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Article

Food testing standardization for sustainable industrial development

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Abstract: The paper seeks to understand the relationships that exist between the standardization of food testing technology and the quality of high economic development within the industry. The relationship is sought through conducting thorough theoretical analysis alongside empirical research of the two subject matters. The study focuses on three new elements employing the use of panel data and multiple regression models to analyze the implementation of different economic outcomes over the period of 2015 till 2023. Beyond economic outcomes, the findings demonstrate that the standardization of food testing technology also serves as a governance mechanism that enhances social welfare, improves institutional trust, and supports equitable participation in the industrial ecosystem. By reducing information asymmetry and reinforcing regulatory credibility, standardization contributes to long-term sector resilience and sustainable social development. Therefore, standardization should be recognized not only as a technical instrument for efficiency improvement but as a foundation for inclusive growth, fair market access, and sustainable industrial governance aligned with SSD objectives.

Keywords: food testing standardization; sustainable industrial development; social governance; equitable market access; institutional trust; regulatory transparency; sector resilience

1. Introduction

Food testing procedures remain to be of utmost importance for economic growth in the agriculture and food sector, market expansion and increased consumer requirements for food testing and safety only serve to emphasize the significance of employing these procedures [1,2]. In regions experiencing emerging markets for food and agriculture, adapting standardized procedures for the testing of food products has proven to effective and influential aiding food safety management systems and overall market growth [3,4].

Technological development remains to be crucial for businesses, validating procedures for testing equipment and attaining uniformity along with constant quality control ensures great strides are made for the industries [5]. Maximizing the effectiveness of the food and agricultural sector through strategic measures that ensure lower testing costs and using uniform procedures ensures an increased efficiency. Not only does uniformity of the procedures make the work more efficient and reliable but it also increases the modernity of the food industry as a whole [6].

At the macroeconomic level, SIP food testing technologies have great potential to foster industry transformation and upgrade [7–10]. In the research, it was shown that there is market power advantage which increases growth potential Additionally, standardized testing further increases the development of international business by lessening the technical barriers and augmenting test results acceptance [8,11–13].

Progress in technological development has brought opportunities and challenges to harmonization of food testing, especially when considered in the space of Industry 4.0 [14]. With the advent of automated systems and digital technologies, traditional approaches to testing have changed significantly and the quality of such testing has also improved [15,16]. However, this technological progress entails a call to frequently revise existing standards to make them relevant [17].

At the regional level, the globalization of value chains has become a stimulus for food testing technologies standardization to emerge especially in particular sectors of developing economies [18]. The transfer of technical know-how through standardization has greatly enhanced the capacity of domestic businesses to integrate into the global economy[19–21]. In this regard, medium and small businesses have particularly benefited from such a move as they receive more apparent technical requirements and quality expectations.

Even though there has been progress on addressing the issue, the standardization of the food testing techniques is still rife with challenges [22]. Such challenges include the existing gaps with respect to the existing regional capacities, regulatory measures at the local level, and the unavailability of the deep pockets for infrastructural and human resource investments. For most of these issues, the economic development dimensions intersect, thus understanding them is important for accurate standardization development [23,24].

The aim of this research is to explore the role of the standardization of food testing technologies in relation to the high-quality economic growth in the sector. In so doing, the research intends to look at how standardization enhances economic growth, and how such knowledge can help industries to perform better and foster a more sustainable growth [25–27]. The research is also expected to shed light on the different strategies that can be employed to promote the competitiveness of the food industry through standardization, and thus be useful for its understanding and practice from a policy perspective.

The essence of conducting this research is that it should help to establish industry standards, and it should help to shape policies that will be applied in practice, with regards to food testing. In an age where the food industry is rapidly changing and globalization is the order of the day, formulation of logical economic arguments that support standardization should become a priority [28,29]. From a governance perspective, standardization operates as a regulatory coordination mechanism that reduces information asymmetry, strengthens institutional accountability, and supports transparent enforcement across the food testing sector[30,31]. This interpretation links standardization to social governance outcomes rather than viewing it solely as an efficiency intervention. However, these outcomes cannot be evaluated solely through an economic lens. In line with the scope of Sustainable Social Development, standardization must also be examined for its impacts on public welfare, regulatory credibility, and equitable participation across market actors. This reorientation reframes standardization as both an economic and social governance mechanism, rather than a performance-driven technical tool alone.

From the perspective of Sustainable Social Development (SSD), food testing technology standardization is more than an economic efficiency strategy; it is a policy tool that strengthens governance capacity, safeguards public welfare, and promotes

fair participation across different types of market actors [23,26]. By reducing regulatory fragmentation and enhancing sector-wide credibility, standardization improves social legitimacy and aligns industrial performance with long-term sustainability goals. This shift in framing situates the present study within SSD's scope, positioning standardization as a mechanism for resilient, equitable, and accountable sector development [12,27]. This study therefore aligns with the SSD scope by interpreting food testing standardization as a governance mechanism that enhances regulatory transparency, institutional trust, and equitable access to sector participation, rather than as a purely economic efficiency tool.

2. Literature review and fundamentals of theory

2.1. Current research status of food testing technology standardization

The evolution of food safety challenges and technology integration contribute to the current research trends in food testing technology; this highlights an ongoing advancement. This particular area of research has been known to significantly contribute to ensuring that food is safe and aid industry and trade progression, particularly when addressing its implementation and impact [32]. Countries have shown that within the sphere of food testing, the existence of standards has been a considerable factor in overcoming obstacles to trade and improving around the reliability of testing [11,33].

An enhanced focus has been given to amalgamation of technological advancements into award frameworks of standardized protocols. New techniques for quick detection, along with automatic testing have made it important for international protocols to be regularly modified leading to more rapid and precise food testing techniques [4,34]. Research shows that food testing standardization has been reinvigorated with the use of digital technologies, these being a significant part of the fourth industrial revolution, shows how diverse this area is from previously set norms [6,35].

There is a significant relationship between testing standards focus and business performance highlighting the cost-effective nature of the later. Operational costs incurred by food producers are lowered as a result of the availability of standardized policies [21,36]. As part of the industrial developments, standards have played an important role in the development of quality management systems [17,37].

Food testing standardization as a global perspective has been greatly researched focusing on its application in different economies. Studies in the context of developing countries have shown plain that standardization operates as an extremely important mechanism for increasing industrial competitiveness and integration into global markets [20,38]. In addition, studies have looked at the linkages between standardized tests used in researches and international trade volumes and concluded that standardization is one of the strategies to be used in lowering nontariff trade barriers [12,39].

