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A Systematic Literature Review on Trigonometric Ratio-Product Estimators of Population Mean under Multiple Imputation Technique.

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Abstract

Missing data remain a persistent challenge in survey sampling and demographic studies because they can reduce precision and introduce bias into estimates of population parameters. Multiple Imputation (MI) has emerged as one of the most effective approaches for handling missing observations by replacing each missing value with multiple plausible values and combining the resulting estimates to account for imputation uncertainty. Simultaneously, ratio-type estimators that incorporate auxiliary information have been widely developed to improve the efficiency of population mean estimation. Among these, trigonometric ratio estimators, which utilise trigonometric functions such as sine, cosine, and tangent transformations, have attracted increasing attention due to their ability to reduce bias and mean squared error under various sampling conditions. This systematic literature review synthesises existing studies on trigonometric ratio estimators of the population mean and their application within multiple imputation frameworks. The review examines theoretical developments, methodological advancements, efficiency comparisons, and empirical applications reported in the literature. Evidence from the reviewed studies indicates that trigonometric ratio estimators generally outperform conventional estimators such as the sample mean, ratio estimator, and regression estimator when strong correlations exist between study and auxiliary variables. Similarly, multiple imputation methods consistently provide more reliable estimates than complete-case analysis and single imputation techniques by preserving variability and reducing estimation bias. The review concludes that combining trigonometric estimation approaches with multiple imputation techniques offers significant potential for improving the accuracy and efficiency of population mean estimation and provides a promising direction for future methodological research in survey sampling.

Keywords: Multiple Imputation, Ratio-type Estimators, Population Mean, Bias, Mean Squared Error.

1. Introduction

Estimation of population parameters has remained one of the fundamental objectives of sample survey theory. Government agencies, International organizations, Health institutions and researchers rely on sample surveys to generate reliable estimates for policy formulation, planning and monitoring of socioeconomic and health indicators. Among the various population parameters, the population mean is one of the most frequently estimated because it summarises the central tendency of quantitative variables such as household income, maternal age, etc. The quality of these estimates influences evidence-based decision-making.

In survey sampling, auxiliary information has long been recognised as an effective means of improving the precision of estimators. Auxiliary variables are variables whose population characteristics are known or can be estimated with high precision and are correlated with the study variable. When an auxiliary variable exhibits strong positive correlation with the study variable, ratio estimators generally outperform the conventional sample mean estimator. Conversely, product estimators are more efficient when the correlation between the study and auxiliary variables is negative. These developments have significantly enriched sampling theory and demonstrated that efficient utilisation of auxiliary information can improve estimation accuracy.

Researchers have developed ratio-cum-product estimators, exponential estimators, logarithmic estimators, regression estimators, calibration estimators and generalised classes of estimators designed to achieve lower mean squared error under different sampling conditions. Ratio-cum-product estimators are particularly attractive because they combine the strengths of ratio and product estimation and are capable of exploiting multiple forms of auxiliary information simultaneously. Theoretical studies have shown that these hybrid estimators frequently dominate traditional ratio or product estimators under suitable correlation structures and sampling designs.

More recently, trigonometric transformations have emerged as an innovative direction in survey sampling estimation. Trigonometric estimators employ mathematical functions such as sine, cosine and tangent to transform auxiliary variables before incorporating them into estimation procedures. These nonlinear transformations are intended to capture complex relationships between study and auxiliary variables that may not be represented by conventional linear ratio or product forms. Nevertheless, the majority of existing trigonometric estimators have been developed under complete-response assumptions and have rarely been examined in the presence of missing survey data.

Missing data constitute one of the most significant challenges in modern sample surveys. In almost every large-scale household survey, some sampled units fail to provide complete information because of non-response, refusal, recall problems, interviewer errors, recording mistakes or data processing failures. Missing observations reduce the effective sample size, decrease statistical power and may introduce substantial bias when ignored or handled inappropriately. Statistical literature

classifies missing data mechanisms into three major categories: Missing Completely at Random (MCAR), Missing at Random (MAR) and Missing Not at Random (MNAR). Since the validity of statistical inference depends heavily on the underlying missing-data mechanism, selecting an appropriate method for handling missing observations has become an important aspect of survey methodology.

