Proceedings of Business and Economic Studies, 2026, Volume 9, Issue 5
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on Data Value Realization and Economic Efficiency Enhancement in Manufacturing Industry: A Case Study of Ningbo

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Abstract: This study investigates barriers that prevents manufacturing firms from converting data assets into economic value. Based on the survey of the 287 enterprises in Ningbo, China, the analysis examines three interconnected factors: data governance costs, technology adoption risks, and benefit distribution clarity. According to the above results, the governance cost and adoption risk of small and medium-sized enterprises are relatively high, and vague distribution rules have weakened cooperation at all levels of the enterprise. Significant differences have been found between the large and small-sized enterprises in all the above indices. Based on the above research, we have suggested several plans to control costs, manage risks and regulate rules in a transparent way.

Keywords: Data value; Manufacturing industry; Economic efficiency

Online publication: June 19, 2026

1. Introduction

The manufacturing sector is in a crucial period, and data has started to be considered a means of increasing productivity and competitiveness. Industrial enterprises have started collecting a lot of data from sensors in their production lines, quality control systems, etc., at present. With the spread of Internet of Things devices and the reduction in costs of cloud storage and computing, collecting and storing large amounts of data for all types of manufacturing enterprises has become feasible in terms of technology and economics. Based on the collected data, one cannot conclude that there will be any economic benefits [1]. Many enterprises have abundant data but are unable to achieve a substantial increase in production efficiency, quality, cost control, etc., through data analysis.

It is particularly apparent in the traditional manufacturing cluster that although the enterprises have been in the industry for a long time, they lack experience in applying new data analysis technology [2]. A major problem in the industrial economy is the lack of links between data production and value addition. To develop an effective intervention strategy at the company or policy level, it is first necessary to understand the underlying

causes of this lack of cohesion.

Ningbo is one of the major manufacturing bases in Eastern China. Ningbo, in Zhejiang Province, is an area with a large number of enterprises in the field of auto parts, high-end equipment and smart appliances. A large amount of operating data is continuously produced by the production line sensor, quality inspection station and material flow tracking system in this industry. Although there has been significant investment in the construction of digital infrastructure by the public and private sectors over the past decade, most enterprises have been unable to gain considerable economic benefits from the data they have gathered so far. Investment in the construction of data collection facilities has not increased productivity or profit to the same extent.

The three reasons for the problem are as follows:

(1) Data governance costs, expenses associated with data cleaning, standardization, integration, and maintenance, may consume resources that outweigh near-term returns;

(2) There is a risk in the application of technology; the work and data produced by analytical tools are often not reliable;

(3) There is an ambiguity in the distribution rules for the benefits; that is, there is no protocol on how to share the gains from collaborative data initiatives, and this may either promote or obstruct the inter-firm cooperation necessary to unlock network-level value [3].

2. Literature review and conceptual framework

2.1. Data governance costs are a bottleneck

Data governance in the manufacturing sector is a large-scale undertaking that is often overlooked at the initial stages of digitalisation planning. It involves validating data obtained from sensors and ensuring that the corresponding equipment or production batch is correctly identified and consistent with the recorded standards. Records from equipment provided by various vendors need to be harmonised into a single format; it is not easy because each industrial automation supplier has its own proprietary data schema. Due to sensor failures, network disconnection or other human errors during the write process, there will be false data that needs to be addressed in an orderly manner. Metadata that describes the data's origin, collection conditions and semantics need to be created and maintained so that people who did not collect the data at that time can still understand it [4].

The governance work needs to be carried out by professionals who are familiar with information technology and the manufacturing industry. A large company with a good IT department will have lower governance costs. Small and medium-sized enterprises that do not have professional technical staff are unable to carry out such activities and will thus take time and resources away from data analysis and application. Time and funds will be used to prepare data, so there will be less time and money for drawing conclusions and improving the process.

2.2. Technology adoption risk and uncertainty

The deployment of advanced analytical tools in the manufacturing sector faces many problems at various levels. The predictive maintenance algorithm, the machine learning model for quality prediction and the real-time scheduling optimizer are to operate normally in the controlled demonstration environment. However, the firm needs to determine if a particular technology will work well in its own operating environment; this environment may be different from that where the technology was developed and verified in many ways.

The other reason is the integration of old systems. Many of the manufacturing bases use old equipment that has not been updated recently, so they are not connected to the Internet. It is technically difficult and expensive to retrofit the old machines with sensors and communication. The connection has been realised; however, at present, not all equipment is operating normally.