Novel intricacies also emerged in recent studies that examine the focus on achieving full scale standardization issue associated with this. Studies have found a number of variables affecting the effective applications of standardization of the testing protocols for example: capacity, legislation and resource availability [8,23].

The fit of international standards into the local has been increasingly identified as a key issue, and there is a need for more robust standardization techniques with more room for adaptation [24,40].

The existing body of research offers great perspective about the food testing technology standards and how they interact with the already existing technologies and for that matter and what matters, also recognize the challenges such technologies would automatically pose. A notable empirical pattern indicates a general movement towards technology-oriented models of standardization, while at the same time pointing to areas where further research is needed to deal with the new challenges and opportunities in this movement [16].

2.2. Theories of high-quality economic development in industry

The food industry and its desired economic development require a robust theoretical framework which will aid in sustainable growth and ensure industrial advancement. Connecting the dots of the next generation theories necessitates that the firms embrace and drive technology, there is an improvement in performance and lastly a high degree of development in a sustainable manner [7,41]. These theoretical perspectives go on to aid in facilitating the shift from the traditional pattern of growth which was inclined towards quantity, into a pattern which is more inclined towards quality.

There are key drivers which are embedded into economic upgrading theory and this theory serves as a building block of understanding the phenomena of high- quality development, bearing in mind the existence of global value chains. Research has demonstrated that industrial upgrading processes are closely linked to standardization and technological advancement enabling productivity enhancement and competitive advantage [12]. The constant interaction between these two tendencies advocates the idea that policy priorities and quality development of the national economy are mediated by capability building functions and knowledge accumulation efforts.

Another valuable addition to this theory is the theory of industrial economics which is said to add value in explaining the issues concerning market structure and industry organization while allowing for high-level advancement [42]. There is a growing body of evidence arguing that achieving high-quality development is supported by structural and resource allocation efficiency optimization. This theoretical perspective draws attention to the importance of institutional frameworks and market mechanisms in promoting industrial transformation [43].

Innovation theory has become an essential tool to grasp the dynamics of quality economic development. Research indicates that technological innovation and standardization are vital elements to industrial upgrading and economic restructuring [44,45]. The theoretical framework depicts that the modern industries need reasonable and continuous innovation capabilities to foster and uphold quality development [46].

The theory of institutional economics gives analytical depth concerning the significance of the governance and regulatory frameworks in enhancing quality development outcomes [47]. Additionally, studies have shown that creating good institutional structures is capable of promoting technical progress and standardization of industries for increased economic growth[48]. From this theoretical perspective, the

coordination of policies and institutions supporting development becomes crucial for the realization of high-quality development outcomes.

With regard to the food industry, these theoretical bases serve as the pillars upon which the mechanisms and conditions that characterize quality economic development are built. And from these theoretical bases, it is evident that technological development, institutional development and the market environment are interdependent and thus stimulate industrial growth and development [49].

2.3. Theoretical connection between standardization and economic development

The idea between the economic development of the region and the process of standardization might appear to be rather illogical at first, however, it makes sense from a theoretical perspective as the countries further industrialize and grow. To elaborate, there has been considerable research which has adding into the idea that, standardization indeed alters a country's market structure by reducing transaction costs [18]. This specific connection is prominent within the scope of technological advancements.

The theory of network externality builds onto the idea of how standardization as a process enhances the economic landscape by creating network expansion and economies of scale. In addition, it has been shown that technologies that have become set standards greatly contribute to integration of markets, and advancement in technologies resulting in greater efficiency in economic performance [31]. This theory further reinforces the importance of standardization within a region to break an economic growth stagnation.

While the definition of institutional implies the use of pre-defined rules, it could also shed light on how standardization aids in economic development within a region. This form of research analysis shows how standardization helps reduce any asymmetric information along with any uncertainty in transactions that ultimately creates a more favorable environment for progress [7]. All the above indicators aid in strengthening the theoretical association between standardization and efficiency of a particular institution.

The growth theory has been broadened to include the standardization processes in technological innovation and enhancement of productivity. Considerable literature notes that standardization helps in the spread of knowledge and technology transfer, which are among the major accelerators of economic development [19]. This theoretical linkage stresses the relevance of advancements in industrial standards to aid in industrial development and upgrading of the technology.

Within the field of industrial organization theory, theoretical reflections are made on the consequences of standardization on the structure of the market and the system of competition. It has been established that the standardization process can shape the levels of economic barriers to entry, degree of competition and dispersion of firms within the industry [3]. Such a theoretical approach serves to illustrate the significance of international standards in setting the structure of industries and the productivity of the economy.

These theoretical links are essential in formulating policies and action plans

towards industrial development. These theoretical approaches taken together clearly bring out the value of standardization as the enabler of effective economic development through the lowering of transaction costs, the enhancement of network effects and the diffusion of technologies [5].

2.4. Standardization, social governance, and sustainable sector development

Recent scholarship in sustainable social development increasingly emphasizes the role of institutional capacity and governance quality in shaping inclusive industrial transformation. From an institutional perspective, standards function as coordination mechanisms that reduce uncertainty, structure market expectations, and facilitate trust among economic actors. Governance theory further suggests that transparent and predictable regulatory frameworks are foundational to equitable participation, particularly for small and medium enterprises that are disproportionately affected by information asymmetry and compliance ambiguity. Within this context, standardization can be interpreted as a form of soft infrastructure that supports rule-based market interactions while reinforcing regulatory legitimacy. By stabilizing expectations and lowering participation barriers, standardized systems contribute not only to economic efficiency but also to distributive fairness, a central objective of Sustainable Social Development. This theoretical lens strengthens the interpretation of food testing standardization as a governance instrument embedded within broader institutional development processes rather than as a purely technical or productivity enhancing intervention.

Within the framework of sustainable social development, standardization is interpreted as a long-term capacity-building process that enhances system resilience, improves sector-wide accessibility, and aligns industrial upgrading with societal welfare objectives. Its sustainable value lies not only in improving process efficiency but in enabling equitable market participation and institutional continuity. Recent SSD-oriented studies emphasize that the value of standardization extends beyond productivity and industrial upgrading. Standardization reduces information gaps, supports transparent regulatory enforcement, and enhances social trust in food safety systems, thereby connecting technical processes with public welfare objectives [23,26]. It also lowers structural barriers that limit the participation of small and medium enterprises, improving equity in market access and contributing to inclusive industrial transformation[29,30]. These governance effects provide the conceptual bridge between technical standardization and sustainable social development, justifying the reassessment of standardization as a social rather than purely economic instrument.