Simple approaches such as listwise deletion, pairwise deletion, mean substitution and single imputation were commonly adopted because of their computational simplicity. However, these methods often underestimate variability, distort relationships among variables and produce biased parameter estimates, particularly when the proportion of missing data is substantial. To overcome these limitations, multiple imputation has become one of the most widely recommended approaches for handling incomplete survey data. Multiple imputation replaces each missing value with several plausible values generated from an appropriate predictive distribution, thereby producing multiple complete datasets. Statistical analyses are then performed separately on each completed dataset, and the results are combined using Rubin's combining rules to obtain overall parameter estimates and associated measures of uncertainty. This approach appropriately reflects both within-imputation and between-imputation variability, resulting in statistically valid inference under the MAR assumption. Existing studies that combine imputation with ratio or product estimation have largely focused on conventional ratio estimators, exponential estimators or generalised imputation estimators, with relatively little attention devoted to nonlinear trigonometric ratio–product estimators.

The integration of multiple imputation into finite population estimation remains an interesting area of research. However, most of these developments are confined to simple random sampling or two-phase sampling designs and rarely investigate the interaction between advanced nonlinear estimators and multiple imputation procedures. Furthermore, many proposed estimators are evaluated using simulated datasets rather than nationally representative health survey data, limiting their practical applicability.

2. Methods

This study adopted the method recommended by Haddaway et al. (2022), Liberati *et al*. (2009) and Lichtenstein *et al*. (2008) in implementing this review. Accordingly, Figure 1 showcases the review procedures involved in achieving the research questions; these procedures are in four (4) phases, which are as follows: research questions, search design, study selection, and data synthesis. In the first phase, we formulated a couple of research questions in line with the study aim. In the second phase, we designed the search strategy in accordance with the research questions; this phase also involves the search terms and the strategies used in selecting the resources (i.e. literature). In the third phase, the review focused on data extraction and resource consideration in line with the quality measures/assessment criteria. Finally, in the fourth phase, we focused on the data synthesis involving final study selection for inclusion.

2.1. Research Questions

The Systematic Literature Review (SLR) is aimed at understanding and summarising empirical facts regarding Trigonometric Ratio Product (TRP) estimators of population mean under the Multiple Imputation technique, the theory behind the framework and identifying possible research gaps for research opportunities. To accomplish this aim, research questions (RQs) have been formulated;

i. How can TRP estimators based on auxiliary information be developed under the MI technique?
ii. Under what conditions do the proposed TRP estimators perform better than existing estimators?
iii. Can the integration of MI and TRP estimators provide a robust approach for estimating the population mean in large-scale surveys with missing observations?

These formulated RQs are used in forming the foundation for the study and were examined.

2.2. Research Design

The search design, as shown in Figure 1, involved the search terms, resources (i.e. literature), and search procedure. Finally, identified literature was then retrieved and imported into the Rayyan software for additional screening (Ouzzani, 2016).

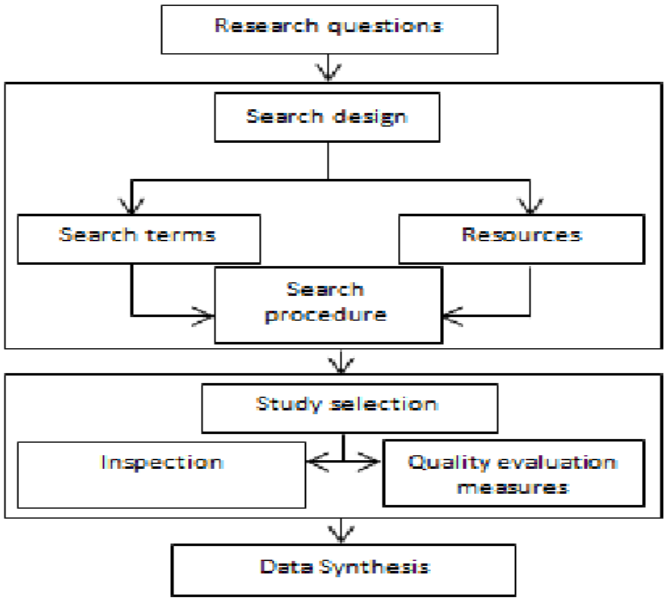

Figure 1. Algorithm for the stages of the review procedure (Azihaiwe-Justin, 2025).

2.2.1. Search Queries

The search terms were developed using guidelines which involves the following:

i. What studies have applied MI in survey sampling?
ii. What ratio and ratio-product estimators have been developed for estimating population means?

iii. What trigonometric estimators have been proposed in sampling theory?

