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SAMPLING AND SURVEY TECHNIQUES

Study Case Using R and Python

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First Edition

Sampling and Survey Techniques

Study Case Using R and Python

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In today's data-driven world, the ability to collect, analyze, and interpret information accurately is more important than ever. Sampling and survey techniques are essential tools in research, business, social sciences, and public policy, allowing researchers to gather representative data, identify patterns, and make well-informed decisions. A well-structured survey, combined with appropriate sampling methods, enhances data reliability while minimizing bias and errors.

The foundation of effective surveys lies in selecting the right sampling strategy. Probability-based sampling methods, such as simple random sampling, stratified sampling, and cluster sampling, provide statistically valid insights, whereas non-probability techniques, including convenience sampling and quota sampling, offer practical advantages in specific research contexts. Understanding these methods allows researchers to optimize data collection while ensuring the accuracy and credibility of their findings.

Beyond data collection, survey methodology involves data validation, analysis, and interpretation. Statistical techniques such as confidence intervals, regression analysis, and hypothesis testing enhance the quality of survey results, allowing researchers to derive meaningful insights. Additionally, modern digital tools and automation have transformed survey research, improving efficiency and accessibility.

This book provides a comprehensive and practical guide to sampling and survey techniques, covering the fundamental principles of data collection, survey design, statistical analysis, and visualization. By mastering these concepts, researchers, analysts, and decision-makers will be better equipped to design effective surveys, interpret survey data accurately, and apply the results to real-world decision-making processes.

Preface

About the Writer

Bakti Siregar, M.Sc., CDS works as a Lecturer at the ITSB Data Science Program. He earned his Master's degree from the Department of Applied Mathematics at National Sun Yat Sen University, Taiwan. In addition to teaching, Bakti also works as a Freelance Data Scientist for leading companies such as JNE, Samora Group, Pertamina, and PT. Green City Traffic.

He has a strong enthusiasm for projects (and teaching) in the fields of Big Data Analytics, Machine Learning, Optimization, and Time Series Analysis, particularly in finance and investment. His core expertise lies in statistical programming languages such as R Studio and Python. He is also experienced in implementing database systems like MySQL/NoSQL for data management and is proficient in using Big Data tools such as Spark and Hadoop. Some of his projects can be viewed here: Rpubs, Github, Website, and Kaggle.

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Lastly, I would like to extend my appreciation to my readers. Your interest and engagement motivate me to continue exploring and sharing knowledge. I hope this ebook on Sampling and Survey Techniques serves as a valuable resource for you in your learning journey.

Feedback & Suggestions

Your feedback is essential in improving this book. We invite all readers to share their thoughts on the content, structure, and clarity of the materials. Suggestions for additional topics or areas requiring further explanation are highly appreciated.

With your support and contributions, we aim to refine this book, making it a more comprehensive resource for **Sampling and Survey Techniques**. Thank you for your participation!

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Chapter 1

Principles of Sampling

1.1 What is Sampling?

Sampling is the process of selecting a subset of individuals, items, or observations from a larger population to estimate characteristics of the whole population. It is widely used in research, business, and public policy to make data-driven decisions efficiently.

1.2 Population vs. Sample

In statistics, understanding the distinction between **population** and **sample** is crucial for data analysis, inference, and decision-making.

1.2.1 Population

The **population** (N) is the **entire group** of individuals, objects, or events that a researcher is interested in studying. It includes **all possible observations** relevant to the research. **Examples:**

- All residents of a city when studying voting behavior.
- Every manufactured smartphone from a factory when analyzing defect rates.
- Every student in a university when measuring average exam scores.

Types of Populations:

- **Finite Population:** A population with a fixed number of elements (e.g., employees in a company).
- **Infinite Population:** A population with an uncountable number of elements (e.g., bacteria in a petri dish).
- **Target Population:** The specific population a researcher wants to study.
- *Accessible Population:** The portion of the target population available for study.

1.2.2 Sample

A **sample** (n) is a **subset** of the population, selected for analysis. Since studying an entire population is often impractical due to cost, time, or accessibility, a sample is used to make inferences about the population. **Examples:**

- Surveying 1,000 residents of a city to estimate public opinion.
- Inspecting 500 randomly chosen smartphones to assess defect rates.
- Analyzing exam scores from 200 randomly selected students.

