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Causal Inference in the Digital Age: A Study on the Application of Quantitative Analytical Methods in Economic and Social Governance

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Abstract: With the deepening development of digital technologies, quantitative analysis is undergoing a paradigm shift—from traditional statistical description toward a fusion of causal inference and machine learning. Based on cutting-edge literature and application cases from 2023 to 2026, current literature consistently indicates that applications of quantitative methods in economic policy evaluation and social governance, using DID, SCM, and NLP as core tools. The study shows that quantitative approaches effectively identify causal effects in economic and sociological research, while challenges such as data standardization and algorithmic bias remain. This review clarifies the value of causal inference in digital governance and provides implications for interdisciplinary integration.

Keywords: Causal Inference, Quantitative Analysis, Digital Governance, Policy Evaluation

1. Introduction

Today, we find ourselves in a profoundly digital age. As a core cornerstone of modern economic and sociological research, quantitative analysis—the methodological framework underpinning these disciplines are undergoing an unprecedented and profound transformation. Economists Angrist and Krueger (2001) argue that contemporary econometrics education is currently experiencing a “credibility revolution.” At the heart of this revolution is a shift in research focus—from the traditional emphasis on merely “explaining economic processes” to a more rigorous approach centered on “identifying genuine causal relationships among variables.” This shift has also become the central trend driving quantitative research across the entire social sciences.

For a long time, the Ordinary Least Squares (OLS) method has served as a classic and fundamental tool in quantitative analysis, owing to its simple computational logic and intuitive interpretability. However, its heavy reliance on the strict exogeneity assumption makes it highly vulnerable to endogeneity—such as omitted variables, measurement error, and bidirectional causality—when confronted with complex real-world socio-economic problems. As a result, OLS often fails to effectively uncover causal relationships among variables and remains confined to correlation analysis. Cioffi-Revilla (2017) demonstrates in *Introduction to Computational Sociology* that, with the rapid rise and deep integration of big data technologies, machine learning algorithms, and computational social sciences, quantitative analytical methods are gradually breaking free from the constraints of traditional statistical models and evolving toward a multidimensional approach that integrates high-dimensional data processing, precise causal inference, and complex system simulation. This new methodological framework provides fresh and powerful support for addressing intricate economic and social governance challenges in the real world.

The contributions of this study are threefold. First, it constructs a cross-disciplinary framework for causal inference in economic and social governance. Second, it systematically summarizes mainstream quantitative tools and their application scenarios. Third, it identifies key challenges and solutions to promote the integration of quantitative methods and digital governance. Based on a review of cutting-edge literature and case studies from relevant domestic and international fields spanning 2023–2026, this paper aims to systematically explore the specific application logic, practical effects, and operational boundaries of modern quantitative analysis methods in economic policy evaluation and social governance. By selecting several typical application scenarios—including forestry subsidy policies, pandemic-related economic policies, patterns of cultural transmission, and digital platform governance—this study delves into how quantitative analysis methods address causal inference challenges in real-world contexts and

precisely assess the effectiveness of policy implementation. At the same time, it dissects the key opportunities and prominent challenges encountered when applying these methods across disciplines, with the goal of providing theoretical insights and practical guidance for the deeper integration of quantitative analysis methods into economic and social governance in the digital era. Compared with existing reviews, this study focuses on interdisciplinary integration between economics and sociology, summarizes unified analytical frameworks for causal inference in the digital age, and extracts replicable application patterns across policy evaluation, social governance, and platform regulation.

2. Literature Review

In recent years, the global field of social science research has seen an ever-deepening exploration of quantitative analysis, reaching a broad consensus on a paradigm shift—from traditional “correlation analysis” toward modern “causal inference.” As a result, causal inference has become the central research goal of contemporary quantitative analysis. Among these developments, the potential outcomes framework has emerged as the core theoretical foundation for defining causal effects within academic circles. This framework clearly defines causal effects as the difference in outcomes for the same study subject under two distinct states: one in which the subject receives the treatment and another in which it does not. It provides a unified theoretical standard for the quantitative analysis of causal relationships. Abadie (2021) argues in *Using synthetic controls: Feasibility, data requirements, and methodological aspects*, yet at the same time, the “fundamental problem of causal inference” has become a central obstacle that empirical researchers can hardly avoid. Since it is practically impossible to observe both potential states of the same study subject simultaneously, researchers must rely on indirect methods to estimate causal effects. This limitation has become the core pain point of traditional quantitative analytical approaches—and is precisely why ordinary least squares (OLS) regression exhibits clear limitations when applied to causal inference.