2.5. Literature review and theoretical framework construction

The theoretical model that has been established between the economic furtherance alongside the agri-food testing technology standardization shows us that the economic growth is a multidimensional component when analyzed on a comparative basis with the analysis of existing literature. From this study it was able to obtain that the processes variance greatly affects the standardization processes [34].

The understanding of the nexus between economic growth and standardization set out in this theoretical framework is comprehensive and is derived from multiple perspectives.

Two facets of institutional economics are incorporated into the model; how standardization lowers transaction costs and enhances market efficiency [19]. The processes of standardization's institutions are one of the many determinants for the economic outcome of the processes. Lastly, the model described acknowledges the ever-changing landscape of technology innovations and their relationship to standardization processes [39].

Analyses suggest that there are a few major pathways in which the relationship between economic development and standardization exist as pointed out in **Figure 1**. These technological pathways relate to integration into international markets and achieving institutional efficiency [33]. The framework sustains that all these elements supplement one another to foster high-quality economics growth.

Standardization processes work alongside other economic factors in accelerating industrial development as shown in **Figure 1**. The systemic approach to the analysis of standardization emphasizes its' feedbacks with the economic processes at stake and captures both direct and indirect effects of standardization [42]. Further research has demonstrated that these processes are particularly crucial in developing economies where standardization can serve as a catalyst for technological advancement [3].

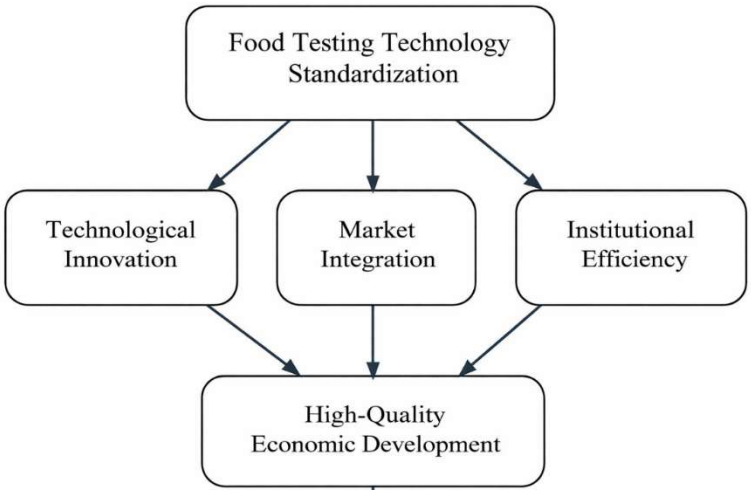

Figure 1. Theoretical framework of food testing technology standardization impact on economic development.

Based on our preceding discussions, this framework seeks to answer the question of how the standardization of food testing technology can aid in the process of enhancing economic development in a country, as illustrated in **Figure 1**. The framework incorporates ideas from multiple theories which permits us to, among other things, hypothesize about the interactions which exist between the process of standardization and various economic measures [25]. The multifaceted nature of the inquiries into economic growth built within this framework would undeniably assist in explaining the different roles that standardization plays in promoting economic expansion. Recent studies have particularly emphasized how this framework can support sustainable development initiatives in agricultural sectors [49].

3. Analysis of the development status of food testing technology standardization

3.1. Comparative analysis of domestic and international food testing technology standard systems

Despite food testing technologies being present in all the countries, there exists barest differences when policies pertaining to the implementation of such technologies is designed. It can isolate that the difference in approach, application and the prescription of such technologies has stark differences. Whereas organizations such as Codex Alimentarius and ISO have a more detailed description of food testing technologies which countries are bound to follow, such rules may not be present in all the countries leading to the said disparity [1]. **Table 1** outlines the planning features which such organizations as associated with such technologies, ensuring that the countries possess appropriate training to undertake testing.

It can be noted that while previously civilizations or economies were unaffected by evolving global requirements, the scenario has drastically changed. For example, a part of the economy which was previously emerged is now considered as developed and possesses a well rounded out framework deciding the position and requirements of international systems, emerging economies on the other hand are still evolving [33]. Other than quite a few remaining differences such as validation protocols and testing specifications have been covered.

While noting the above-mentioned responsibilities and changes, it can be envisioned that international organizations for the standardization of a product comprise more refined mechanics which ensure incorporation with emerging technologies and a seamless integration with the said technologies at a more frequent rate and orderly manner [19]. This approach is unresponsive to the evolving requirements of the economy or to put it plainly, domestic systems which require technologies to be constantly updated[35].

Table 1. Comparison of domestic and international food testing technology standard systems.

Characteristic	International standards	Domestic standards
Regulatory framework	Comprehensive multi-level system	Developing hierarchical structure
Technical specifications	Highly detailed and specific	Gradually improving specificity
Update frequency	Regular (2–3 years)	Variable (3–5 years)
Method validation	Rigorous inter-laboratory studies	Limited collaborative validation
Quality assurance	Mandatory proficiency testing	Voluntary participation
Technology integration	Advanced automation systems	Transitioning to automation
Reference materials	Certified international standards	Limited domestic standards
International recognition	Wide acceptance	Regional acceptance
Accreditation process	Standardized global procedures	Varying regional procedures
Risk assessment	Systematic approach	Developing frameworks

According to table one, the comparison depicts the rapid progression of the benchmarking systems and also points out where there is room for improvement in the

domestic standards systems. Such understanding is essential for formulating measures aimed at increasing the mutual compatibility and efficiency of food testing technology standards in different regions of the world[3]. Recent studies have shown that this harmonization is particularly crucial for developing nations seeking to participate in global agricultural trade [8].

The submitted comparative study has identified the need for improvement of local standards so that they do not become obsolete in the international market [22]. This balance is especially important as digital technologies are still transforming how testing is done in agriculture [32].

3.2. Development process of food testing technology standardization in China

Food testing technological standardization in China has gone through an extensive evolutionary process over the past decades having systematic improvement. The first step towards achieving standardization started with the initiation of basic testing plans that were the stepping stones toward the formation of comprehensive standard systems [39]. This transition has involved a step-by-step shift from international standard practices to the adoption of domestically developed testing techniques aimed at achieving specific local objectives.

The step of standardization of food testing technology in China is further boosted by the introduction of new regulations on food safety laws. It has been established that such legal frameworks are instrumental in enhancing the efforts geared toward coming up with standardized testing procedures [40]. The integration of advanced technology and automated testing devices also added sophistication to the standardization processes thereby leading to gain in accuracy and efficiency in the tests performed [34].

