Basics of Survey Sampling and Sampling Design

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Importance of data and survey

- The need for data seems endless in today's world
  - Empirical research is getting increasingly popular in India
  - Data are being used for informing and evaluating policy
  - Good quality data collected in a scientific manner are useful for many reasons:
    - It helps to draw inference about the population in an unbiased way with respect to certain indicators of interest
    - It helps to monitor different programs and schemes (both Govt. and private)
    - It helps to evaluate the effectiveness of different programs and schemes
    - It helps to understand the (causal) association between different phenomenon/events
    - It can explain the reasons behind the occurrence of an event
  - The above mentioned functionalities of data influence policy decisions

Sampling vs Complete enumeration

- One of the most common ways to satisfy the demand for data is to conduct a survey
  - Surveying the fraction of the population is known as sampling
  - When an entire population is enumerated, it's known as complete enumeration or census (e.g., population census of India- 15th population census 2011, 7th economic census 2019-20)
- While using surveys to collect data, sampling is often preferred over the complete enumeration for various reasons

Advantages of sampling over census

- Less time consuming- leading to more timely reporting
- Less costly
- Sampling method of data collection leads to sampling error in survey estimates
- Sampling error emerges from the fact that a fraction of the population is surveyed to draw inference about the population and not the entire population
    - estimates from sample survey still can be more accurate as non-sampling error component can be smaller in sampling compared to complete enumeration
- Non-sampling error includes coverage error, nonresponse error, measurement errors, among others
- Countries like US and Canada are gradually switching from census to surveys because of the reasons mentioned above
    - Few basic questions (short-form) are collected in census and for all other information the census (long-form) is replaced by American Community Survey in US and National Household Survey in Canada

Key terminologies relevant for surveys

- Target population
  - entire set of units for which the survey data are to be used to make inferences
  - The geographic location and demographic and temporal characteristics of the target population need to be specified
  - Inclusion and exclusion criteria for the types of units being part of the target population should be clearly defined
- Sampling frame
  - Sampling frame is the list of units from where the sample is selected
  - Usually the latest census data is used as sampling frame (e.g., list of districts, list of villages and urban wards)
  - Sometimes it's not readily available, particularly for the ultimate sampling units (e.g., households, individuals)
    - Construct the sampling frame through houselisting
    - Use of alternative (imperfect) existing frames: Address-based survey: Voter roll, Web survey: Facebook users (300 million), Phone survey: Kantar Public database of 500K+ phone numbers collected over the past 5 years

Different sources of errors in surveys

- Sampling error
  - a fraction of the population is surveyed to draw inference about the population and not the entire population
  - standard methods available to measure
    - Standard Error (SE)
    - Coefficient of variation (CV)
    - 95% confidence interval (CI)
- Nonsampling errors
  - Coverage error- imperfect sampling frame
  - Nonresponse error- respondent burden and fatigue, attrition

  } Nonobservation error
  - Measurement error- iwer, respondent, data entry and processing } Observation error
  - Often difficult to quantify and usually ignored

Data quality

- A reliable and useful survey aims to minimize sampling error as well as all sources of nonsampling error, given the budget and resources
- Sampling error is minimized by calculating the required sample size using the correct formula and selecting the sample using appropriate sampling designs
  - It is important to use reliable estimates of the parameters involved in sample size calculation
- Another important precursor to good quality data is the monitoring and supervision of data collection activities

Design of a survey

- The design of a survey involves many interrelated components
- Mode of data collection
  - how to collect data- F2F, telephone, web survey (self-interviewing)
  - minimize bias and variance in data
  - Mixed mode surveys are common in many countries
- Questionnaire design
  - tool to collect data
  - minimize bias and variance in data (e.g., impact of reference period)
- Sampling design
  - how to select sample
  - representativeness of sample
- Sample size
  - reliability of survey estimates

MODE OF DATA COLLECTION

(Although part of the PPT- was not covered during the presentation as it was supposed to be covered in another session)

Mode of data collection (how to collect data)

- Different modes are used for data collection
- In low- and middle-income countries (LMICs) like India, historically, surveys have been carried out by conducting face-to-face interviews
- Many countries adopt mixed mode designs
- Face-to-face interviewing
  - This type of data collection requires an interviewer collecting data and involves direct interaction between interviewer and respondent
  - Two alternative versions for such surveys: PAPI (Pen and paper interviewing mode) and CAPI (Computer assisted personal interviewing)