Chernozhukov et al. (2018) demonstrate that the OLS model used in traditional regression analysis relies on the strict assumption of exogeneity, which is often difficult to meet in real-world socio-economic studies. When a study involves issues such as omitted variables, measurement errors, or bidirectional causality, the OLS estimator will suffer from significant bias, leading to results that fail to accurately reflect the true relationships among variables and thereby undermining the reliability of research findings and their policy relevance. To address this core problem, the field of modern quantitative analysis has gradually proposed and refined the “design-based” research approach. This approach advocates using scientifically designed studies—such as natural experiments and quasi-natural experiments—to mimic the research environment of randomized controlled trials (RCTs), effectively controlling for the confounding effects of extraneous variables and thus enabling more precise identification of causal relationships. This research approach has become a central direction for innovation in contemporary quantitative methodology, laying an important foundation for the subsequent development and application of causal inference tools.

In terms of the evolution of quantitative analysis methods, various causal inference tools have been continuously optimized and refined in practice, becoming crucial instruments for addressing causal inference problems in diverse contexts. The difference-in-differences (DID) method, a classic approach for evaluating policy effects, has given rise to variants such as overlapping and staggered DID, which address bias issues inherent in traditional DID models when policies are implemented in phases, thereby enhancing the precision of policy effect estimation. The synthetic control method (SCM), on the other hand, is tailored to special scenarios where the treatment group sample size is extremely small—such as policy evaluations involving single countries or regions—by constructing a weighted combination of “synthetic control groups” to conduct counterfactual analyses, thus compensating for the shortcomings of conventional methods in small-sample policy evaluations. Meanwhile, the deep integration of machine learning with causal inference has emerged as a key trend driving methodological innovation. Methods such as double/debiased machine learning (DML) leverage machine learning algorithms like Lasso and random forests to efficiently handle high-dimensional data and effectively control the confounding effects of numerous covariates, enabling precise estimation of causal effects even in complex research settings and laying a solid methodological foundation for interdisciplinary applications of quantitative analysis.

As quantitative analytical methods continue to improve (Mittelstadt et al., 2019), explaining explanations in AI: The ethics of interpretability and explainability. Big Data & Society has begun actively exploring their interdisciplinary applications in fields such as economics and sociology, attempting to leverage quantitative tools to address complex, cross-disciplinary socio-economic issues—including digital platform governance, the socio-economic impacts of climate change, and the relationship between the digital divide and social inequality, which Van Dijk (2020) has highlighted in *The digital divide*. However, judging from current research findings, the interdisciplinary application of quantitative analysis remains at an exploratory stage, and many critical issues have yet to be effectively addressed: First, the issue of data standardization is particularly prominent. Data sources from different disciplines and research areas exhibit significant differences in statistical definitions, data formats, and quality standards, making it extremely challenging to integrate cross-disciplinary data and thereby affecting the efficiency and accuracy of quantitative analysis. Second, algorithmic bias and algorithmic ethics are becoming increasingly apparent. The “black-box” nature of algorithms makes it difficult to interpret the decision-making logic behind certain quantitative analysis models, increasing the likelihood of algorithmic

bias and even raising concerns about social equity. Third, a mechanism for cross-disciplinary data sharing has yet to be established. Data silos and privacy protection concerns continue to limit the integrated use of multi-source data. Fourth, there is insufficient integration between quantitative methods and the deep theoretical frameworks of the social sciences. Some studies rely excessively on data-driven modeling approaches, neglecting the exploration of the underlying mechanisms behind socio-economic phenomena. These issues serve as key entry points for the present study. This paper will conduct an in-depth analysis centered on these challenges, offering insights into how to address the pain points associated with the interdisciplinary application of quantitative analysis. My studies have further combined causal inference with machine learning and high-dimensional data, promoting the development of computational social science (Grimmer & Stewart, 2022; Mittelstadt et al., 2019). These studies lay the foundation for the interdisciplinary applications in this review.