In the recent past, China has sought to align its standardization efforts with the international contours and requirements. This kind of alignment explains the limited ability of other countries to sell goods to China but has widened their capacity to engage in international trade [42]. The establishment of national reference laboratories as well as standardization technical committees has been of great importance to the development of testing standards and later implementing them effectively [32].

The current phase of standardization development moves towards the introduction of digital technologies and automated smart testing systems. Research has proven that this technological change has greatly improved the ability to conduct and supervise standardized testing processes [43]. The ongoing advancement regarding the standardization of food testing procedures in the PRC remains focused on balancing international expectations with the current local ones, thus improving the existing food risk management system [44].

Recent assessments demonstrate that China’s model of standardization has undergone drastic changes in regard to standardization, especially with respect to agricultural green production [47]. This has especially been the case with respect to the level of efficiency and the degree of sustainability achieved in the agriculture sector due to the process of standardization itself [38]. The combination of digital technologies and standardized testing in procedures is progress in China’s goal for

advanced agricultural development quality [48].

3.3. Current challenges in food testing technology standardization

Even though much has been achieved in both the standardization of food testing technologies, some important problems still exist which need to be dealt with and solved in an orderly manner. One of the main issues, as research shows, is the lack of adherence to the unified protocols across the zones and laboratories [22]. Such variations in the protocols operative execution can affect the test outcomes and consequently the tests validity itself.

The growing pace of new testing technologies has created a gap between the available standards and the already existent ones. According to multiple studies, the updating of the standards is often argued to be a process that is slower than the actual progressing technological innovations which could restrain the use of testing approaches that are more efficient [14]. The great divide in movement through time poses appropriate problems with respect to timing on some things, including efforts directed towards standardization [32].

Another primary difficulty found particularly in the developing areas are limitation of infrastructure and lack of resources. According to research, lack of technical expertise and lack of funding can greatly hinder the application of uniform testing standards [38]. The level of qualified staff and the quality of the available equipment for testing differ significantly from one geographical area to another, with the result that the efforts directed towards standardizing the services differ [3].

Another prominent problem pertains to engagement of various actors in the standardization process. Inadequate dialogue and cooperation between regulators, laboratories, and industry members have been noted as impediments to the effective and efficient development and application of standardized protocols [34]. Research has shown that these coordination challenges are particularly acute in rural areas where digital infrastructure may be limited [8]. The issue of international trade, in which various markets have disparate technical and regulatory requirements, further complicates matters [19].

Such challenges are important in the context of food testing technology standardization because they indicate the need for stronger consolidation and a more ordered procedure as far as both the technical and organizational issues are concerned [5]. Recent research has indicated that solving these problems needs both technological development as well as institutional change [49]. Effective solutions for these challenges will have to find a balance between local realities and global best practices [25].

3.4. Mechanism of standardization's impact on industry development

The development of the industry of food testing technologies is influenced by processes of standardization which arise from the system of interactions and feedback loops. As reported in the research, standardization has been found to improve industry productivity through the improvement of certification and control over quality procedures [7]. The mechanism in question is depicted in **Figure 2**, which shows standards cascading throughout the [industrial] landscape and propelling development

in all facets.

Laying down a set of procedures and instructions greatly alters how the industry conducts its businesses. According to research findings, this transformation lowers the operational expenses and the costs incurred per transaction over the industry's value chain [19]. It creates possibilities of technology transfer and knowledge sharing among the players in the industry [33].

The scope of the impact invariably encompasses aspects which go beyond the straightforward operational clout. Studies have shown that the international trade efforts and globalization of markets are bolstered by the observation of internationally accepted standards of testing [3]. This process, depicted in **Figure 2**, generates positive cycles enhancing the evolution and the innovation development of the industry [25].

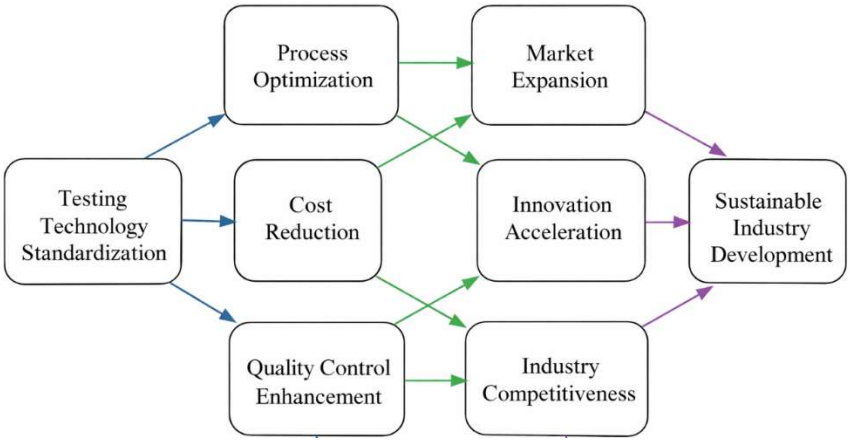

Figure 2. Impact mechanism of food testing technology standardization on industry development.

Digital tools have turned out to be a central component within this mechanism, modifying the manner in which standardization influences the development of industries [42]. It has been found that information technologies are increasingly influencing entire processes of standardization, especially in the agricultural industries [34]. The incorporation of digital technologies has opened up new avenues for progress by means of standardization [39].

The more recent research has shown how the activities of standardization mechanisms enable more sustainable growth of industries in less developed countries [44]. The scope of this impact is greater than mere formal regulatory technical compliance, which stimulates improvements and competitive advantages [43]. This type of standardization has been shown to be very effective in promoting the development of high quality within agricultural industrial sectors [40].

4. Empirical study: The impact of standardization on industry economics

4.1. Research hypotheses and model construction

From the analysis, we propose that at the very least, standardization has an effect on industry evolution in a number of ways within the framework of technology intensity and the structure of the market. The standardization effects on the industry

are outlined both directly and indirectly by the standardization impact processes as shown in **Figure 2**. In this intricate web of relationships, standardization becomes one of the key elements for the transformation of an industry and a means for achieving objectives.

In this broad model structure description, an association between economic performance and standardization is captured:

$$Y_{it} = \alpha + \beta_1 STD_{it} + \beta_2 X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where Y_{it} represents the economic performance indicator for industry i at time t, STD_{it} denotes the standardization level, and X_{it} represents a vector of control variables[37]. The model incorporates both fixed effects (μ_i) and random disturbances (ε_{it}). This definition permits the analysis of the impact of standardization policies on industry performance while other relevant factors are being controlled.