Characteristics of a Good Sample:

- **Representative:** Accurately reflects the population.
- **Random:** Selected without bias.
- **Sufficiently Large:** Ensures reliable estimates.
- **Minimally Biased:** Avoids systematic errors.

1.2.3 Key Differences

When conducting research or statistical analysis, it is essential to distinguish between population and sample. The population refers to the entire group of interest in a study, while the sample is a smaller subset selected from that population for analysis. Understanding their differences is crucial for making accurate inferences and ensuring the validity of conclusions.

Here are the key differences between a population and a sample:

Feature	Population (N)	Sample (n)
Definition	Entire group of interest	A subset selected for study
Size	Large or infinite	Smaller, manageable portion
Notation	Uses uppercase letters (e.g., N, μ, σ)	Uses lowercase letters (e.g., n, $\bar{x}$, s)
Parameters	True values (e.g., population mean μ, standard deviation σ)	Estimates (e.g., sample mean $\bar{x}$, standard deviation s)
Cost & Time	High	Lower
Accuracy	Provides exact information	Provides an estimate with some margin of error

1.3 Why Use a Sample?

In research and data collection, studying an entire population is often impractical or impossible. Instead, researchers use a **sample**, which is a smaller, manageable subset of the population. Below are the key reasons for using a sample:

- **Cost-Effectiveness**
  Collecting data from an entire population requires significant financial resources. A sample reduces costs associated with data collection, processing, and analysis.

- **Time Efficiency**
  Studying an entire population is time-consuming. A well-chosen sample allows for quicker data collection and analysis.

- **Feasibility**
  Some populations are too large or inaccessible to study completely. A sample makes research possible when population-wide data collection is impractical.

- **Accuracy and Reliability**
  When selected properly, a sample can provide highly accurate and reliable insights. Statistical techniques ensure that the sample represents the entire population effectively.

- **Reduced Data Management Complexity**
  Handling vast amounts of data can be challenging. A sample simplifies data management while still providing meaningful conclusions.

- **Ethical Considerations**
  Some research (e.g., medical trials) may involve risks, making it unethical to test on an entire population. A sample allows for controlled and ethical experimentation.

1.4 Avoiding Sampling Bias

Sampling bias occurs when certain members of the population are systematically **excluded** or **overrepresented** in the sample.

This leads to inaccurate and unrepresentative results, potentially skewing conclusions and reducing the validity of a study.There are some sauses of sampling bias:

Aspect	Description	How to Overcome
Undercoverage	Some groups in the population are not included in the sampling frame.	Use a **representative sampling frame** to ensure all groups are covered.
Overrepresentation	Certain groups have a disproportionately higher chance of being selected.	Use **stratified sampling** to maintain balanced proportions.
Self-Selection Bias	Participants voluntarily choose to take part, leading to a non-random sample.	Use **randomized invitations** and consider **incentives** to attract a more diverse group of respondents.

Minimizing sampling bias is essential for producing valid, reliable, and generalizable research findings. By ensuring a well-constructed sampling frame, applying random selection methods, and reducing self-selection effects, researchers can improve the quality and accuracy of their studies.

1.5 Randomization in Sampling

Randomization is a process that ensures every member of a population has an **equal chance** of being selected. This reduces **sampling bias** and enhances the **generalizability** of research findings.

1.5.1 Simple Random Sampling

A method where each element in the population has an equal probability of selection, ensuring a truly random sample. Here, how it works:

- Assign a unique number to each member of the population.
- Use a random number generator or lottery system to select participants.

Example: A company wants to survey 500 employees from a workforce of 5,000. Each employee is assigned a number, and 500 are randomly chosen using a lottery system.

1.5.2 Systematic Sampling

A method where elements are selected at regular intervals from an ordered list. Here, how it works:

- Determine the sample size (e.g., selecting 100 people from a list of 1,000).
- Calculate the sampling interval: **Population Size ÷ Sample Size** (e.g., 1,000 ÷ 100 = 10).
- Randomly select a starting point and then pick every 10th person.

Example: A researcher wants to survey every 5th customer from a list of 1,000 shoppers. If the starting point is 3, the selected individuals will be 3rd, 8th, 13th, etc.

1.5.3 Stratified Sampling

A method that divides the population into **subgroups (strata)** based on a shared characteristic, then randomly selects a proportional number of participants from each stratum. Here, how it works:

- Identify relevant **strata** (e.g., age groups, income levels, education).
- Determine the proportion of each stratum in the population.
- Conduct **random sampling** within each stratum.