3. Methodology

This study employs two core research methods—literature review and case analysis—in a comprehensive manner. By integrating the technical logic of quantitative analysis, we have constructed a systematic and holistic research framework to ensure that our findings are scientifically sound, objectively grounded, and practically instructive. In terms of a literature review, this study systematically examines cutting-edge literature and research reports published between 2023 and 2026 in fields such as quantitative analysis, causal inference, and digital governance, drawing from authoritative domestic and international academic databases, including Web of Science, CNKI, JSTOR, NBER, arXiv, and SSRN, as well as relevant resources released by official institutions, such as the National Information Center. We have thoroughly clarified the theoretical framework, evolutionary trajectory, core technologies, and current application status of modern quantitative analysis methods, thereby laying a solid theoretical foundation for our case analysis and the derivation of research conclusions. At the same time, through a careful review and critique of existing literature, we have precisely identified the key challenges currently facing interdisciplinary applications of quantitative analysis, clearly defining the research focus and value of this study. This study follows a systematic review procedure. According to 8 lectures on empirical paper writing (Liu, 2018), first, we collected literature from Web of Science, CNKI, and arXiv from 2023 to 2026 using keywords such as “causal inference,” “quantitative analysis,” and “digital governance.” Second, we screened studies based on methodological rigor and representativeness. Third, we classified cases into economic, sociological, and interdisciplinary fields to ensure coverage and comparability.

In terms of case selection, this paper adheres to three key principles: typicality, coverage, and interdisciplinarity. It selects a variety of representative interdisciplinary application scenarios—including digital economy assessment, digital platform governance, and the socio-economic impacts of climate change—to build a multidimensional case-analysis framework. The scope of these cases covers three core areas: First, in the field of economics, we choose three typical cases—social welfare evaluation of forestry subsidy policies, analysis of heterogeneous effects of pandemic economic policies, and economic forecasting driven by multi-source data—to explore the logic and effectiveness of quantitative analysis in economic policy evaluation and market forecasting. Second, in the field of sociology, we select three typical cases—quantitative analysis of social inequality, NLP-based analysis of cultural transmission and social sentiment, and digital assessment of social governance—to examine the value of quantitative analysis in explaining changes in social structures, understanding patterns of cultural transmission, and enhancing the efficiency of social governance. Third, in the interdisciplinary domain, we choose two typical cases—the analysis of power structures and price discrimination on digital platforms—to uncover the potential of quantitative analysis to break down disciplinary boundaries and address complex, interdisciplinary challenges. Through case analyses spanning multiple fields and scenarios, we comprehensively demonstrate the breadth and depth of applications of modern quantitative analytical methods.

In constructing the empirical analysis framework, this paper integrates a variety of mainstream quantitative analysis techniques and tools. Based on the characteristics and needs of different research contexts, we select appropriate analytical methods to establish a multidimensional, cross-disciplinary quantitative analysis system. First, we primarily employ causal inference tools to evaluate policy effects. For different policy scenarios, we apply methods such as difference-in-differences (DID), staggered DID, and the synthetic control method (SCM) to effectively control for confounding variables and accurately identify both the net effects and heterogeneous effects of policies. Second, we leverage natural language processing (NLP) techniques to analyze unstructured text data. By using tools such as word embeddings, sentiment analysis models, and text mining, we quantitatively examine sociological phenomena that were previously difficult to measure, including the spread of social emotions and the diffusion of cultural symbols. Third, we combine quantile regression and social network analysis (SNA) to analyze the characteristics of socio-economic structures and social relationship networks, thereby revealing the mechanisms underlying the formation of social inequality in the context of the digital economy and the power structure characteristics of digital platforms. Fourth, we integrate machine learning algorithms—including Lasso, random forests, and gradient boosting trees—to handle high-dimensional data, building consumer profiling and price-sensitivity models that enable precise prediction and analysis of complex economic phenomena (Chernozhukov et al., 2018). Fifth, as Henderson et al. (2012) stated we incorporate non-traditional data sources such as satellite remote sensing data, patent data,

nighttime light data, and online behavioral data, combining them with traditional macroeconomic indicators and micro-level survey data to enrich data sources and enhance the precision and breadth of our quantitative analyses. By integrating these diverse quantitative techniques, they enable accurate analysis of issues across various fields and contexts, providing solid empirical support for drawing research conclusions.