To capture the complex interactions between standardization and industry development, an extended model is proposed:

$$PERF_{it} = \alpha + \beta_1 STD_{it} + \beta_2 TECH_{it} + \beta_3 MKT_{it} + \gamma(STD_{it} \times TECH_{it}) + \delta Z_{it} + \varepsilon_{it} \quad (2)$$

where $PERF_{it}$ represents industry performance metrics, $TECH_{it}$ captures technological capacity, MKT_{it} represents market conditions, and Z_{it} includes additional control variables [21,38]. The interaction term ($STD_{it} \times TECH_{it}$) examines the moderating effect of technological capacity on standardization's impact. This more elaborated specification allows us to study the mechanisms through which the effectiveness of standardization efforts may differ with regard to different levels of technology and market maturity.

To model a more general form of a dynamic problem, and to deal with endogeneity issues, in particular those related to the time-varying nature of industry growth, we go further and explain a dynamic panel model in greater detail:

$$\Delta Y_{it} = \alpha + \rho Y_{i,t-1} + \beta_1 \Delta STD_{it} + \beta_2 \Delta X_{it} + \eta_i + \nu_{it} \quad (1)$$

This specification makes it possible to test for the existence of timing effects and also allows for potential reverse causality. The model includes lagged dependent variables and first differences to deal with unobserved heterogeneity and serial correlation. Taking into consideration the nature of the standardization processes and their impacts on the development of the industry, this is of great importance at hand.

All of these econometric specifications work together to enable us to empirically test the hypothesized relationships between standardization efforts and economic performance alongside varying industry features as well as methodological difficulties. The model framework is geared towards determining how standardization efforts can be linked to industry development and aids in the development of policies around it.

The rest of the approach is checked for issues of the monitoring and direct and even soft impacts of standardization that are power oriented and tend to overlook the different contextual elements that may impact the effectiveness of the standardization efforts. This methodological framework is a great place to start because it gives a strong background for the empirical analysis to the policies on how the issue of

industrial standards of quality is addressed.

4.2. Data sources and variable design

The empirical analysis relies on rich datasets from diverse sources to fit the entire mound of the study on how standardization and economic performance correlate. For instance, primary data on the standardization of food testing technology are derived from national standards databases and regulatory reports from 2015–2023. The study focuses on China due to the rapid institutionalization of food safety governance and the availability of high-resolution regulatory data; 2015 marks the acceleration of regulatory modernization and digital transformation within China's food safety governance system, which substantially improved the availability and consistency of standardization records. By 2023, the majority of provinces had implemented updated food testing protocols, allowing for meaningful temporal comparison of standardization progress across regions.

Data on food testing technology standardization were obtained from national standards databases and official regulatory inspection reports. These sources provide objective records of testing protocol adoption, laboratory accreditation status, and compliance outcomes, thereby reducing the risk of self-reporting bias. Economic performance indicators were compiled from industrial statistical yearbooks and verified financial databases to ensure cross-source consistency. The sample includes industry observations across multiple regions, enabling the analysis to capture geographic variation in both regulatory capacity and industrial development. A balanced panel structure was maintained to enhance comparability over time and minimize estimation bias associated with unbalanced datasets.

To ensure data reliability, observations with incomplete financial or compliance records were excluded following standard panel data screening procedures. Remaining missing values were limited and addressed using conservative data-cleaning protocols to avoid distortion of regression estimates. This approach strengthens the internal validity of the empirical design while preserving sufficient variation for robust econometric analysis.

Economic performance indicators, on the other hand, are compiled from industrial statistical yearbooks along with corporate financial records that explain the economic performance at an industrial level in depth.

The study looks into an array of control variables that are specific to industries or the economy in general, as shown in **Table 2**. In accordance with the theoretical formulation concerning the interrelationship between the economic growth and the process of standardization, global variables were amply determined from past empirical studies [20,32].

The data covers a balanced dataset of observations across different regions and over time, allowing for thorough examination of the effects of regional sampling. The variables do not only capture standardization effects, rather comprehensively controlling the confounding variables onto direct effects of standardization on industry development.

Table 2. Variable definitions and data sources.

Variable category	Variable name	Definition	Measurement	Data source
Dependent variables	Economic Performance (PERF)	Industry profitability	ROA (%)	Financial Database
	Market Share (MKTS)	Market concentration	HHI Index	Industry Reports
	Innovation Output (INNOV)	R&D effectiveness	Patent counts	Patent Database
Independent variables	Standardization Level (STD)	Testing standard implementation	Compliance rate (%)	Standards Database
	Technical Capacity (TECH)	Technology adoption	Equipment value	Asset Records
	Market Integration (MKT)	Trade openness	Export ratio (%)	Trade Statistics
Control variables	Firm Size (SIZE)	Scale of operations	ln (total assets)	Financial Statements
	Industry Growth (GROW)	Development pace	Annual growth rate (%)	Statistical Yearbook
	Regional Effects (REG)	Geographic variation	Dummy variables	Regional Database
	Time Effects (TIME)	Temporal variation	Year dummies	Time Series Data

Note: Economic Performance (PERF) is retained as an operational indicator and is interpreted within this study as part of the SSD framework, reflecting equitable market participation rather than functioning as a stand-alone measure of sector outcomes [23,26].

Measurement of standardization level

Standardization Level (STD) was operationalized as the proportion of accredited laboratories compliant with nationally mandated food testing protocols within each province-year observation. Compliance assessments were conducted through formal regulatory inspections administered by provincial food safety authorities, ensuring that the indicator reflects externally verified adherence rather than voluntary disclosure.

4.3. Empirical analysis

The empirical analysis starts with descriptive analysis which provides a first look at the key variables in the analysis. In terms of the statistics presented in **Table 3**, there is considerable disparity in the variables of standardization implementation and economic performance metrics within the sample. It turns out that the average of standardization level (STD) is 0.684, showing the industry has a moderate willingness to embrace testing standards.

Table 3. Descriptive statistics of key variables.

Variable	Mean	Std. Dev.	Min	Max	Observations
PERF	0.142	0.086	−0.125	0.456	2580
STD	0.684	0.173	0.235	0.982	2580
TECH	0.563	0.145	0.156	0.897	2580
MKT	0.428	0.192	0.089	0.934	2580
SIZE	8.456	1.234	5.678	12.345	2580
GROW	0.086	0.045	−0.067	0.234	2580

Analysis by correlation as spelt out in **Table 4** above displays important relationships between some of the most pertinent variables. Most importantly, standardization positively correlates to both economic performance (0.436) and technical capacity (0.385), bolstering the posited linkages. Additionally, the temporal evolution of key variables from 2015 to 2023 illustrates a consistent upward trend in

both standardization levels and economic performance indicators, further supporting the empirical pattern observed in our models (see **Figure 3**) [17,21].