Advantages of CAPI over PAPI

- In CAPI, data are uploaded to the server at a regular interval (daily or twice a week)
- Uploaded data can be used for monitoring data quality and sharing feedback with the field team to avoid repetitions of same mistakes
- Data collection and data processing phases tend to be merged, and, as a consequence, processing errors may be reduced
- Interviewers do not need to pay attention to the complicated skip pattern and logical routing (it’s pre-programmed using CAPI software)
  - they can focus only on interviewing
- CAPI surveys generate a lot of process data (paradata) which can be used for remote monitoring

Telephone survey

- HH surveys conducted using face-to-face (f2f) interviews tend to be costly and resource-intensive
  - The process of designing and implementing a survey and producing a clean dataset that is ready for analysis often takes several months
  - Moreover, the need for more frequent surveys limits the use of face-to-face surveys
  - In certain circumstances f2f surveys may not be feasible to implement
- Frequent surveys may be more useful in the following context:
  - To accurately capture certain rapidly changing conditions (e.g., seasonal employment, fragmented job pattern, pandemic situation)
  - To reduce variance in annual estimates based on data collected for a shorter reference period (e.g., HH consumption expenditure or out-patient health expenditure collected for last 15/30 days)
  - To reduce recall bias by shortening the reference period for certain types of data (e.g., hospitalization expenses in the last 3 months as opposed to 12 months)

Telephone survey

- The widespread use of mobile phones in India offers a new opportunity to remotely conduct surveys with increased efficiency and reduced cost
- Telephone surveys involve reduced level of direct interaction between interviewer and respondent
- Telephone surveys can also be computer-assisted, which is known as CATI (computer-assisted telephone interviewing)

Limitations of telephone survey

- The major challenge of telephone survey is to obtain a reliable sampling frame of telephone numbers
  - Often phone numbers are collected through face-to-face surveys and then used for subsequent telephone surveys
- Response rates tend to be lower compared to face-to-face surveys
- Difficult to put respondent's neighborhood and background characteristics in perspective
- Body language and facial expressions are difficult to visualize
- Not suitable for long, complex surveys

Self-administered mode of data collection

- Examples of such surveys include the following:
  - Mailing questionnaire
  - Web surveys
  - Audio computer-assisted self-interviewing (ACASI) through voice recording of questions and use of headphones by the respondent for privacy
- Avoid interactions between interviewer and respondent during data collection
- Such modes of data collection are known to increase sensitive behaviour reporting because of increased privacy and confidentiality
- Can reduce social desirability bias for certain types of surveys involving sensitive topics, e.g., alcohol consumption, political preference, contraceptive use, selective abortions, domestic violence, practice of discrimination based on caste, religion and economic status
- Response rates are usually lower compared to face-to-face surveys
- Ability of respondent to use ACASI and user preferences may vary with level of education

COVID-19 Trends and Impact Survey (CTIS)

- CTIS is a world-wide web survey (self-administered) in the times of COVID-19
- University of Maryland and Carnegie Mellon University in partnership with Facebook have been conducting this survey daily since April 2020
    - > 200 countries and > 50 languages
- FB users are invited to take part in the surveys
    - self-report COVID-19-related symptoms
    - experience with COVID tests
    - contacts with others
    - mental health and economic security
    - disruptions in routine health services
    - Vaccination and vaccine hesitancy
- Designed to help monitor and forecast how COVID-19 may be spreading, without trading off the privacy of the people who took the surveys
- FB does not share background information of the respondents (FB users) with their academic partners, and they in turn do not share survey responses with FB

Methodology

- Sampling frame: Facebook Active User Base (FAUB) aged 18+ in India
- Study design: Repeated cross section design is used to draw new random sample of users daily
  - There could be repetition of survey request to the same users (particularly in small states), but should be treated as a new sample
- Sampling design: To select daily sample, stratified random sampling is considered (strata being the states) in order to provide representative sample at the national level
- Survey weights: The objective of constructing weights is to provide a weight per respondent so that respondents of CTIS better represent the target population