2.2.2. Database Records

In this study, we employed secondary data which are literature identified and sourced using search queries. Accordingly, resources were sourced from the following databases, namely PubMed, Google Scholar and other sources. Also, the title and abstract were key components that these databases used to conduct the search for peer-reviewed journals, book chapters, proceedings and workshops.

2.3. Study Selection

As earlier mentioned, SLR involves a broad search of relevant literature from vital sources concerning the subject matter. Nevertheless, the search procedures adopted in this study include some steps (see Figure 2). As listed in Section 2.2.2, three electronic literature databases were used as sources for this search; a full and exhaustive search was conducted on these databases, and the retrieved results (i.e. literature) were collected as potential resources. We equally conducted another search in line with RQs by going through the reference sections of each prospective study obtained earlier and found additional records that were relevant to records collected initially.

2.3.1. Inspection

1261 potential studies were collected. It was considered necessary to further streamline the collated studies into important ones according to the study aim, RQs, and assessment criteria. We first considered the "title", and subsequently, the full "content" of these studies was concisely reviewed. Thus, the study excluded all papers that were unable to address one or more of the RQs, and also that couldn't reflect the aim of this study. Furthermore, we only considered resources that were written/or translated and published in the English language for inclusion in the Rayyan software, where we collated the relevant studies. The published materials are from only journals that are peer-reviewed, books, conference proceedings and workshops. Duplicate studies appeared the most across the respective databases, but only the most recent and complete one was included in the study for further scrutiny. We explicitly performed an SLR for MI representations on studies published between 2020 and 2025; thus, the eligibility and screening criteria.

Records identified through database searching

(n = 1261)

⇓

Duplicates removed

(n = 685)

⇓

Records screened

(n = 576)

⇓

Records excluded

(n = 370)

⇓

Full-text articles assessed
(n = 206)
⇓
Full-text articles excluded
(n = 189)
⇓
Studies included in review
(n = 17)

Figure 2. The PRISMA-compliant study selection diagram.

2.3.2. Inclusion and Exclusion Criteria

Inclusion Criteria

a. Published in peer-reviewed journals.
b. Focus on multiple imputation.
c. Published between selected years (e.g., 2020–2025).

Exclusion Criteria

a. Editorials.
b. Books.
c. Incomplete studies.
d. Irrelevant methodologies.

2.4. Data Synthesis

Data synthesis in SLR seeks to evaluate and summarise facts/proofs in connection to the selected studies so as to provide a valid response to the RQs. In synthesising the data, the 17 chosen studies, in line with our formulated RQs, have been further perused so as to evaluate each study's content in detail. For better results and to improve precision, we have properly synchronised the selected studies, which is the aim of this review. The data obtained from this study consist of both qualitative and quantitative data.

Table 1. Selected Reviewed Literatures

S/N	Title	Authors Name	Year	Study Objectives	Findings
1	A Multiple Imputation Method for High –Dimensional Neuroimaging Data.	Tong	2025	The researcher proposed a novel approach, High-dimensional Multiple Imputation (HIMA), based on Bayesian models specifically designed for large-scale neuroimaging datasets.	HIMA also demonstrates improved precision and stability of imputed data.
2	New Adjusted Missing Value Imputation in Multiple Regres-	Juthapom and Saichon	2025	They compared the efficiency of several adjusted missing value imputation methods in multiple regres-	For both SRS and RSS, AR-MCRQ1 was the best method for missing value

	sion with Simple Random Sampling and Rank Set Sampling Methods			sion analysis, using four imputation methods: regression-ratio quartile1,3 (R-RQ1,3), adjusted regression-chain ratio quartile1,3 (AR-CRQ1,3), adjusted regression-multivariate ratio quartile1,3 (AR-MRQ1,3) and adjusted regression-multivariate chain ratio quartile1,3 (AR-MCRQ1,3) under SRS and Rank Set Sampling (RSS) schemes, adopting MSE and Mean Absolute Percentage Error (MAPE) performance measures.	imputation in multiple regression analysis, followed by AR-MCRQ3. Moreover, the RSS estimators provided smaller MSE and MAPE than the SRS estimators. Therefore, the RSS estimators were more efficient than the SRS estimators.
3	Handling Missing Values in Surveys with Complex Study Design: A Simulation Study.	Natasa *et al.*	2024	They evaluated the effectiveness of missing data treatment methods using data from the National Survey of Morbidity and Risk Factors (EMENO), a multistage probability sample survey.	The performance of different IPW and MI approaches was evaluated through both simulation experiments and empirical analyses of the survey data, providing insight into the conditions under which each method performs effectively.
4	Comparing Weighting and Imputation Methods for Enhancing Statistical Inference of Health Surveys given Administrative Claims Data.	Seho *et al.*	2023	They focused on the use of administrative claims data to improve estimates about means of survey items for the finite population.	The resulting estimates were more accurate than those obtained from analyses involving multi-level models estimated using survey weights.
5	On the Use of Multiple Imputation to address	Melissa *et al.*	2023	They conducted a simulation study to assess and compare the performance of	The findings suggested that a combined MI/IPW ap-