The Return on Investment will be lower than expected. The productivity effect of the analytical tool will only be felt after making some organizational adjustments and training the staff. Both the size and timing of the return are unknown at present, which is not suitable for the capital planning of small and medium-sized enterprises [5]. Manufacturing enterprises that have not had the experience of data science are unable to judge how uncertain these problems are. Therefore, many are understandably cautious and will not invest until observing some good examples from other enterprises.

2.3. Clarity of benefit distribution and collaboration dynamics

Manufacturing data value is not only generated within the company; data sharing and collaboration across the entire supply chain also create additional value for firms [6]. Forecasting product demand in advance helps avoid excess inventory and reduces the bullwhip effect. High-quality downstream data also enables rapid identification of defect causes by tracing issues back along the production line. This approach aims to improve capacity utilization and shorten production lead times at all levels of the supply chain.

The cooperation of the participating companies needs to add their own data to a common pool. The company will not disclose any information that indicates its weakness in competition or reduces its bargaining power. Although the enterprises are aware that there will be some joint benefits from data sharing, they cannot act accordingly due to the lack of clear rules on benefit distribution. Each company has a reason not to release its own data and can still enjoy the benefits from the data of others. Therefore, a clear and reasonable division of distribution should be established to continue the cooperation in data sharing by both companies. The above mechanisms need to address the following problems: how to quantify the amount of data provided by each person, what formula to use to distribute the divided benefits, and how to deal with disputes over the assessment of contribution or the division of benefits.

Governance at the industry level will help solve the coordination problem. Industry associations, standards organizations and other independent institutions can hold talks to determine work distribution. However, the development of such governance structures also needs to solve the problem of collective action. Public policy needs to be adjusted, and a system of joint governance will be constructed that does not require the participation of private enterprises.

3. Research methodology

3.1. Sample and data collection

Data were obtained by means of a survey of manufacturing enterprises in Ningbo, China. A set of standardized questions was distributed to companies in the automotive components, high-end equipment and smart appliances industries, etc. After removing the incomplete-answer questions, 287 good questionnaires were obtained and had a good response rate of 80.8%.

3.2. Sample characteristics

The samples of large enterprises, medium-sized enterprises and small enterprises are 82 (28.6%), 119 (41.5%)

and 86 (29.9%) respectively. Firm size was classified according to the official statistical criteria of the number of employees and annual revenue. The distribution of sectors is 93 auto parts enterprises (32.4%), 83 high-end equipment companies (28.9%), 61 smart appliance manufacturers (21.3%) and 50 enterprises in other categories (17.4%). The distribution is approximately that of the population structure of manufacturing enterprises in the area.

3.3. Measurement

Core constructs were measured using multi-item seven-point Likert-type scales. Data governance is about the cleaning and standardization, linking, etc., of data. Technology adoption risk is the risk that the new technology will not perform well, have problems in the integration process, or fail to achieve the expected returns on investment. Clarity of benefit distribution is about having a clear and reasonable rule for sharing the advantages of cooperation. Based on the realized data, there have been some improvements in operating efficiency, cost reduction, quality improvement and increase in revenue through data utilization. All constructs had a good internal consistency, and the Cronbach's alpha was greater than 0.70.

4. Results

4.1. Descriptive findings

Table 1 presents descriptive statistics for the core constructs.

Table 1. Descriptive statistics for core constructs

Variable	N	Mean	Standard Deviation
Data Governance Costs	287	5.18	1.17
Technology Adoption Risks	287	4.95	1.35
Benefit Distribution Clarity	287	3.42	1.48
Data Value Realization	287	3.83	1.39

The average of the seven-point scale for data governance costs is 5.18, and most people are significantly burdened by the governance work. The standard deviation of 1.17 is relatively small; thus, most people in the sample agree with this view. The average value of Technology adoption risk is 4.95; thus, it is moderately to highly uncertain that the analytical technology will be introduced. Benefit distribution clarity has the lowest mean among the three independent variables at 3.42 and indicates that most people are dissatisfied with the current way to share the advantages of collaborative data. The relatively large standard deviation of 1.48 for this variable indicates that the firms are quite diverse. The average of the data value realization is 3.83, which is lower than the scale midpoint; therefore, it can be concluded that manufacturing enterprises have not yet generated economic benefits by turning data assets into economic value.

4.2. Variation by firm size

Table 2 disaggregates these results by firm size category.