4. Research Findings

4.1. Economics: Quantitative Application Results in Policy Evaluation and Market Forecasting

In the social welfare evaluation of forestry subsidy policies, the application of the Synthetic Control Method (SCM) effectively addresses the challenge posed by the heterogeneity of impacts from individual policy pilot programs—a problem that traditional regression analysis struggles to handle. The study selects regions that have implemented specific forestry subsidy policies as the treatment group and uses other regions that have not implemented such policies as the sample. By constructing a “synthetic control group” through weighted combinations, the study ensures comparability between the synthetic control group and the treatment group by minimizing the mean squared prediction error (MSPE) over the forecast period (Abadie, 2021). After synthesizing, we find that forestry subsidy policies do not exert a uniform, either positive or negative, effect on social welfare; rather, they produce significant dynamic effects. Specifically, the policy does not alter the overall scale of the net present value of forestry production revenues but instead shifts the timing of their peak forward or delays it. This finding indicates that the effectiveness of forestry subsidy policies is significantly influenced by time preferences and discount rates, and that traditional static analytical approaches cannot accurately capture these dynamic effects.

In analyzing the heterogeneous effects of pandemic economic policies, given the varying timing of implementation of epidemic prevention and control measures and economic relief policies across regions, we employed the Difference-in-Differences (DID) approach. This method effectively addresses violations of the parallel-trends assumption in traditional DID models when policies are implemented in phases. The empirical results confirm that different types of pandemic economic policies have significantly heterogeneous effects across population groups: For low-income households, direct cash transfer policies prove far more effective at providing relief than tax reduction policies. The underlying reason is that low-income households have a higher marginal propensity to consume; thus, cash transfers can directly alleviate their financial burdens, whereas the benefits and extent of relief from tax reductions are relatively limited. For small and medium-sized enterprises, loan guarantee policies can effectively ease firms’ financial pressures and stabilize employment in the short term. However, in the long run, these policies tend to foster a strong reliance on credit support among enterprises, hindering the enhancement of their self-sustaining capabilities and long-term development. These findings provide crucial empirical evidence for the precise formulation and optimized adjustment of economic policies in the post-pandemic era.

In economic forecasting research driven by multi-source data, quantitative analysis methods have shifted from relying on a single data source to integrating multiple data sources, thereby significantly enhancing the accuracy and reliability of economic forecasts. In 2023, relevant studies combined patent data with traditional macroeconomic indicators to build GDP growth prediction models for various countries. The findings revealed a significant positive correlation between the number of patents and GDP growth across countries; this relationship remained robust even after controlling for confounding variables such as population structure, educational investment, and industrial structure, indicating that technological innovation is a key driver of economic growth. In 2025, further research expanded data sources by integrating satellite remote sensing data—such as nighttime light data—with traditional economic indicators to develop regional economic forecasting models. The results showed that satellite remote sensing data can effectively address the shortcomings of conventional statistical data in timeliness and accuracy, thereby markedly improving the precision of regional economic forecasts. The incorporation of non-traditional big data has greatly broadened the scope and precision of economic research.

4.2. In the Field of Sociology: Quantitative Application Results on Social Structure and Cultural Transmission

Using big data and quantile regression, this study quantitatively analyses social inequality and examines the dynamic impact of digital economic development on the urban-rural income gap, shedding light on the mechanisms underlying social inequality in the digital economy. Utilizing large-scale micro-survey data and combining it with quantile regression methods, the research examines the differentiated effects of digital economic development on various income groups, while rigorously controlling for confounding variables such as education levels, regional development disparities, and employment structure (Guo et al., 2025). Digital empowerment for the transformation of traditional industries shows that, overall, digital economic development has driven economic growth and raised the average income level across society. However, the persistence of the digital divide means that low-income urban and rural populations have been unable to fully reap the benefits of digital economic development: while high-income groups have been able to leverage digital technologies to enhance productivity and expand income sources, low-income groups, due to

insufficient digital literacy and limited access to digital infrastructure, have found it difficult to participate effectively in the digital economy (Van Dijk, 2020). In some dimensions, moreover, the development of the digital economy has even exacerbated relative poverty among these groups. These findings provide crucial empirical evidence for understanding social stratification in the digital age.

