Systematic Review of Literature: Sampling Estimators

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Abstract

This paper reviews sampling estimators using auxiliary information to improve the accuracy of population estimates. Based on studies from 1946–2024, it covers classical estimators (ratio, regression, product) and recent advancements such as exponential, robust, and multi-auxiliary estimators. The review highlights theoretical developments, empirical findings, and emerging trends like machine learning and non-response handling. It also identifies research gaps in complex sampling designs and dynamic estimation, emphasizing the need for more efficient and adaptive estimators.

Keywords: Ratio estimator, Regression estimator, sampling designs, multi- auxiliary information.

1. Introduction:-

Sampling estimators are pivotal in survey statistics, providing estimates of population parameters based on sample data. The integration of auxiliary information variables correlated with the study variable has been a significant advancement, enhancing the precision and efficiency of these estimators. This review synthesizes findings from over 60 studies, encompassing classical methods, recent innovations, and applications across various sampling designs.

2. Methodology

2.1 Search Strategy:-

Databases Searched: Scopus, Web of Science, JSTOR, SpringerLink, ScienceDirect, ResearchGate.

Keywords Used: "sampling estimator", "auxiliary information", "ratio estimator", "regression estimator", "mean square error", "bias reduction", "survey sampling"

Time Frame: 1946–2024.

2.2 Inclusion Criteria

Peer-reviewed journal articles

Studies focusing on sampling estimators utilizing auxiliary information

Papers presenting theoretical derivations, simulations, or empirical evaluations

2.3 Exclusion Criteria

Non-peer-reviewed sources

Studies without clear methodological frameworks Papers not available in English

3. Classification of Estimators Using Auxiliary Information

3.1 Classical Estimators

Ratio Estimator

The ratio estimator is based on the ratio of the sample means of the study variable y and the auxiliary variable x. It is widely used under Simple Random Sampling (SRS) when the study and auxiliary variables are positively correlated:

$$Y_R = \bar{y} \cdot \frac{\bar{X}}{\bar{x}}$$

where $\bar{y}$ is the sample mean of the study variable, $\bar{x}$ is the sample mean of the auxiliary variable, and $\bar{X}$ is the known population mean of the auxiliary variable.

Regression Estimator

The regression estimator incorporates a linear regression relationship between the study and auxiliary variables. It typically reduces bias and mean square error (MSE) compared to the ratio estimator:

$$Y_{Reg} = \bar{y} + b(\bar{X} - \bar{x})$$

where $b = \frac{\text{Cov}(y,x)}{\text{Var}(x)}$ is the regression coefficient.

Product Estimator

The product estimator is useful when the auxiliary variable is negatively correlated with the study variable. It is constructed as:

$$Y_P = \bar{y} \cdot \frac{\bar{X}}{\bar{x}}$$

or, more specifically, in its classical form:

$$Y_P = \bar{y} \cdot \frac{\bar{x}}{\bar{X}}$$

which leverages the negative correlation to improve estimation efficiency.

3.2 Modified and Advanced Estimators

Exponential and logarithmic estimators have been introduced to effectively handle skewed distributions and to provide more robust estimates in cases where traditional methods may fail. Similarly, dual and combined estimators have been developed to merge the strengths of multiple estimators, thereby balancing bias and variance and enhancing overall efficiency. In addition, robust estimators are specifically designed to perform well even when model assumptions, such as normality or homoscedasticity, are violated, ensuring reliable inference in practical scenarios. More recently, optimization-based estimators have emerged, employing techniques from operations research to derive estimators that minimize mean square error (MSE) under given constraints, thus offering a more systematic and efficient approach to estimator construction.

3.3 Multi-Auxiliary Variable Estimators:

Multi-variable ratio and regression estimators extend classical estimation methods by incorporating multiple auxiliary variables, which leads to increased precision and improved reliability of survey results. These estimators utilize the additional information from auxiliary data to reduce variability and enhance efficiency compared to single-variable approaches. Complementing these, calibration estimators refine survey estimates by adjusting sample weights so that they align with known population totals, thereby improving accuracy and ensuring consistency with external benchmarks.