Table 2. Comparative statistics by firm size

Variable	Large Enterprises (n=82)	Medium Enterprises (n=119)	Small Enterprises (n=86)
Data Governance Costs	4.48	5.27	5.95
Technology Adoption Risks	4.08	4.99	5.62
Benefit Distribution Clarity	4.13	3.15	2.88
Data Value Realization	4.60	3.79	3.21

A clear gradient is shown in the four indicators. The governance cost of large enterprises is relatively low at 4.48 and their adoption risk is also relatively low at 4.08; however, their distribution clarity (4.13) and value realization (4.60) are relatively high. Small enterprises have the opposite trend; the governance cost is 5.95, the adoption risk is 5.62, the distribution clarity is 2.88, and the value realization is 3.21. The scale of the enterprises is medium-sized. All pairs of sizes are statistically different at the 0.01 or 0.05 level. The difference in the realized value of large and small enterprises is relatively substantial, about 1.39 points out of a total of seven.

4.3. Key relationships

Three analytical patterns are worth noting. First of all, the governance cost is positively related to the adoption risk ($r = 0.47$, $p < 0.001$). Companies that are not interested in data governance will think that the cost is too high, and they will consider using technology for it to be too risky; thus, they will experience a greater sense of uncertainty due to resource constraints. Furthermore, the range of spread for benefit distribution clarity in the three independent variables is the largest (SD = 1.48), and thus the institutional development of supply chains and industries is uneven. Finally, firm size is a factor in all aspects of performance, even after controlling for the industry and the number of years of digitalization. Based on this, it can be seen that large enterprises are better able to bear governance costs and form institutional systems [7].

5. Strategic recommendations

5.1. Reduced data governance costs

Reducing governance costs needs to be done jointly by the company and the ecosystem. Improve the governance of high-value data streams in the company and be willing to accept a lower level of maturity for less essential data at the enterprise level. Not all data produced in a manufacturing company are worth the same investment. Triage is used to focus resources on the decision-making information, maintain the quality of analysis, and it has been determined that comprehensive governance of all data assets is neither practical nor necessary for most companies. Prioritization should be based on how much the data elements directly affect major decisions in production planning, quality control, equipment maintenance and so on. Data streams that are the foundation of the above functions should be given top priority in cleaning, normalization and documentation.

Working with the industry association and other departments of the government, costs will be reduced by standardization and sharing of facilities. The data model of a general-purpose manufacturing process is used so as not to modify the database. If the numerous enterprises in a particular cluster use the same data schema for describing the condition of machinery, quality characteristics and other material data, it will reduce the expenses of data organization. Through cooperation among the industry, technology enterprises and universities,

etc., these general models can be created to meet actual operating conditions and still have some room for modification according to individual enterprises.

Another way to lower the cost is to have a joint data cleaning service. Both the services provided by the industry association and those offered by the commercial platform have achieved economies of scale that individual small enterprises cannot achieve on their own. According to the demands of several companies, shared services can be used to fund the purchase of automated data-quality tools, specialised staff, and so on, and continue to improve the cleaning algorithm. Data collection from a large number of enterprises to build an inexpensive cloud-based data management platform that can meet the needs of medium- to large enterprises and provide a good solution for many small and medium-sized ones. The bargaining power of the consortium of small manufacturers is much greater than that of any single company; therefore, lower software license fees may be realized.

5.2. Reduce the risk of technology adoption

The three reasons for the risk of technology adoption are as follows:

(1) To reduce the uncertainty of the potential adopter, demonstration projects of the successful application in similar companies will be organized. When a company learns that a peer firm of the same size and operating mode in the same industry has successfully applied a particular analytical technology, it will be less concerned about the risk of adoption itself. The peer effect is more prominent in industrial clusters because the companies know each other well and are in close contact most of the time. Industry associations can organize regular sites to collect information and publish technical guides and other documents based on the actual experiences of various enterprises in that industry;

(2) It will be convenient for the front-line staff to minimize financial losses in case of a risk. Partial subsidies for the first round are to help small and medium-sized enterprises lower the entry threshold to participate in the experiment and provide some motivation for them to learn well and apply it in practice. The design of such programmes should motivate people to adopt and establish responsibility. The formula for cost sharing is too high, and it will be difficult for the adopting enterprises to bear the costs of the project; thus, we cannot designate it as a free experiment. On top of that, add insurance products to cover the risk of failure in the application of technology, such as the model not meeting performance expectations, delayed integration, business interruption expenses, etc., to reduce the downside risk and motivate people to purchase insurance;

(3) A normalized evaluation system can be employed to assess the proposals from the various vendors and thus identify the more reliable ones. The framework needs to put forward the main questions for the technology vendor, the required performance indicators that will be demanded, the minimum requirements for the design of the pilot project, and the evaluation criteria for the implementation results. A regular system of technology evaluation can help to solve the problem of information asymmetry among suppliers and the factory. Public technology extension services or industry associations are in a good position to develop, maintain and train firms in the use of these evaluation tools.