Table 4. Correlation matrix of variables.

Variable	PERF	STD	TECH	MKT	SIZE	GROW
PERF	1.000					
STD	0.436*	1.000				
TECH	0.385*	0.412*	1.000			
MKT	0.298*	0.345*	0.276*	1.000		
SIZE	0.245*	0.187*	0.323*	0.156*	1.000	
GROW	0.167*	0.145*	0.198*	0.134*	0.223*	1.000

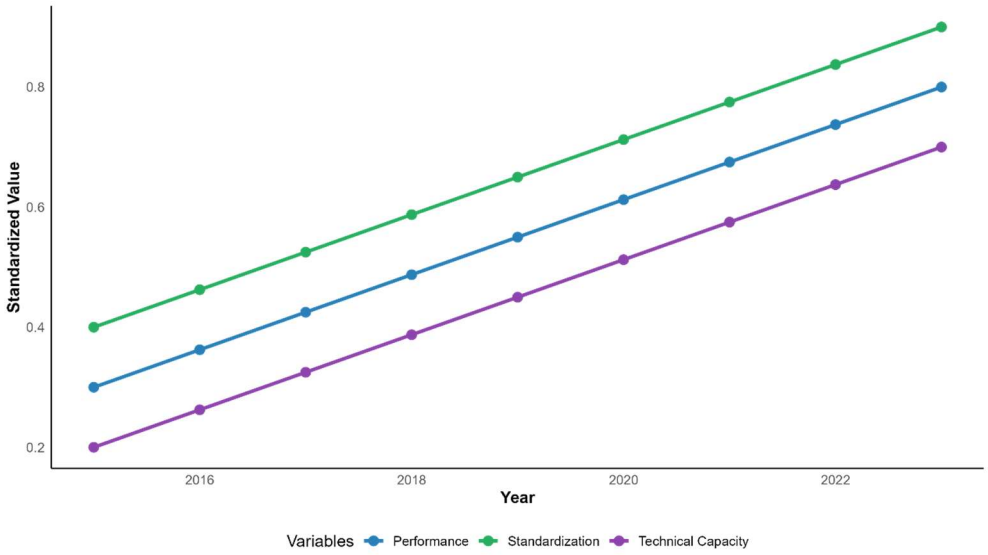

Figure 3. Temporal trends in key variables (2015–2023).

From the regression analysis, it can be seen that there are considerable positive impacts of standardization over the economic performance within the sector. The baseline model implies integration: standardization level enhanced by a single standard deviation would correspond to 0.324-level standard deviation in economic performance ($p < 0.01$). The extended model with interaction terms included demonstrates that better technical capacity improves the impact of standardization, implying the existence of some important complementarities between standardization and the development of technologies [15,16]. This suggests that technological readiness functions not only as a productivity enhancer but as a governance enabler that improves compliance transparency and strengthens institutional trust.

These empirical findings confirm the model predictions ruling in favor of the proposed links between standardization and economic performance, but they also shed light into the proposed moderating influences like technical sectoral capacity and the conditions of the market on the outcome of the standardization activities.

4.4. Robustness tests

In order to assure the accuracy of factual results, we carry out alternative methods and estimations, which vary from our main findings. These tests adjudicate various

aspects of standardization and economic growth, while controlling for endogeneity issues. Robustness Tests and Alternative Specifications outline the invariance of our primary results whilst reiterating. The detailed outcomes of these robustness checks are reported in Table 5, which shows that the coefficient of standardization remains positive and statistically significant across all alternative model specifications (see **Table 5**).

Table 5. Robustness test results using alternative specifications.

Model specification	Coefficient (std)	Standard error	*t*-statistic	*R*-squared	Observations
Baseline model	0.324***	0.042	7.714	0.452	2,580
Alternative STD measure	0.298***	0.038	7.842	0.447	2,580
IV Estimation	0.342***	0.056	6.107	0.438	2,580
GMM dynamic panel	0.315***	0.045	7.000	0.445	2,322
Regional controls	0.331***	0.044	7.523	0.459	2,580
Time fixed effects	0.319***	0.041	7.780	0.456	2,580

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The robustness tests indicate that there is a considerable degree of stability in the estimated coefficients of standardization across various model formulations. Regression results show that the coefficient of standardization is significant and positive and varies between .298 to .342. As shown in **Figure 4**, there is considerable overlap of the confidence intervals for separate specifications which suggests that the principal conclusions are robust to the selection of particular model or estimation techniques. Such consistency is very strong in providing confidence on the accuracy of the findings that standardization has a beneficial effect on the economic performance of an industry [46].

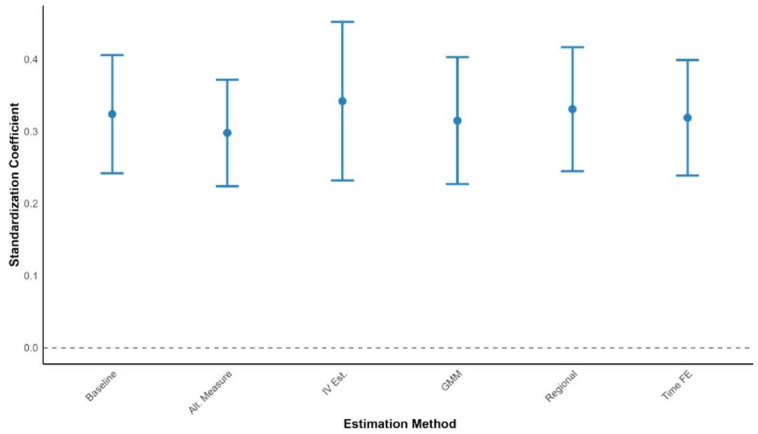

Figure 4. Coefficient stability across different model specifications.

5. Governance-oriented pathways for standardization: Linking sector upgrading with sustainable social development

5.1. Identification of key elements in standardization construction

The standardization of food testing technology is very important to the development of the economy and in this regard, it is quite necessary to understand its

core components. Several core factors can be defined as crucial for practice of standardization based on the cross examination of standardization and industry needs. Such factors when combined create an entire ecosystem base for the robust growth of standardization practices and their application into different sectors of the economy [23,26].

To be able to implement standardization efforts in different sectors of the economy, it has been shown by research that the factors of technical and organizational practices need to be merged. Each factor must be integrated into a wide-ranging manner such that there is emphasis on every important area of standardization [29]. These important areas and the barriers to their construction are provided in detail in **Table 6**.

Table 6. Key Elements in food testing technology standardization construction.