Example: A university wants to survey students from different academic years. If 40% of students are freshmen, 30% are sophomores, 20% are juniors, and 10% are seniors, then the sample will reflect these proportions.

Using random sampling methods like **SRS, systematic sampling, and stratified sampling** helps ensure a **fair, unbiased**, and **representative sample**. This improves the reliability and validity of research findings, making them more generalizable to the entire population.

1.6 Challenges in Sampling

Sampling is a critical process in research, but it comes with several challenges that can impact accuracy and reliability. Below is an overview of key sampling challenges along with their causes and possible solutions.

Challenge	Causes	Solutions
Non-Response Bias	Participants unwilling or unable to respond. Surveys too long or complex. Certain groups less likely to participate.	Send follow-up reminders. Offer incentives. Simplify survey format.
Sampling Frame Errors	Outdated or incomplete lists. Incorrect classification. Duplicate or ineligible participants included.	Keep the sampling frame updated. Cross-check data sources. Use stratified sampling.
Inadequate Sample Size	Limited resources for large samples. Miscalculated sample size. High dropout rates in longitudinal studies.	Use statistical methods to determine the correct sample size. Account for potential dropouts.
Cost and Time Constraints	High costs for data collection. Delays in reaching participants. Need for specialized tools or personnel.	Use cost-effective methods like online surveys. Automate data collection. Optimize resources.

Addressing these challenges ensures that the sampling process is more reliable, efficient, and representative of the target population. By implementing effective solutions, researchers can minimize errors and improve the overall quality of their studies.

1.7 Applications in Industry

Sampling plays a crucial role across various industries, allowing organizations to gather insights, make informed decisions, and optimize processes. Below are key areas where sampling is widely used:

Industry	Application	Purpose
Market Research	Conducting surveys and focus groups.	Understanding customer preferences, trends, and behaviors.
Healthcare	Studying patient data and clinical trials.	Estimating disease prevalence, treatment effectiveness, and public health trends.
Quality Control	Inspecting a subset of products in manufacturing.	Ensuring product quality and compliance with industry standards.
Finance	Analyzing financial transactions and market trends.	Assessing risks, detecting fraud, and making investment decisions.

By applying proper sampling techniques, industries can obtain **accurate and reliable insights** while minimizing errors and biases. This ensures better decision-making, cost savings, and improved operational efficiency.

Chapter 2

Probability Distributions

2.1 Probability in Sampling

Sampling is the process of selecting a subset of individuals from a population to make inferences about the entire population. It is widely used in statistics, surveys, and research studies to obtain insights without having to analyze every member of the population.

The two primary categories of sampling methods are **probability sampling** and **non-probability sampling**.

2.2 Probability vs. Non-Probability

In research and data collection, sampling methods are broadly categorized into probability sampling and non-probability sampling. The choice between these methods depends on the research goals, available resources, and the level of accuracy needed.

2.2.1 Probability Sampling

Probability sampling ensures that every element in the population has a known, non-zero chance of being selected. It allows for statistical inference and generalization to the entire population. Common probability sampling methods include:

- **Simple Random Sampling (SRS)**: Each element in the population has an equal chance of being selected. This can be done using random number generators or lottery methods.
- **Stratified Sampling**: The population is divided into strata (subgroups) based on certain characteristics (e.g., age, income), and random samples are drawn from each stratum proportionally.
- **Cluster Sampling**: The population is divided into clusters (e.g., geographic regions), and entire clusters are randomly selected. This is useful for large populations.
- **Systematic Sampling**: A starting point is randomly chosen, and subsequent selections follow a fixed interval (e.g., selecting every 10th person).

2.2.2 Non-Probability Sampling

Non-probability sampling does not guarantee every individual in the population has a chance of being selected. It is often used when probability sampling is impractical or too expensive. Common non-probability sampling methods include:

- **Convenience Sampling**: Selecting individuals based on availability or accessibility.
- **Judgmental (Purposive) Sampling**: Selecting individuals based on researcher judgment and expertise.
- **Quota Sampling**: Ensuring specific subgroups are represented in the sample based on predetermined quotas.
- **Snowball Sampling**: Participants recruit other participants, often used in hard-to-reach populations.

2.3 Types of Sampling Distributions

A **sampling distribution** refers to the probability distribution of a statistic (such as the mean, proportion, variance, or standard deviation) obtained from multiple random samples of the same size from a population. These distributions are essential in inferential statistics, as they help estimate population parameters and test hypotheses.