	Data Missing by Design as well as Unintended Missing Data in Case-Cohort Studies with a Binary Endpoint			approaches using only multiple imputation (MI), only inverse probability weighting (IPW), and a combination of MI and IPW, for handling intended and unintended missingness in the case-cohort setting.	proach should be preferred to handle intended and unintended missing data in case-cohort studies with binary outcomes.
6	Missing Data and Multiple Imputation: A Sampling Study with the SAGA Cohort.	Marin	2023	The researcher evaluated the performance of several methods for handling missing data using the SAGA (Stress And Gene Analysis) cohort dataset by fitting a Poisson regression model with robust error variance for a binary outcome.	Based on its accuracy, computational efficiency, and ease of implementation, Marin recommended MI-PMM as the preferred method for handling missing data.
7	A Simulation Study of Multiple Imputation Methods for the Producer Price Index.	Yoel and Monica	2022	They examined a few different multiple imputation methods with packages in R, including: CART (Classification and Regression Trees), Random Forest, and Amelia (bootstrap EM (Expectation Maximisation) algorithm)	They recommended that in the future, PPI should update its imputation method to the CMRF (Combined Multiple Random Features) algorithm, using a 20% reported weight minimum.
8	A Bootstrap Method for a Multiple–Imputation Variance Estimator in Survey.	Lili and Yichuan	2022	They proposed a bootstrap-based variance estimator for multiple imputation that overcomes a key limitation of existing methods.	Through both theoretical investigations and simulation studies, they demonstrated that the proposed bootstrap variance estimator is unbiased and asymptotically valid.
9	Performance Comparison of Imputation	Kyei	2021	The researcher looked at the best multiple imputation methods used to handle	The results showed that the random forest imputation

	Methods for Mixed Data Missing at Random with Small and Large Sample Data Set with Different Variability			mixed variable datasets with different sample sizes and variability along with different levels of missingness.	method was the best for mostly a sample of 150 and 500, irrespective of the variability. The classification and regression tree imputation methods worked best mostly on a sample of 30 irrespective of the variability.
10	Standard Multiple Imputation of Survey Data didn't Perform better than Simple Substitution in Enhancing an Administrative Dataset: The Example of Self-rated Health in England.	Frank *et al.*	2021	They investigated the effectiveness of combining survey data with multiple imputation techniques to generate health-related variables for the general population.	The findings indicated that the multiply imputed estimates of poor or very poor self-rated health did not provide a substantially better fit to the census data than estimates obtained directly from survey proportions.
11	Consequences of Multiple Imputation of Missing Standard Deviations and Sample Sizes in Meta-analysis	Stephan *et al.*	2020	They conducted a systematic review of the prevalence and handling of missing data in published ecological meta-analyses and found that incomplete reporting of primary studies was a widespread issue.	The researchers concluded that multiple imputation offers a practical and effective approach for handling missing variance measures and sample sizes.
12	On Multiple Imputation for Unbalanced Ranked Set Samples with Application in Quantile Estimation	Saeid *et al*.	2020	They considered multiple imputation (MI) for Unbalanced Ranked Set Samples (URSS) by considering them as data sets with missing values.	They applied their results to estimate the mean and quantiles of the mercury in contaminated fish under perfect and imperfect URSS. Numerical studies

