to-ten-year range—demonstrated the strongest exploratory interest in new business models when they invested over five percent of their annual budget in research and development (R&D), prioritized innovation and experimentation at moderate to high levels, operated within mid-to-high revenue tiers, and actively used automated, subtractive, or additive manufacturing technologies.

5.2. Market implications and TAM estimation

We also considered Hypothesis two which posited a formula for estimating the TAM for agile manufacturing based on key organizational characteristics. Although the original hypothesis was not **statistically supported**, refinements suggest that adoption potential correlates with a narrow subset of firm-level traits.

An updated model to estimate the global total addressable market of agile manufacturing follow:

$16.177 trillion: global manufacturing ouput as of 2023 (MacroTrends, 2023)
× 0.45 (% of firms investing more than 5% of their annual budget in R&D)
× 0.83 (% that prioritize innovation and experimentation at a moderate to high level)
× 0.899 (% of firms less than 10 years old)
× 0.808 (% operating in mid-to-high revenue tiers)
× 0.629 (% using automated, subtractive, or additive manufacturing technologies)

Estimated TAM: $2.48 trillion

It's important to note that the characteristics used to refine the TAM estimate, such as R&D intensity, innovation focus, firm age, revenue tier, and technology use, are based on insights from a small, targeted empirical study rather than broad industry datasets. These attributes reflect patterns specific to the surveyed sample and may not fully capture the diversity of the broader manufacturing landscape. As such, while they offer useful directional insight into which firms may be more receptive to new business models, the findings should be interpreted with caution. The segmentation criteria are best understood as illustrative filters shaped by a limited dataset, not definitive indicators of industry-wide behavior.

5.3. Practical implications

For suppliers of PPU manufacturing solutions

Suppliers are advised to segment their go-to-market strategies by focusing on the most innovation-ready and structurally compatible firms with PPU models. This begins with prioritizing innovation-driven companies that demonstrate high research and development (R&D) intensity and strong digital readiness. To accelerate adoption, suppliers should directly address known barriers by offering solutions to challenges such as a lack of physical and IT infrastructure, compliance complexity, and a perceived loss of production control. It will be critical to educate the market through use-case demonstrations and financial models that clearly illustrate the cost–benefit advantages of shifting from traditional, ownership-based manufacturing to PPU. Finally, to position themselves as strategic partners rather than just technology providers, suppliers should offer onboarding support, training programs, and performance transparency tools that build trust and confidence throughout the adoption process.

For PPU consumers (adopting firms)

Suppliers are advised to segment their go-to-market strategies by focusing on the most innovation-ready and structurally compatible firms with PPU models. This begins with prioritizing innovation-driven companies that demonstrate high research and development (R&D) intensity and strong digital readiness. To accelerate adoption, suppliers should directly address known barriers by offering solutions to challenges such as a lack of physical and IT infrastructure, compliance complexity, and a perceived loss of production control. It will be critical to educate the market through use-case demonstrations and financial models that clearly illustrate the cost–benefit advantages of shifting from traditional, ownership-based manufacturing to PPU. Finally, to position themselves as strategic partners rather than just technology providers, suppliers should offer onboarding support, training programs, and performance transparency tools that build trust and confidence throughout the adoption process.

5.4. Future research directions

Although this study provides a foundational view of the organizational and contextual variables influencing PPU adoption, several avenues remain open for further inquiry:

1. **Longitudinal studies**
   Future researchers should examine how adoption attitudes evolve over time, especially in response to external events, such as tariff fluctuations, geopolitical realignments, or macroeconomic shocks.
2. **Sector-specific analysis**
   Deep dives into specific industries (e.g., the aerospace, FMCG, and pharmaceutical industries) could reveal differentiated adoption triggers based on certification regimes, capital requirements, and legacy system constraints.
3. **Behavioral and organizational factors**
   Further study is warranted regarding the decision-making psychology underpinning model adoption—particularly the role of risk orientation, leadership mindset, and internal innovation culture.
4. **Pilot studies**
   Empirical studies to measure the operational outcomes of real-world PPU deployments could help validate theoretical models, reveal transition bottlenecks, and quantify long-term benefits (e.g., total cost of ownership reduction and agility gains).

6. Conclusion: Toward a resilient and adaptive manufacturing future

In an era defined by economic uncertainty, technological transformation, and heightened geopolitical risk, the manufacturing sector must evolve beyond the binary make-or-buy framework. This research confirms the growing relevance of a third (make it agile) approach to leverage flexibility, servitization, and digital integration and to facilitate more responsive, efficient, and resilient production systems.

The findings of this study highlight that although widespread adoption of PPU models is not yet realized, significant interest and foundational readiness exist—especially among firms with high innovation intensity, mid-to-high revenue, and global or regional market exposure. Firms that already engage in R&D, prioritize adaptability, and recognize the limitations of both in-house and outsourced models are well positioned to adopt agile solutions.

Importantly, the study revealed that adoption is not merely a function of technology or sector; it depends on a broader alignment of strategic vision, operational capability, and market readiness. Companies with perceived constraints—whether related to infrastructure, compliance, or outsourcing limitations—may benefit the most from PPU adoption if properly informed and supported.

Suppliers need more than technical capability. They must foster ecosystem leadership, deliver education, and provide integration support and proof of value. For adopters, PPU models offer ways to reduce risk, unlock flexibility, and facilitate future-proof operations without the heavy burden of capital expenditure.

As the manufacturing renaissance unfolds, this study provides a strategic framework for understanding, targeting, and accelerating the adoption of new production paradigms. Agile manufacturing based on PPU models is no longer a fringe concept—it is rapidly becoming a critical pathway to industrial resilience, competitive differentiation, and long-term national and economic security.

The journey ahead involves more than deploying new equipment; it requires reshaping organizational systems, redefining supplier partnerships, and embedding agility into every layer of the manufacturing enterprise.

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ARTIFICIAL intelligence was used to assist with select aspects of this report’s development. All inputs and analyses were handled with respect for data integrity, privacy, and ethical research practices, ensuring that human oversight guided interpretation and final outputs.

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