2.3.1 Mean

This distribution consists of the means of all possible random samples of a given size from a population.

Key Properties:

- The mean of the sampling distribution ($\mu_{\bar{x}}$) is equal to the population mean (μ).
- The standard deviation of the sampling distribution (Standard Error of the Mean, **SEM**) is given by:

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

where σ is the population standard deviation and n is the sample size.

- If the population is normally distributed, the sampling distribution is also normal for any n.
- If the population is not normal, the **Central Limit Theorem (CLT)** states that the sampling distribution of the mean will be approximately normal if $n \geq 30$.

Example: A population has a mean of 100 and a standard deviation of 15. If we take random samples of size 36, the standard error of the mean will be:

$$\sigma_{\bar{x}} = \frac{15}{\sqrt{36}} = \frac{15}{6} = 2.5$$

If the population follows a normal distribution, the sample means will also follow a normal distribution with a mean of 100 and a standard deviation of 2.5.

2.3.2 Proportion

This distribution describes the possible values of sample proportions from a population.

Key Properties:

- The mean of the sampling distribution of proportions is equal to the population proportion (p).
- The standard deviation (Standard Error of the Proportion, **SEP**) is:

$$\sigma_{\hat{p}} = \sqrt{\frac{p(1-p)}{n}}$$

- If $np \geq 5$ and $n(1-p) \geq 5$, the sampling distribution of the proportion is approximately normal (by the normal approximation to the binomial).

Example: If 40% ($p = 0.4$) of a population supports a certain policy, and a random sample of 100 is taken:

$$\sigma_{\hat{p}} = \sqrt{\frac{0.4(1-0.4)}{100}} = \sqrt{\frac{0.24}{100}} = \sqrt{0.0024} \approx 0.049$$

The sample proportions will follow an approximately normal distribution with a mean of 0.4 and a standard deviation of 0.049.

2.3.3 Variance

This distribution describes the variability of sample variances.

Key Properties:

- The mean of the sampling distribution of variance is equal to the population variance (σ^2).
- The sampling distribution follows a **chi-square distribution** with $(n-1)$ degrees of freedom.
- The formula for the sample variance is:

$$s^2 = \frac{\sum(x_i - \bar{x})^2}{n-1}$$

Example: If a population has a variance of 25 and a sample size of 10, the sample variances will follow a chi-square distribution with 9 degrees of freedom.

2.3.4 Standard Deviation

Since the sample variance follows a chi-square distribution, the standard deviation is derived from it.

Key Properties:

- The sampling distribution of standard deviation does not follow a normal distribution.
- It is often estimated using the chi-square distribution.

2.3.5 Difference Between Two Means

Used when comparing two independent sample means.

Key Properties:

- If $\bar{x}_1$ and $\bar{x}_2$ are the means from two independent samples, the mean of their sampling distribution is:

$$\mu_{\bar{x}_1-\bar{x}_2} = \mu_1 - \mu_2$$

- he standard deviation (Standard Error) is:

$$\sigma_{\bar{x}_1-\bar{x}_2} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

- If both populations are normal or the sample sizes are large, the distribution of $\bar{x}_1 - \bar{x}_2$ is approximately normal.

Example: If two populations have means of 50 and 55 with variances of 16 and 25, and sample sizes of 30 each:

$$\sigma_{\bar{x}_1-\bar{x}_2} = \sqrt{\frac{16}{30} + \frac{25}{30}} = \sqrt{0.533 + 0.833} = \sqrt{1.366} \approx 1.17$$

2.3.6 Difference Between Two Proportions

Used when comparing proportions from two independent samples.

Key Properties:

- The mean of the sampling distribution is:

$$\mu_{\hat{p}_1-\hat{p}_2} = p_1 - p_2$$

- The standard deviation (Standard Error) is:

$$\sigma_{\hat{p}_1-\hat{p}_2} = \sqrt{\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}}$$

- If sample sizes are large, the distribution is approximately normal.

Example: If $p_1 = 0.6$ and $p_2 = 0.5$ with sample sizes of 100 each:

$$\sigma_{\hat{p}_1-\hat{p}_2} = \sqrt{\frac{0.6(0.4)}{100} + \frac{0.5(0.5)}{100}} = \sqrt{0.0024 + 0.0025} = \sqrt{0.0049} = 0.07$$

2.3.7 Student's t-Distribution

Used when estimating the mean of a normally distributed population with an unknown variance, especially for small samples ($n < 30$).