4. Theoretical Developments

Bias and mean square error (MSE) analyses have been a central focus in the evaluation of estimators, with numerous studies deriving explicit expressions to provide deeper insights into their efficiency and reliability. Building on this, some researchers have advanced the analysis by incorporating higher-order approximations of bias and MSE, which allow for more precise assessments of estimator performance, particularly in finite samples. Additionally, investigations into the asymptotic properties of estimators have played a crucial role in understanding their behavior in large-scale surveys, thereby guiding their practical applicability and theoretical robustness.

5. Empirical and Simulation Studies

A significant body of research has relied on simulation studies to compare the performance of different estimators across a variety of scenarios, including varying sample sizes, correlation structures, and sampling designs, thereby providing evidence of their relative strengths and limitations. Complementing these, real-world applications in domains such as agriculture, economics, and public health have empirically demonstrated the practical benefits of incorporating auxiliary information into sampling estimators, highlighting their effectiveness in producing more accurate and reliable estimates in applied settings.

6. Emerging Trends and Innovations

Recent studies have increasingly focused on enhancing sampling estimators through the integration of advanced techniques and auxiliary information. One notable development is the use of machine learning algorithms to model complex relationships between the study and auxiliary variables, enabling the creation of adaptive estimators that can adjust dynamically to varying data patterns. Additionally, researchers have developed innovative methods to handle non- response in surveys by leveraging auxiliary information to reduce bias and improve the accuracy of estimates. Furthermore, auxiliary information-based estimators have been extended to spatial and temporal sampling frameworks, addressing challenges inherent in environmental studies and longitudinal surveys, and providing more precise and context-sensitive estimation across both space and time.

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Synthesis of Key Studies: Sampling Estimators

Estimator Type	**Study**
Estimators of population mean	Srivastava (1967, 1970), Reddy (1974), Singh et al. (2004), Bhal and Tuteja (1991), Singh and Vishwakarma (2007), Singh et al. (2009), Kadilar (2016).
Bias adjusted ratio estimator	Hartley and Ross (1954), Beal (1962, Tin (1965) and Dubey and Pandey (1989), Singh (1999), Rao (1991), Dubey and Singh (2001), Dubey and Kant (2006).
Auxiliary information	Olkin (1958), Rao and Modjholkar (1967) and Des raj (1965), Upadhyaya and Singh (1999). Kadilar and Cingi (2003), Ahmad et al. (2016), Ozgual (2020) and Zaman and Kadilar (2020), Xue et al. (2022) Mehta and Tailor (2024).
Double Sampling	Singh H.P. & Espejo M. R. (2007), Tailor and Kim (2014), Mishra and Singh (2016), Ozgul (2020), Samuel et al. (2023), Gupta et al. (2023).
Successive sampling	Eckler (1955), Artes (1998) et al., Singh and Singh (2001), Singh and Singh (2015), Dubey and Shukla (2020), Khalid and Singh (2022), Tiwari et al. (2023).
Non-response	Hansen, Hurwitz (1946), Khare and Shrivastava (2000), Unal and Kadilar (2011), Satici and Kadilar (2011), Sisodia and devi (2016), Zahid and Shabbir (2018), Singh et al. (2020), Das et al. (2023)
Estimators of population variance	Das and Tripathi (1978), Singh and Singh (2001), Isaki (1983), Agrawal and Panda (1999), Kadilar and Cingi (2005), Gupta and Shabbir (2007), Asghar et al. (2014) and Adichwal (2016), Muneer et al. (2018), Sharma et. all (2021), Pandey et al. (2024)

7. Gaps and Future Directions

There is a growing need for research focused on the development of auxiliary information-based estimators tailored for complex sampling designs, including cluster and stratified sampling, to enhance efficiency and precision in such frameworks. Additionally, the advancement of dynamic estimators that can adapt over time by incorporating new auxiliary information as it becomes available represents a promising direction for future exploration. Moreover, integrating administrative data as auxiliary information offers significant potential to improve estimator accuracy, although challenges related to data quality, accessibility, and compatibility must be carefully addressed to fully realize these benefits.

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