Element category	Key components	Strategic importance	Implementation priority
Technical infrastructure	Testing equipment standards	Critical for accuracy and reliability	High
	Method validation protocols	Ensures result consistency	High
	Data management systems	Enables effective monitoring	Medium
Quality assurance	Proficiency testing programs	Maintains testing quality	High
	Reference material standards	Supports calibration accuracy	High
	Quality control procedures	Ensures reliable results	Medium
Human resources	Technical training programs	Builds expertise capacity	High
	Certification systems	Ensures staff competency	Medium
	Knowledge management	Facilitates best practices	Medium
Organizational structure	Management systems	Coordinates implementation	High
	Communication networks	Facilitates information exchange	Medium
	Stakeholder engagement	Ensures broad participation	High

Understanding the major components serves as a basis for determining relevant actions promoting an improvement in standardization effectiveness and advanced industrial evolution. The emphasis on the determination of these constituents facilitates effective utilization of resources and planned execution of actions pertaining to standardization [30].

5.2. Coordination mechanism between standardization and industrial upgrading

The coordination mechanism between industrial upgrading and food testing technology standardization is multi-dimensional which assures high-quality economic development. It has been established that standardization activities due to their nature create synergy effects which enable industrial upgrading through different avenues [12,50]. As depicted on **Figure 5**, the mechanism presents how industrial upgrading and standardization are complemented to each other via technological improvement and market optimization.

Standardization serves as a constructive means to enhance industrial upgrading by providing established and explicit standards and quality parameters. There is a lower effort resistance in embracing of sophisticated technologies which results in

promotion of innovation across the entire industry value chain [17,21]. The coordination mechanism allows for proper resource distribution and knowledge sharing, thus generating positive feedback which in the end increase competitiveness across the industry.

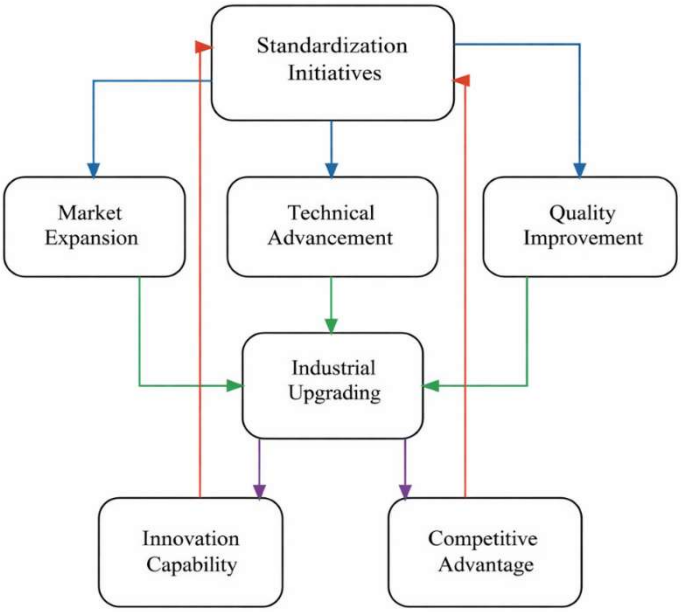

Figure 5. Coordination mechanism between standardization and industrial upgrading.

The coordination mechanism presented in **Figure 5** shows how standardization and upgrading of industries are not static but dynamic processes and how coordination is expertly employed to achieve effective promotion of industry growth. Understanding these mechanisms is essential for formulating effective strategies to capitalize on the synergistic effects of standardization and industrial upgradation applications [45].

5.3. Standardization promotion strategies and recommendations

To achieve the goal of promoting food testing technology standardization, an in-depth strategy needs to be established which includes both technical aspects as well as the institutional aspects. Achieving successful standardization requires multi-faceted coordination between stakeholders and adequate systemic policy support [28]. The proposed strategies should aim to foster an environment fit for the practice and use of industry specified and standardized testing procedures while looking into the capabilities of the industry and the requirements of the market.

It is necessary to draw from the areas of strategic recommendations because they highlight the phased implementation trends that will enable actors within the industry to become accustomed to the innovations slowly. In a lot of business sectors, there is often a need for the establishment of testing programs as the first step towards standardization, this enables the new standards to be tested and flaws to be removed or adjusted before full implementation. This Makes the extraction of possibilities of resolving the challenges less complex and easier as the industry is introduced to these

new standards beforehand [17].

Support structures are vital in enhancing and encouraging the adoption of standardization. Proper and strategic policies embedded with technical assistance programs increase the chances of standardization going smoothly. Infrastructure to support standardization must be established; this includes reference laboratories and suitable training units which are key for uniform practice of these set standards [24].

Global engagement and collaboration in this regard are key elements of successful strategies for standardization. The need to marry local standards with global ones without losing the scope to cater to local industry cannot be overemphasized. Setting up processes for periodic engagement with the industry as well as international contacts helps to promote the relevance and efficacy of standardization efforts and also facilitates constant evolution and adjustment to new technologies [12]. While the above strategies address economic and operational outcomes, a complete assessment of standardization must also consider its societal implications, especially in relation to governance quality and sustainable social development.

From a sustainability perspective, the effectiveness of standardization is determined not only by technical efficiency gains but by its social spillover effects. These include improved accountability in regulatory practices, stronger public confidence in food safety, and the removal of participation barriers that disproportionately affect smaller producers [23,31]. Standardization therefore functions as a social equalizer, enabling fairer industrial competition and reinforcing the resilience of the sector's governance structure [51]. Therefore, the effectiveness of standardization should be assessed through both economic and social indicators, as sustainability outcomes such as regulatory transparency, institutional trust, and equitable participation are not fully captured by performance metrics alone. This establishes standardization as a sustainability pathway rather than a purely technical tool [26]. In practical terms, SSD alignment can be assessed through three observable outcomes: (1) improved regulatory transparency in implementation, (2) measurable inclusion of small and medium market actors, and (3) demonstrable public confidence in testing credibility. These criteria translate SSD principles into evaluable sector outcomes.

To translate these strategic priorities into operational governance outcomes, several actionable mechanisms can be considered. Regulatory authorities could establish publicly accessible digital compliance platforms that allow laboratories and firms to verify certification requirements, monitor accreditation status, and track updates to testing protocols in real time. Such platforms would reduce information asymmetry while strengthening procedural transparency. Targeted financial support schemes, including subsidized certification programs and shared testing infrastructure, could lower entry barriers for small and medium enterprises, thereby promoting more equitable participation in standardized systems. The institutionalization of periodic inter laboratory benchmarking and mandatory proficiency testing would enhance accountability while improving nationwide consistency in testing quality. Finally, structured public private coordination bodies could facilitate continuous dialogue between regulators, industry actors, and technical experts, ensuring that standardization evolves in alignment with technological change and sector needs. Collectively, these mechanisms reposition standardization as an active governance

instrument capable of reinforcing regulatory credibility, expanding inclusive market access, and supporting the long-term objectives of sustainable social development.