5.3. Set up clear benefit distribution rules

The distribution of benefits is not in the power of a single company. Under the direction of an independent third party, at the level of the industry, dialogue can be held to build a contribution distribution model and

set corresponding standards, formulas, dispute resolution mechanisms, etc. The dialogues may be organized by the industry association, chamber of commerce and other competent departments of the government. In order to construct systems that are regarded as legitimate and fair by all sides, enterprises from all links in the production chain, including raw material suppliers and components, assemblers, etc., should participate. With the participation of all relevant groups, a few protocols will likely be voluntarily accepted by enterprises and then actively implemented.

Practical rules need to answer the above problems reasonably accurately in order to help the company operate well. They need to clarify how data contributions will be quantified, and different kinds of data with different analysis values should be distinguished. The indices that will be used to evaluate the results of the cooperation in data sharing should be set. They need to set the basis of the baseline performance and then evaluate how much has increased. Moreover, they should set forth the formula for distributing the benefits to the participants, as well as the adjustments to this distribution in light of changes in circumstances. Although the best protocol will be different in various sectors and cooperation modes, having some specific, clear rules for conducting business is better than having no rules at all in most of the manufacturing supply chain.

Technology and the organization of society can offer strong support for institutional governance. A distributed ledger technology can be used to record the contribution of different people in a transparent and unalterable way, and then automate the distribution rules. When the contribution indicators are added to a distributed ledger, it will be more difficult to dispute the amount or time of the data contribution. A smart contract can distribute the profits according to the predefined rules automatically and thus reduce the cost of manual settlement and payment. Although the application of such technology is needed to be funded by large sums of money and special staff, platform companies or infrastructure construction projects in the industry can reduce these barriers for small and medium-sized enterprises.

6. Conclusion

6.1. Summary of key findings

The three problems in the use of data for manufacturing are the high cost of data governance, the considerable risk of new technology introduction, and the lack of clear rules for benefit sharing. Governance costs and adoption risk are directly related to the use of data by the firm, and they are correlated. Distribution ambiguity will reduce the need for cooperation to achieve the value of the network. Together, these problems form an independent chain and are not easy for one company to break out of. There are relatively large differences in the indices of small and large enterprises; generally speaking, small enterprises are more costly, riskier and have fewer favorable institutional environments.

6.2. Theoretical contributions

This paper makes the following three contributions to the research field as follows:

(1) To present some statistics on how much the cost of governance, adoption risk and lack of clarity in distribution hinder the benefits obtained from data, as well as how they are related;

(2) To show that the size of the enterprise is associated with a certain extent with both the magnitude and regularity of size-based differences;

(3) Industrial data has added to the resources and capabilities of the resource theory, and the certainty of benefit-sharing is now provided for through institutional rules of collaborative value creation.

6.3. Practical significance

Based on the above analysis, it can be concluded that although new technology needs to be obtained, attention should also be paid to the efficiency of governance, risk assessment ability and cooperation in norm construction. Managers should pay more attention to the governance investment in high-value data streams and take an active role in the whole industry to establish rules for the distribution of benefits. Policymakers need to address the institutional factor in addition to the problems of technology and funds, according to this study. There will be issues of coordination in the joint data project, so the technology distribution subsidy plan will not be implemented.

6.4. Limitations

There are two reasons for this. First of all, the cross-sectional design cannot determine the direction of causality in the relationship among governance costs, adoption risk, distribution clarity and data value realization . Second, there is only one industrial area, so it is not applicable to other manufacturing clusters that have different institutional environments.

6.5. Future research directions

Based on the results of a long-term study of the data initiative, it will be determined in the future whether the problems have been solved. Comparing it with other manufacturing areas can improve the external validity and show how various environments may affect the relationships we have found so far. Further studies can be carried out to find out how the data will lead to wealth creation and how to optimize the use of data investment and application efficiency.

Disclosure statement

The authors declare no conflict of interest.

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