Weighting: Step 1

- Two types of adjustment are done to construct final weights so that the sample on each day represents the adult population at the state level and India level
  - minimize nonresponse error and coverage error in survey estimates
- Step 1: From CTIS respondents to the FAUB
- Not everyone selected for CTIS responded- nonresponse
- Nonresponse error is minimized by using Inverse Propensity Score Weighting (IPSW) method to make the sample more representative of FB users
- Covariates in the IPSW model: FB team included user characteristics collected from FB users

Weighting: Step 2

- Step 2: From FB users to general adult population
- Not all adults are FB users- undercoverage
- Coverage error is minimized by adopting poststratification adjustment of weights with Step 1 weights as inputs
- Poststrata are defined over age (4 categories: 18-24, 25-44, 45-64, 65+) and gender (2 categories) within each state
  - Urban-rural area of residence was not considered as a poststratum
- External benchmarks are obtained from the UN 2019 world population projections
- Conclusion: The final weights can be interpreted as the (estimated) number of adults in the general adult population represented by a CTIS respondent for that day

QUESTIONNAIRE DESIGN

(Although part of the PPT- was not covered during the presentation as it was supposed to be covered in another session)

Questionnaire design

- Quantitative and qualitative method of data collection
  - Survey data collected through a structured questionnaire is commonly known as quantitative data
  - Data collected without a structured questionnaire is known as qualitative data
    - For example, data collected through focus groups discussions (FGDs), in-depth interviews (IDIs) or key informant interviews (KIIs)
- In this course, we focus on quantitative data collection
- Questionnaire designing is an important component for any survey
  - It requires a lot of effort to come up with the right questions appropriately framed and worded
  - Reasonable amount of time needs to be devoted
  - Lousy questionnaires lead to erroneous data

Questionnaire design

- Pre-testing and pilot-testing of questionnaires
  - It is crucial to follow this step before starting the data collection so that field realities are addressed in the questionnaire
  - The project/research team members should visit the field for pre-testing of questionnaires to get direct feedback from the field
- Linking of different questionnaires based on unique IDs is the key
  - household-mother-child-health facility survey questionnaire
  - survey of one male and female member from the same household and the village questionnaire where they reside
  - household and police station questionnaire for crime related surveys
- Implement and program skip patterns logically and accurately
  - The goal is not to ask “Not applicable” or irrelevant questions to the respondents
  - At the same time, we should not lose out legitimate and valid information from participants

Questionnaire design

- Questions should be comprehensible to the respondent
  - The questionnaire should pay attention to use appropriate examples and references
  - For example, while recording childhood immunization status based on mother’s recall, it is important to ensure that mother understands what vaccines are being referred to in the questionnaire so that accuracy of response can be guaranteed

Questionnaire designing in computer assisted surveys

- Interview process less intimidating and stress free for interviewers
  - Program all the skip patterns and logical routing accurately so that no relevant data is lost and no irrelevant questions are asked
- Grid approach, as usually done in paper-based mode, may not be the most efficient
  - Use loops efficiently to capture all instances
  - Use cues in such as way that it helps capturing the underlying truth better (e.g., work details of all HH members, hospitalization episode wise expenditure, contraceptive use before each pregnancy)
- Use fill logics to display the questions differently depending on the situation (e.g., selling price of crops vs harvesting price, wage rate: daily/ monthly/ fixed one-time)

SAMPLING DESIGN

Sampling design is the method of selecting random sample

Choice of sampling design is an integral part of the overall survey design

We will discuss different sampling designs and their relative advantages

Sampling design: Method of selecting sample

- Probability sampling is a scientific approach of sample selection that satisfies certain conditions:
  - Each element in the population has a (known) nonzero probability of selection
  - A sample is selected by a random mechanism (implemented by some type of algorithm)
- Advantages of probability sampling
  - Selection biases are avoided
  - Randomly selected samples are viewed as objective
  - Statistical theory can be used to derive properties of the survey estimators

Nonprobability sampling

- Convenience, judgement or purposive sampling, quota sampling
  - For example, volunteer subjects for studies; the patients of a given doctor; persons posting their comment on Facebook
- Main weaknesses of nonprobability sampling:
  - Subjectivity, bias
  - Precludes the development of a theoretical framework for it
  - Can be assessed only by subjective evaluation
- Still widely used in practice, mainly for reasons of cost and convenience (e.g., in the absence of sampling frame)