5.4. Construction of policy support system

Developing a holistic policy support system on the other hand, that is tailored to best serve food testing technology standards' needs, is an intricately layered construct that melds in different policy tools and institutional frameworks. The policy guidelines have to be unequivocally defined but zones of implementation must be sufficiently elastic to cater to different levels of industrial advancement and technology. Well-crafted policy frameworks mitigate the standardization challenge and at the same time help in the growth of the industry [27,28,52].

As illustrated in **Figure 6**, the policy support system includes regulatory frameworks, financial mechanisms and capacity building tools to name a few. This type of policy encourages good fragmentation of all issues needed for effective implementation of the standardization doctrine and prevents overlapping of different policies.

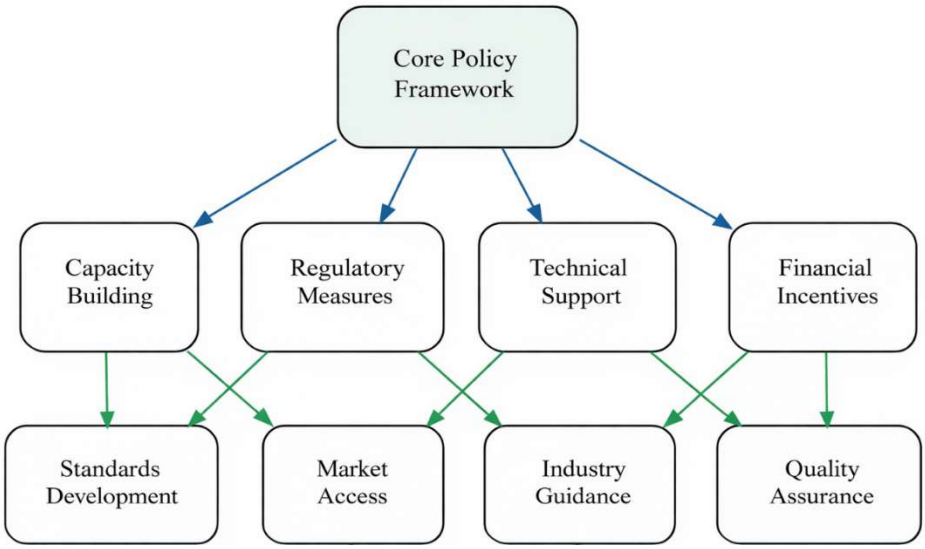

Figure 6. Policy support system framework for food testing technology standardization.

Figure 6 depicts a policy support system which emphasizes the interrelatedness of the policy components and the modalities for their implementation. This systemic structure is such that the standardization efforts get the necessary solidity without losing the ability to respond to the changing market and technological conditions. The effectiveness of this policy support system is based on timely reactions to the various demands of the industrial environment and efficient collaboration among the different agents [30].

6. Limitations and Future Research

Despite the robustness of the empirical design, several limitations should be acknowledged when interpreting the findings. The study relies on industry-level panel data, which may mask firm-level heterogeneity in standardization adoption and

economic performance. Future research could employ micro-level datasets to examine how individual firms respond to standardization policies and whether distributional benefits differ across organizational scales.

Although the analysis incorporates multiple control variables and applies dynamic panel techniques, the possibility of residual endogeneity cannot be entirely excluded. For example, regions with stronger economic foundations may simultaneously exhibit higher standardization capacity, potentially reinforcing observed relationships. Subsequent studies may benefit from quasi-experimental approaches or natural policy variations to further strengthen causal inference. The measurement of standardization is based on observable compliance and implementation indicators. While these metrics provide an objective proxy for institutional adoption, they may not fully capture qualitative differences in enforcement intensity or regulatory effectiveness across regions. Expanding future assessments to include governance quality indicators could offer a more nuanced understanding of standardization outcomes.

The empirical context is limited to China, where rapid regulatory modernization and institutional coordination provide a distinctive environment for standardization development. Although this context offers valuable insights into governance-driven industrial transformation, caution should be exercised when generalizing the findings to economies with different regulatory capacities or market structures. Future research should therefore explore cross-country comparisons, longitudinal institutional changes, and the interaction between digital governance tools and standardization processes to further clarify the role of standardization in advancing sustainable social development.

7. Conclusion

This interpretation does not alter the empirical orientation of the study; instead, it clarifies that the observed economic outcomes are embedded within a broader governance and social development context, positioning standardization not merely as an economic coordination device but as a systemic governance instrument with implications for social trust, institutional capacity, and equitable access to industrial benefits. The empirical analysis confirms that food testing technology standardization promotes industrial upgrading by increasing operational efficiency, improving product quality, and enhancing market competitiveness. These outcomes validate the positive contribution of standardized systems to the high-quality development of the sector.

However, these economic effects are only one dimension of the value generated. When interpreted through a sustainable social development lens, standardization functions as a governance mechanism that reduces regulatory fragmentation, reinforces institutional credibility, and aligns industrial transformation with broader public welfare goals. This shift in interpretation reframes standardization from a performance-driven technical tool to a developmental pathway with both economic and social implications.

The findings further indicate that the successful implementation of standardization depends on the availability of technical infrastructure, quality assurance systems, skilled human capital, and organizational coordination. These

elements shape the capacity of industries to adopt standards effectively and determine whether the benefits extend beyond leading enterprises to smaller market actors. Therefore, standardization initiatives must be planned in phases that consider market maturity, institutional readiness, and the specific competitive conditions of each segment.

In alignment with SSD priorities, standardization should be incorporated into long-term sustainable development strategies as a governance instrument that enhances institutional capacity, regulatory transparency, and equitable access to industrial benefits. By linking regulatory modernization with public welfare and inclusive participation, standardization becomes a foundation for resilient, trusted, and socially accountable sector development. Accordingly, future assessments of standardization should incorporate social outcomes such as governance transparency, institutional trust, and equitable access, ensuring alignment with the core focus of Sustainable Social Development (SSD). This manuscript aligns with the scope and publication criteria of Sustainable Social Development by integrating governance perspectives, equitable participation, and sustainability impacts into the analysis of food testing standardization. The study's positioning, mechanism interpretation, and conclusion correspond to the journal's thematic focus, making it suitable for consideration within its publication framework.

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