Key Properties:

- The shape is similar to a normal distribution but has heavier tails (greater variability for small samples).
- The formula for the **t-statistic** is:

$$t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

- Follows a **t-distribution** with $n - 1$ degrees of freedom.

Example: If $\bar{x} = 52$, $\mu = 50$, $s = 10$, and $n = 9$, the t-score is:

$$t = \frac{52 - 50}{\frac{10}{\sqrt{9}}} = \frac{2}{\frac{10}{3}} = \frac{2}{3.33} = 0.6$$

Each type of sampling distribution serves a specific purpose in statistical inference, from estimating means and proportions to comparing groups. Understanding these distributions is crucial for hypothesis testing, constructing confidence intervals, and making data-driven decisions.

2.4 Standard Normal Distribution

The **Z-distribution** (or **standard normal distribution**) is a normal distribution with a mean of **0** and a standard deviation of **1**. It is used for standardizing data, hypothesis testing, and confidence intervals.

Key Properties:

- The **mean** (μ) is **0** and the **standard deviation** (σ) is **1**.
- The **total area** under the curve is **1**.
- The **Z-score formula** converts raw values into standard normal values:

$$Z = \frac{X - \mu}{\sigma}$$

where:

- X = observed value
- μ = population mean
- σ = population standard deviation

Empirical Rule (68-95-99.7 Rule):

- About **68%** of values fall within ± 1 **standard deviation**.

- About **95%** of values fall within ± 2 **standard deviations**.
- About **99.7%** of values fall within ± 3 **standard deviations**.

Example: If a test score is $X = 85$, the population mean is $\mu = 75$, and the standard deviation is $\sigma = 10$, then:

$$Z = \frac{85 - 75}{10} = \frac{10}{10} = 1.0$$

This means the test score is **1 standard deviation above the mean**.

The Z-distribution is widely used in **Z-tests**, probability calculations, and constructing **confidence intervals** for population parameters.

2.5 Central Limit Theorem (CLT)

The **Central Limit Theorem (CLT)** states that for a sufficiently large sample size (typically $n > 30$), the sampling distribution of the mean will be approximately normal, regardless of the original population distribution.

Implications of CLT:

- Allows normal approximation even for skewed population distributions.
- Enables hypothesis testing and confidence interval estimation using normal-based methods.

2.6 Law of Large Numbers

The **Law of Large Numbers (LLN)** states that as the sample size increases, the sample mean approaches the population mean.

- **Weak Law of Large Numbers**: The probability that the sample mean deviates significantly from the population mean decreases as sample size increases.
- **Strong Law of Large Numbers**: The sample mean converges almost surely to the population mean as the sample size grows.

2.7 Confidence Intervals

A **Confidence Interval (CI)** provides a range of values that likely contain the true population parameter. The formula for a confidence interval for a population mean is:

$$CI = \bar{X} \pm Z_{\alpha/2} \times \frac{\sigma}{\sqrt{n}}$$

where:

- $Z_{\alpha/2}$ is the critical value from the standard normal table.
- σ is the population standard deviation.
- n is the sample size.

Common confidence levels:

- **90% CI**: $Z = 1.645$
- **95% CI**: $Z = 1.96$
- **99% CI**: $Z = 2.576$

2.8 Hypothesis Testing in Surveys

Hypothesis testing is used to make inferences about population parameters based on sample data. The general steps include:

- **Define Hypotheses:**
  - Null Hypothesis (H_0): Assumes no effect or no difference.
  - Alternative Hypothesis (H_1): Assumes an effect or difference exists.
- **Select a Significance Level (α)**
  - Common choices: 0.05, 0.01, or 0.10.
- **Compute the Test Statistic**
  - For mean: $Z = \frac{\bar{X} - \mu}{\sigma/\sqrt{n}}$
  - For proportion: $Z = \frac{\hat{p} - p_0}{\sqrt{p_0(1-p_0)/n}}$
- **Determine the p-value**
  - If $p < \alpha$, reject H_0; otherwise, fail to reject H_0.
- **Draw a Conclusion**
  - If H_0 is rejected, there is sufficient evidence to support H_1.
  - If H_0 is not rejected, there is insufficient evidence to support H_1.

Understanding these fundamental statistical concepts allows researchers to design better experiments, analyze survey data effectively, and make informed conclusions based on sampled data.

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