Probability sampling techniques

- Simple random sampling (SRS)
- Systematic sampling (SYS)
- Probability proportional to size (PPS) sampling
- Stratified sampling
- Cluster sampling- usually multistage
- In practice, many sampling designs are often employed together in what become complex sampling designs
  - Most of the large-scale national level surveys in India combine two-three sampling designs together

Basic principles in estimation from probability samples

- Let y_k be the value of the outcome of interest corresponding to the kth unit in the population
- y_k can be income of kth household, employment status of kth individual, whether the kth child is vaccinated
- Population mean (average) is defined as
- $\bar{Y} = \frac{1}{N}\sum_{k=1}^{N} y_k$, N being the (known) population size

Estimation of population mean ($\bar{Y}$)

- We have selected a sample of size n $(< N)$ from the population using a probability sampling design
- Survey weighted sample total is an unbiased estimator of population total
- Hence, an unbiased estimator of population mean is
  $\bar{y}_w = \frac{1}{N}\sum_{k=1}^{n} w_k y_k$
  - w_k is the survey weight for the kth unit
  - It is (usually) defined as the inverse of the selection probability
- If N is unknown, we need to estimate the population size
- An approximately unbiased estimator of population mean is $\bar{y}_w = \frac{\sum_{k=1}^{n} w_k y_k}{\sum_{k=1}^{n} w_k}$

Unbiasedness

- In repeated sampling, the average of the estimates will be equal to the population parameter
- $Bias(\bar{y}_w) = \mathrm{E}(\bar{y}_w) - \bar{Y}$
- Since $\bar{Y}$ is unknown, it is difficult to quantify the bias
- We need to ensure that we design our survey in such a way that the bias is minimized

Simple random sampling (SRS)

- Natural starting point for a discussion of probability sampling designs
  - Not because it is widely used (it is not), but it is the simplest
  - Helps to understand more complex scenarios
- Definition: every sample s (of size n from a population of size N; $N \gg n$) has the same probability of being selected
  - implies that every element in the population has the same probability of being included in the sample
  - definition is more stringent than this

Estimation of population mean ($\bar{Y}$) under SRS

- Selection probability $\pi_k = \frac{n}{N}$
- $\bar{y}_w = \frac{1}{N}\sum_{k=1}^{n} w_k y_k = \frac{1}{n}\sum_{k=1}^{n} y_k = \bar{y}$
- Sample mean ($\bar{y}$) is an unbiased estimator of $\bar{Y}$
- $Var(\bar{y}) = \left(1 - \frac{n}{N}\right)\frac{S^2}{n}$
- Measure of variability (precision) depends on 3 factors:
  - Finite population correction ($\mathrm{fpc} = 1 - f$, where $f = \frac{n}{N}$ is the sampling fraction)
  - Sample size (n)
  - Variability of the outcome (S^2)

Determinants of precision

1. fpc term reflects the fact that the survey population is finite in size

   In many practical situations the populations are large and, even though the samples may also be large, the sampling fractions are small

2. Larger the sample, the smaller is variance

   Sample size rather than the sampling fraction is more important

   A sample of 1000 individuals drawn from Kerala (3.5 crore population) yields about as precise results as a sample of the same size drawn from the Chandigarh (10 lakh)- assuming that the variability in outcome are same in the two populations

3. Variability in outcome as measured by the quantity S^2
   - Larger the variability lower will be the precision

- How to improve the precision of an estimator if S^2 is large (which we cannot really control)?
  - Increase your sample size (may not always be a good idea)
  - Use better sampling designs and estimators

Estimation of population proportion (P)

- Proportion of stunted children, households having latrine facility, prevalence of diabetes
- Results for a proportion follow directly from those for a mean
- Proportion is just a special case of a mean for binary variables
- Define $y_k = 1$ if the kth unit has the attribute and $y_k = 0$ if not
- Then $\bar{Y}$ is simply P, population proportion with the attribute
- Sample mean $\bar{y}$ is the sample proportion p

Estimation of P

- Sample proportion p is an unbiased estimator of population proportion P
- $Var(p) = \left(1 - \frac{n}{N}\right)\frac{PQ}{n}; Q = 1 - P$
- The formula can also be used with percentages, by defining $Q = 100 - P$