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					were conducted to evaluate the performance of the proposed quantile estimators. The hybrid estimates based on imputation and bootstrap (MI-Boot) were most recommended.
13		Jonathan and Racheal	2020	They examined a number of recent proposals which combine bootstrapping with multiple imputation and determined which were valid under uncongeniality and model misspecification.	They recommend a particular computationally efficient variant of bootstrapping followed by imputation.
14	Accuracy of Five Multiple Methods in Estimating Prevalence of Type 2 Diabetes based on STEPS Survey	Hamid *et al.*	2020	They aimed to evaluate five Multiple Imputation (MI) methods in the context of the STEPS-wise Approach to Surveillance (STEPS) surveys.	Their findings showed that even with a 60% nonresponse rate, some of the MI methods could satisfactorily result in estimates with negligible RB.
15	Accounting for Model Uncertainty in Multiple Imputation under Complex Sampling.	Gyuhyeong and Jae	2020	They proposed a new multiple imputation procedure incorporating model uncertainty in the final inference.	A limited simulation study confirms that their model averaging approach provides better estimation performance than the single-model selection approach.
16	Multiple Imputation for Analysis in Incomplete Data in Distributed Health Data Networks.	Changgee *et al*.	2020	They addressed the missing data problem in distributed environments such as Distributed Health Data Networks (DHDNs) that had not been investigated pre-	Their methods proved to be more reliable than previously investigated methods.

				viously.	
17	Multiple Imputation Method for Handling Missing Values in Longitudinal Studies with Sampling Weights: Comparison of Methods Implemented in Stata.	Anurika *et al.*	2020	They evaluated the performance of several multiple imputation (MI) approaches available in Stata, based on multivariate normal imputation (MVNI), fully conditional specification (FCS) and twofold FCS:	They recommend using MVNI with the design stratum as a covariate in the imputation model.

2.4. Potential Threat to the Review's Validity

This study identified two major threats that could affect the reviewers' validity; these are (i) potential errors in data extraction and (ii) publication bias. We addressed these issues as follows: the reviewers adhered strictly to the search strategy as described in the PRISMA diagram. Another threat was the tendency to ignore relevant or related literature because going through the titles, abstracts, or keywords alone might not be enough. In addressing this particular threat, we physically scrutinised the reference section of the shortlisted literature so as to retrieve any relevant literature omitted during the main search.

3. Results and Discussion

Different electronic databases for literature resources in the TRP estimators of population mean under the MI technique framework were searched so as to search out and identify studies capable of answering our RQs. We conducted data synthesis using several criteria.

Also, from the PRISMA guide used in the study, the results are as follows: Google Scholar (n=535), Springer (n=321) and PubMed (n =305), amounting to 1261 records. Before the screening, 1261 records were removed from the total literature retrieved; out of the 1,261 records, 685 were duplicates, and 576 records were excluded due to other reasons. While 370 records were subjected to further screening, the screening of the 370 records was based on both their title and abstract. Out of 370, 206 records were excluded since they failed to meet the inclusion criteria. Furthermore, the full text for 206 records was retrieved and successfully assessed; 189 records were later excluded due to certain reasons. Finally, 17 records were then selected. All the selected studies were archived and organised.

3.1. Research Gaps Identified

The general idea across the literature is that modified ratio estimators significantly outperform existing estimators in terms of efficiency and precision. However, despite these improvements, few studies have examined the integration of advanced ratio-product or trigonometric estimators with

modern missing data handling procedures such as multiple imputation. Most existing studies assume complete data and do not account for the impact of missingness on estimator performance. Most existing studies focus either on improving imputation methods or enhancing estimator efficiency separately, without jointly examining their combined performance under varying missingness mechanisms and sampling conditions. This creates an important research gap for the development and evaluation of trigonometric ratio-product estimators under multiple imputation frameworks, particularly through simulation-based studies.

3.2. Study Limitations

While we have conducted a comprehensive review and search strategy employing various databases including PubMed, Springer and Google Scholar, completeness cannot be assured. The PRISMA chart displays 1261 retrieved resources, which were further reduced to seventeen (17) studies using eligibility criteria and quality assessment, respectively, signifying rigorous filtering; hence, highlighting possible exclusion of relevant and related literature on MI technique. Both the search query and data synthesis enhance coverage. Still, only studies published in English are included; our time frame only includes literature from 2020 to 2025, and dependence on indexed electronic databases limited search completeness, which possibly might exclude unpublished or emerging theoretical contributions in MI studies.

4. Conclusion

This study proposes the development of trigonometric ratio-product estimators of the population mean within a multiple imputation framework to address missing data problems in survey sampling. By integrating auxiliary information with trigonometric transformations, the proposed estimators are expected to achieve lower bias and mean squared error than existing estimators. The study will provide both theoretical and empirical evidence on the effectiveness of these estimators, offering a more efficient and robust approach for estimating population means from incomplete survey data such as DHS datasets.

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