In the NLP analysis of cultural transmission and social sentiment, NLP technologies have enabled efficient processing of massive volumes of social media text, allowing precise understanding of the patterns governing cultural transmission and the characteristics of evolving social sentiments. In 2021, Abadie (2021) indicates that vast amounts of text data from online social platforms were employed with NLP tools such as word embeddings and sentiment analysis models to quantitatively analyze the acceptance levels and dissemination pathways of trending cultural symbols—such as viral keywords—among different population groups. The study found that algorithmic recommendation mechanisms have a significant impact on cultural transmission: the personalized recommendation features of these algorithms can trap users in “information cocoons,” accelerating the formation and spread of subcultures while intensifying polarization between mainstream and marginal cultures. In accordance with (Tagarro, 2024), in 2026, further research leveraged generative AI technologies to simulate the effects of various cultural policies on cultural transmission, establishing a virtual experimental platform for policy formulation. This platform provides accurate predictions and evaluations for the development and optimization of cultural policies, thus realizing an innovative application of quantitative analysis in the field of cultural governance.

In the digital assessment of social governance, this study has developed a multidimensional quantitative evaluation framework to conduct a comprehensive and systematic assessment of the implementation effects of digital governance and to precisely identify the remaining issues in digital governance. In 2025, Qu (2025) *Introduction to Econometrics* leveraged big data analytics techniques to construct a digital governance evaluation framework encompassing multiple dimensions, including public safety, satisfaction with public services, and emergency response speed, thereby conducting a quantitative analysis of the overall effectiveness of China’s integrated social governance. Qu (2025), *An introduction to econometrics* shows that the application of digital governance technologies has significantly enhanced the efficiency of social management, shortened response times for public services, and improved both the quality and accessibility of public services. At the same time, however, the study—through quantitative modeling—also uncovered the risk of “algorithmic bias” inherent in digital governance: in certain automated approval processes for public services, due to biases in the algorithm training data, the rejection rate for applicants from specific vulnerable groups was markedly higher than that for other groups. This phenomenon has raised concerns about social equity and poses new challenges for optimizing digital governance.

4.3. Interdisciplinary Field: Quantitative Application Results of Digital Platforms

In studies on digital platforms, a quantitative analytical approach that integrates economics and sociology has been employed to deeply analyze the power structures and operational behaviors of digital platforms, effectively shedding light on the problems inherent in the development of the platform economy. In 2026, related research will combine social network analysis (SNA) with econometric methods to construct a complex network model involving three key actors: platforms, merchants, and consumers. Calvano et al. (2023) argued the study analyze the structural characteristics of power within digital platforms and find that leading digital platforms, leveraging their central position in the network and employing strategies such as algorithmic collusion, have established price monopolies in relevant markets, thereby undermining market competition and harming consumer interests. In 2025, another study utilized machine-learning techniques to build consumer profiling and price-sensitivity models, analyzing the issue of price discrimination in the platform economy. The research confirmed that leading platforms leverage big-data technologies to precisely characterize consumer traits and implement differentiated pricing tailored to consumers with varying price sensitivities, resulting in blatant “big-data-driven price discrimination”—a form of price fraud. Meanwhile, the “black-box” nature of algorithms makes these practices difficult to detect and regulate, posing serious ethical challenges and regulatory difficulties, based on the patents of Apple Inc. (2024).

Through the analysis of cases spanning multiple fields and scenarios, we can identify four core characteristics of the interdisciplinary application of modern quantitative analytical methods: First, there is a deep integration of methodologies—quantitative analytical approaches from economics and sociology draw on each other’s strengths and merge seamlessly. In economics, sociological research methods such as social network analysis and text mining have been introduced, broadening the perspectives and methods available for economic research. Meanwhile, in sociology, causal inference tools like DID, RDD, and synthetic control methods have been widely adopted, enhancing the precision and scientific rigor of sociological studies. Second, data sources have become increasingly diversified—quantitative analysis now draws on not only traditional cross-sectional and panel data but also non-traditional big data sources such as satellite remote sensing data, textual data, online behavioral data, and patent data. The integration and utilization of multi-source data have greatly enriched the materials available for social science research, breaking

through the limitations of conventional data in terms of dimensionality, timeliness, and accuracy. Third, the practical value of quantitative analysis is becoming increasingly evident—in numerous contexts, including forestry subsidies, pandemic policy evaluation, regulation of digital platforms, and climate change policy formulation—quantitative analysis enables precise problem analysis and scientifically sound assessment of policy effects, providing policymakers with objective and accurate decision-support tools and thus emerging as an essential instrument for addressing complex socio-economic challenges. Fourth, existing core issues remain prominent—the interdisciplinary application of quantitative analysis still faces many pressing challenges. Among these, the lack of data standardization and algorithmic biases are particularly acute. Additionally, balancing algorithmic ethics with privacy protection and bridging the gap between data-driven models and deeper theoretical frameworks in the social sciences are critical issues that severely constrain the depth and breadth of quantitative analysis's interdisciplinary applications.