Design effect

- While estimating population mean, SRS design coupled with sample mean as an estimator, is often taken as a point of reference
- To compare alternative designs and/or estimators, the ratio of variance of the alternative strategy to the SRS strategy is used
- The variance ratio is called the design effect
- When the design effect exceeds 1, precision is lost by not using the SRS design
  - For multi-stage cluster sampling, the design effect is almost always greater than 1
  - It can take values 2 or even more, depends on the degree of homogeneity of sampling units within cluster
  - The justification for cluster sampling is the logistical convenience and economy it creates for sampling and data collection

How to select an SRS?

- Computer will do it for you- different functions are available across software packages
- Sometimes you might have to do it while out in the field
- One way of selecting the SRS is by using a random number table
- In the long run each digit, each pair of digit, and so on, appears with the same frequency
- Key is to assign equal number of random numbers to each population unit- so that the sample remains an SRS

Random Number Table

11164	36318	75061	37674	26320	75100	10431	20418	19228	91792
21215	91791	76831	58678	87054	31687	93205	43685	19732	08468
10438	44482	66558	37649	08882	90870	12462	41810	01806	02977
36792	26236	33266	66583	60881	97395	20461	36742	02852	50564
73944	04773	12032	51414	82384	38370	00249	80709	72605	67497
49563	12872	14063	93104	78483	72717	68714	18048	25005	04151
64208	48237	41701	73117	33242	42314	83049	21933	92813	04763
51486	72875	38605	29341	80749	80151	33835	52602	79147	08868
99756	26360	64516	17971	48478	09610	04638	17141	09227	10606
71325	55217	13015	72907	00431	45117	33827	92873	02953	85474

Million Random Digits, Rand Corporation, Copyright, 1955, The Free Press. The publication is available for free on the Internet at http://www.rand.org/publications/classics/randomdigits.

Systematic sampling (SY)

- It offers several practical advantages, particularly its simplicity of execution
- A first element is drawn at random (and with equal probability) among the first a elements in the population list- *random start (r)*
- The positive integer a is fixed in advance and is called *sampling interval (N/n)*
- No further random draw is needed
- Rest of the sample is determined by systematically taking every ath element thereafter, until the end of the list
- Selected units are $\{r + a(j-1); j = 1, \ldots, n\}$

Advantages and properties

- The simplicity of only one random draw is a great advantage
- Like SRS, SY gives each element the same chance of being included in the sample
- $\pi_k = {}^{1}/_{a}$ (since each element k belongs to one and only one of the a equally probable systematic samples)
  - This property ensures that the sample mean is an unbiased estimator of population mean
- However, the probabilities of different sets of elements being included in the sample are not all equal
  - The SRS standard error formulae are not directly applicable with SY design

Example

- Suppose that a sample of 20 households (HHs) is required from a village of 300 HHs
- The sampling interval (a) is $300/20 = 15$
- Draw a random number between 1 and 15 (inclusively) to determine the random start (r)
- If r is 7, then the selected HHs would be the 7^{th}, 22^{nd}, 37^{th}, …., 277^{th}, and 292^{nd}
- To implement this technique, it is advisable to have a list at hand
  - Otherwise identifying the exact HH might become subjective- leading to selection bias

When sampling interval is not an integer

- Suppose that the population size is 292
- The sampling interval (a) is $292/20 = 14.6 \approx 15$
- Draw a random number between 1 and 15 to determine the random start (r)
- If the random number is 11, then the selected HHs would be the 11^{th}, 26^{th}, 281^{st}, 296^{th} (which does not exist in the list)
- One viable alternative is the circular systematic sampling method
  - The frame is laid out circularly, i.e., the last element ($k = N$) is followed by the first ($k = 1$) and so on.

Efficiency of systematic sampling

- SY can be more efficient than SRS under certain circumstances
- More homogeneous the elements within systematic samples are, the less efficient the systematic sampling is
- If we can arrange the list in a certain order, low degree of homogeneity can be achieved
  - Arrange the frame by increasing order of a covariate (if available) that is related to the outcome

Probability proportional to size (PPS) sampling

- Recall the unbiased estimator of population mean is $\bar{y}_w = \frac{1}{N}\sum_{k=1}^{n}\frac{y_k}{\pi_k}$; where π_k is the selection probability of the kth unit
- This estimator will have zero variance if π_k is proportional to y_k
  - which is impossible because it requires advance knowledge of outcome (y) for all units
- If we can find a covariate (x) that is proportional to outcome, then by choosing π_k proportional to x_k we can get approximately constant ratios y_k/π_k
  - consequently the variance of the estimator will be small (more efficient design)

PPS design

- Suppose we want to estimate total retail sale for different types of retail stores in Delhi
- Number of employees (size of the retail store) could be used as an auxiliary variable
- $\pi_k = \frac{n x_k}{\sum_{k=1}^{N} x_k}$
- Need to ensure that $\pi_k \leq 1$ is satisfied

Stratified sampling

- A certain amount of information is known about the elements of the population to be studied
- Supplementary information of this type can be used
  - at the design stage to improve the sampling design (e.g., through stratification)
  - and/or at the analysis stage to improve estimators
- Classify the population into subpopulations, or strata, based on some supplementary information
- Select separate samples from each of the strata (usually using SRS)
- Most of the potential gain in efficiency of PPS sampling can be captured through stratified design with SRS within well-constructed strata

Efficiency of stratified sampling

- A stratified design has the potential to be more efficient than SRS, as long as strata means are different wrt outcome
  - Greater the heterogeneity in strata means, more will be the gain in precision relative to SRS
  - Hence, it is important to choose the stratifying variables carefully
- It leads to a more representative sample as the sample covers all strata

Cluster and multistage sampling

- Cluster sampling, two-stage, multistage
- The justification for cluster sampling is the economy it creates for sampling and data collection
- The sampling economies are considerable with cluster sampling
  - Listing needs to be done only in the selected final stage clusters (village/urban wards)
  - With data collection by face-to-face interviewing, multistage sampling can give substantial savings in interviewer travel cost

Sampling design at each stage

- Different stages of sampling contribute to the variance of an estimator, under multistage cluster sampling
- Cluster sampling tend to be inefficient if
  - within-cluster homogeneity is sizable
  - High variation in cluster sizes
- It is important to be mindful about sample selection at each stage
- In practice, stratification is used at all the stages for which useful stratification factors are available, systematic sampling is also used
- Stratification is more important for sampling clusters than for sampling elements
  - It can yield much greater gains in precision when applied with clusters

Example: Delhi Metropolitan Area Study (DMAS)

- The objectives of DMAS are as follows:
  - Conducting methodological experiments in data collection involving technological innovations and innovations in questionnaire designing
  - Demonstrating the concept of remote monitoring of data collection activities to improve data quality by making the most of computer-assisted modes
- Target population for DMAS includes households in the national capital region (NCR) of India
  - Delhi (9 districts)
  - Rajasthan (2 districts)
  - Uttar Pradesh (7 districts)
  - Haryana (13 districts)
- Within a state, we considered a multi-stage stratified cluster sampling design
  - The goal was to select representative random sample at each stages of selection

DMAS sampling design

- Stage 1: Selection of districts (First stage units- FSU)
  - Census sampling frame was used for selection of districts
- Stage 2: Selection of second-stage units (SSUs)
  - SSUs are defined as census villages in rural areas and NSSO UFS blocks in urban areas
- Stage 3: Household (HH) Selection
  - No readily available sampling frame exists in India
  - A separate houselisting exercise was carried out in order to implement a probability sampling technique for HH selection
  - Listing of all households in the selected SSUs was used as the sampling frame for selection of HHs

Sample size estimation: general issues

- Identification of the primary study outcome
  - Outcome variable of interest
  - Indicator of interest (mean, proportion, rate)
- Determination of a margin of error or minimally important effect of intervention
- Specification of a statistical test or confidence interval method along with its directionality
  - One-sided or two-sided test
- It is crucial to incorporate sampling design features in sample size estimation

Role of population size

- Except in very small populations, precision of an estimator is obtained through the absolute size of the sample, not the proportion of the population covered
- Population size has little effect (almost nonexistent) on the variance of an estimator (measure of precision) in large populations
- Population size has little effect (almost nonexistent) on sample size estimation in large populations

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