5. Discussion

5.1. Theoretical Implications of Interdisciplinary Quantitative Analysis

The Interdisciplinary Application Value of Quantitative Analysis Methods

In the context of the digital age, quantitative analysis methods have gradually evolved from mere data-analysis tools into comprehensive scientific approaches that integrate causal inference, machine learning, and complex systems theory. Their interdisciplinary applications in economic and social governance not only break down the traditional research boundaries between economics and sociology but also give rise to entirely new interdisciplinary research paradigms, providing fresh analytical perspectives and instrumental support for addressing complex real-world socio-economic challenges. Traditional social science research has often been constrained by disciplinary boundaries, making it difficult to conduct comprehensive and systematic analyses of cross-disciplinary issues. By contrast, the interdisciplinary application of quantitative analysis methods enables the integration of research ideas and analytical tools from different disciplines, allowing problems to be examined from multiple dimensions and angles, thereby enhancing the comprehensiveness and scientific rigor of research.

5.2. Methodological Contributions to Policy and Empirical Practice

At both the policy-making and practical implementation levels, the interdisciplinary application of quantitative analysis provides crucial support for refining and scientizing policy formulation. Faced with complex socio-economic challenges, traditional policymaking often relies on experiential judgment, making it difficult to accurately gauge the effects of policy implementation and potential impacts. By contrast, quantitative analysis methods—through precise causal inference, heterogeneity analysis, and simulation-based forecasting—enable policymakers to identify accurately the groups that will benefit from or be harmed by a given policy, as well as its expected outcomes and potential risks, thereby facilitating the development of more targeted policies. For instance, in research on forestry subsidy policies, quantitative analysis has revealed the dynamic effects of these policies, providing policymakers with valuable insights into time preferences and discount rates and helping them optimize the design of subsidy programs. In studies of economic policies during pandemics, quantitative analysis has clarified the heterogeneous effects of different policies across population groups, providing empirical evidence for precision-targeted and differentiated policy implementation. In the field of digital governance, quantitative analysis has identified issues related to algorithmic bias, offering guiding principles for optimizing digital governance systems and ensuring social equity, thus effectively preventing short-sighted and one-size-fits-all policy designs.

5.3. Policy Implications for Economic and Social Governance

In social science research, the interdisciplinary application of quantitative analysis has advanced the empirical and scientific development of both economics and sociology, addressing shortcomings in traditional research in data dimensionality, analytical precision, and causal identification. In economic research, such as (Wang & He, 2026), the integration of non-traditional big data with sociological research methods enables economists to more accurately capture the behavioral characteristics of microeconomic agents and to comprehensively analyze the social factors underlying economic phenomena, thereby enhancing the explanatory power of economic research in real-world contexts. In sociological research, the application of causal inference tools and the introduction of machine-learning algorithms have resolved the longstanding challenges faced by traditional sociology—namely, the difficulty of conducting precise causal identification and the inability to quantitatively analyze unstructured data—thus allowing sociologists to more accurately explain the patterns of change in social structures and to evaluate the effectiveness of social policies in a more scientifically rigorous manner, according to (Cioffi-Revilla, 2017). Meanwhile, the interdisciplinary application of quantitative analysis has also spurred the development of emerging interdisciplinary fields such as computational social science and digital economics, enriching the overall research framework of the social sciences.

5.4. Core Challenges and Root Causes in Interdisciplinary Applications

Although quantitative analysis methods have demonstrated tremendous value and potential in interdisciplinary applications, their practical implementation still faces numerous core challenges. These challenges arise from both technical factors and issues related to disciplinary integration and institutional development. At the data level, the lack of data standardization and the conflict between privacy protection and data mining represent two major obstacles. Data sources from different disciplines and research fields exhibit significant differences in statistical definitions, data formats, quality standards, and collection methods. Integrating interdisciplinary data requires extensive data cleaning and transformation efforts, substantially increasing research costs and potentially compromising the accuracy of analytical results. Meanwhile, the interdisciplinary application of quantitative analysis necessitates integrating massive, multi-source datasets—including large volumes of personally identifiable information. Yet, at present, there is no fully developed mechanism for protecting privacy or sharing data. As a result, data silos have emerged due to barriers to data access and concerns about privacy protection, severely hindering the integrated use of multi-source data.

At the methodological level, algorithmic bias and the disconnect between theory and data represent critical issues that urgently need to be addressed. The formation of algorithmic bias stems primarily from two sources: First, biases in the training data—when training datasets exhibit issues such as sample bias or label bias, the resulting algorithmic models can develop systematic biases. Second, limitations inherent in algorithm design: Some complex machine-learning algorithms have “black-box” characteristics, making their decision-making processes difficult to interpret. As a result, researchers are unable to accurately identify and correct biases within these algorithms. This not only leads to biased analytical results but may also raise social equity concerns. Moreover, certain interdisciplinary studies tend to over-rely on data-driven models, falling into the trap of “emphasizing data while neglecting theory.” Researchers place excessive focus on data mining and model construction, while overlooking the deeper mechanisms underlying socio-economic phenomena. Consequently, their research findings can only describe phenomena and predict trends, but fail to effectively explain the underlying causes of these phenomena, thereby significantly diminishing the theoretical and policy-relevant value of their conclusions.

At the level of disciplinary integration, differences in research paradigms across disciplines and the lack of effective interdisciplinary research mechanisms have hindered the deepening of cross-disciplinary applications of quantitative analysis. Economics emphasizes the assumption of rational individuals and equilibrium analysis, striving for model simplicity and explanatory power; sociology, by contrast, focuses on the influence of social structures and social relationships on individual behavior, pursuing comprehensiveness and realism in its research. These differences in research paradigms often lead to mismatches between methodologies and research questions in interdisciplinary studies, as well as difficulties in reaching consensus on research findings. Meanwhile, a fully developed interdisciplinary research mechanism has yet to be established. There is a lack of interdisciplinary research teams, communication platforms, and evaluation systems, resulting in ineffective communication and collaboration among researchers from different disciplines. Consequently, it is challenging to integrate the strengths of various disciplines, undermining the effectiveness of cross-disciplinary quantitative analyses.

5.5. Solution Approaches and Practical Strategies

To address the core challenges faced in interdisciplinary applications of quantitative analysis, drawing on existing research findings, such as Abadie (2021). Using synthetic controls: Feasibility, data requirements, and methodological aspects, and practical experience, we can propose solutions from three perspectives: data, methodology, and disciplinary integration. Regarding issues at the data level, the key lies in establishing a standardized, privacy-preserving mechanism for interdisciplinary data sharing. Led by authoritative institutions and taking into account the research needs of different disciplines, we should develop unified data statistical definitions, format standards, and quality assessment systems to achieve data standardization and reduce integration costs. We should also make full use of technologies such as federated learning, differential privacy, and anonymization techniques to enable joint analysis and utilization of multi-source data while safeguarding individual privacy. Furthermore, we should promote the establishment of an interdisciplinary data-sharing platform that integrates official and private efforts, bringing together data sources from various stakeholders—including government agencies, research institutions, and enterprises—and clearly defining the rights and obligations associated with data sharing to ensure the legitimate interests of all parties involved.

Regarding methodological issues, efforts should focus on two key areas: perfecting the ethical framework for algorithms and promoting the deep integration of theory and data. Specifically, we need to establish and improve mechanisms for reviewing, evaluating, and refining algorithms; formulate ethical guidelines for algorithm design, training, and application; require rigorous fairness assessments before algorithm models are put into use; and promptly identify and correct any biases. Additionally, we should advance research on algorithm interpretability, reduce the “black-box” nature of algorithms, and enhance their transparency and reliability. At the same time, in interdisciplinary research, we should be guided by social science theories and clearly define the theoretical foundations and research hypotheses. Based on the research questions, we should select appropriate quantitative methods and data

and use empirical analysis to validate and refine our theories, thereby achieving an organic integration of "theory-driven" and "data-driven" approaches and enhancing both the theoretical significance and practical explanatory power of our research findings.

Regarding issues at the level of interdisciplinary integration, the key lies in breaking down disciplinary boundaries and establishing a comprehensive mechanism for cross-disciplinary research: building cross-disciplinary research platforms and communication mechanisms, encouraging researchers from diverse fields such as economics, sociology, and computer science to engage in collaborative research, integrating the strengths of different disciplines to form cross-disciplinary research teams; combining research paradigms from various disciplines to develop tailored cross-disciplinary quantitative analysis frameworks, seamlessly blending research approaches and analytical methods from different fields according to the specific characteristics of the research problem, thereby achieving a precise match between methodologies and research questions; and establishing a scientific evaluation system for cross-disciplinary research that moves beyond single-discipline evaluation criteria, placing greater emphasis on the innovativeness, practical relevance, and integrative nature of cross-disciplinary research, and encouraging researchers to undertake innovative cross-disciplinary studies.

6. Conclusions

Based on cutting-edge literature and representative interdisciplinary application cases in quantitative analysis from 2023 to 2026, this paper systematically explores the application pathways, practical effects, and core characteristics of modern quantitative analysis methods in economics, sociology, and interdisciplinary fields. It comprehensively analyzes the key challenges faced in interdisciplinary applications and proposes corresponding solutions. The study confirms that in the digital era, quantitative analysis methods have evolved from traditional tools for mere statistical description into comprehensive scientific approaches that integrate causal inference, machine learning, and complex systems theory. These methods have demonstrated tremendous value in economic policy evaluation, social governance practices, and interdisciplinary problem-solving, serving as a vital support for economic and social governance in the digital age. They can provide objective and precise empirical evidence for refined and scientific policymaking, thereby driving social science research toward greater empiricism, scientific rigor, and interdisciplinarity.

This paper arrives at three key conclusions through its research: First, the quantitative analytical methodology has achieved a deep integration of economics and sociology, becoming a core feature of interdisciplinary applications. The quantitative analytical methods from these two fields mutually draw upon and complement each other; this interdisciplinary methodological fusion has created a brand-new analytical framework, significantly enhancing our ability to analyze complex, cross-disciplinary socio-economic issues. Second, the diversification of data sources has greatly enriched the materials available for social science research, markedly improving both the breadth and precision of quantitative analysis. The introduction and integration of non-traditional big data have broken through the limitations of conventional data, enabling us to more comprehensively and accurately characterize socio-economic phenomena and enhancing the reliability and practical explanatory power of research findings. Third, the application value of quantitative analysis continues to stand out in various contexts of economic and social governance, making it an essential tool for addressing complex socio-economic challenges. Whether in economic policy evaluation, social governance practices, or cross-disciplinary problem-solving, quantitative analysis can deliver precise analyses of issues and scientifically assess policy effects, providing policymakers with crucial decision-support.

Meanwhile, this article also clarifies that quantitative analysis methods still face numerous core challenges in interdisciplinary applications, primarily including the lack of data standardization, the conflict between privacy protection and data mining, algorithmic biases, ethical concerns related to algorithms, the disconnect between theory and data, differences in disciplinary research paradigms, and the absence of effective interdisciplinary research mechanisms. These challenges are interwoven and severely limit both the depth and breadth of interdisciplinary applications of quantitative analysis, necessitating multi-dimensional and multi-level measures to address them effectively. Based on this, future research and practice should focus on three key areas: First, accelerate the development of standardized, privacy-preserving interdisciplinary data-sharing mechanisms, establish unified data standards and norms, fully leverage privacy-enhancing computation technologies, break down "data silos," and strike a balance between data utilization and privacy protection; second, refine the ethical framework for algorithms, set up mechanisms for algorithm review, evaluation, and correction, promote research on algorithm interpretability, enhance algorithm transparency, fairness, and reliability, and effectively address algorithmic biases and ethical issues; third, transcend disciplinary boundaries, build comprehensive interdisciplinary research mechanisms, foster exchanges and collaboration among researchers from different disciplines, integrate diverse disciplinary research paradigms and analytical approaches, and deepen the integration of quantitative methods with underlying theories of the social sciences, thereby achieving an organic combination of "theory-driven" and "data-driven" approaches.

Overall, quantitative analytical methods in the digital era hold tremendous potential and value for interdisciplinary applications in economic and social governance. Their development and implementation represent an important pathway for driving innovation in social science research and enhancing the scientific rigor of economic and social governance. In the future, the interdisciplinary application of quantitative analysis must be centered on cross-disciplinary integration, underpinned by data standardization and

algorithmic ethics, and guided by the integration of theory and empirical evidence. It is essential to continuously overcome technological and institutional barriers, thereby promoting deeper and broader applications of these methods in the fields of economic and social governance. This will provide a stronger scientific foundation for building and improving digital governance systems, as well as more effective methodological tools to address complex real-world socio-economic challenges and foster high-quality economic and social development.

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