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Meta-Analysis and Its Applications in Agricultural Sciences

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ABSTRACT

Meta-Analysis (MA) is one of the emerging and advanced methodology for quantitatively reviewing literatures for research that provides a wider picture of a research problem. The methodology combines secondary data from various primary studies and estimates the overall effect of an intervention or treatment. Though, it was first used in the field of medical sciences and psychology, its application has become wider and common even in agricultural sciences, especially economics and extension. MA helps in estimating the impact of an intervention by taking two different groups for comparison *viz.,* Control and Treatment. Researchers frame certain criteria (Inclusion-Exclusion) in order to decide the studies to be included or excluded for analysis. Once the number of studies to be included are finalized, the analysed data from these studies are pooled and analysed again through various Meta-Analytical methods. These methods include Basic MA and Advanced MA which involves calculation of effect sizes, heterogeneity tests, moderator and sensitivity analysis and publication bias assessment. The inference of an MA can be derived from the overall effect sizes (estimates of MA) which indicates the amount of effect or impact an intervention has on the sample. Therefore, MA by aggregating data from various primary studies is said to have higher statistical power and hence reveals increasing prominence in social sciences as well as in efficient policy making process.

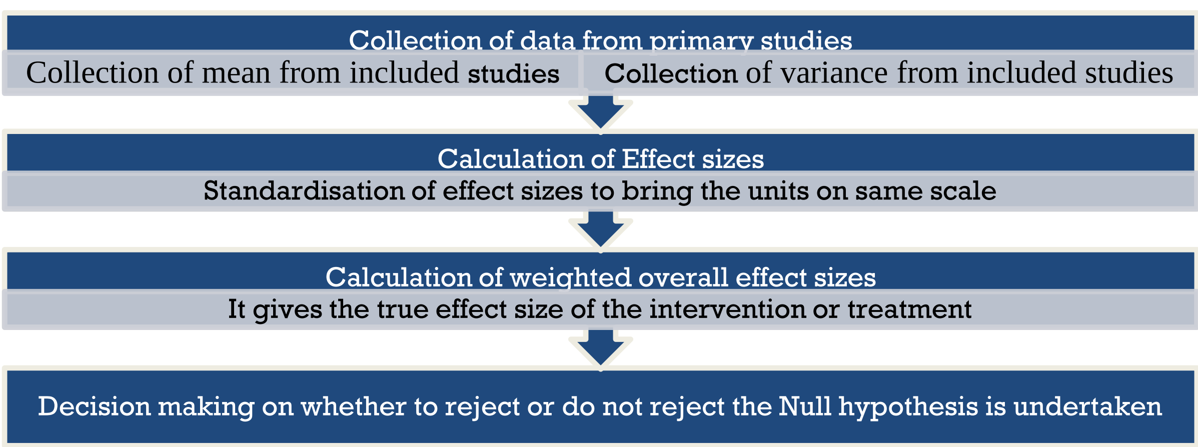
INTRODUCTION

Research, irrespective of the discipline, begins with framing a research question that pertains to a particular problem prevalent in the current time or region. Building the research on and relating it to the existing literatures is the building blocks of any research. An exhaustive review of literature helps in building foundational knowledge as well as identifying the existing gaps (researchable problem). This can either be narrative (traditional literature review) or systematic literature review (SLR). In the recent times, SLR has been evolved to quantitatively assess the existing literatures as Meta-Analysis (MA).

MA is defined as a statistical tool to estimate mean and variance of underlying population effects from a collection of studies addressing ostensibly the same research question (Field and Gillet, 2010). MA is a statistical technique that quantitatively pool results of individual included studies and thus helps in creating database, providing objective and significant result in terms of weighted average effect sizes. MA is specifically referred to as "Analysis of Analysis" because it involves extracting the already analysed data from the primary or included studies and analysing them one more time through the methods of MA. As reported by Joshi *et al.*, in 2005, MA up-scales numerous spatially and temporally distributed combinable micro-level studies to distil logical macro-level policy inferences.

WHAT MA DOES?

MA combines data from various sources such as already published or existing primary studies those answer the same research question. The combined data are extracted to separate excel sheets and then analyzed using various methods of MA such as Basic or Advanced Meta-Analysis. In general, MA provides the researcher with the overall effectiveness of the treatment



or intervention by comparing two groups' *viz.,* control group and treatment group.

HOW MA DOES?

TRADITIONAL UNIVARIATE META-ANALYSIS

The traditional univariate Meta-Analysis involves the calculation of effect sizes and gives the magnitude of variance among primary studies for quantitative synthesis. It can be grouped into two categories based on the analytical methods used for estimating the effect sizes. The first group of methods are called as Basic Meta-Analysis which deals with the enumeration of number of studies required for MA, calculating of effect sizes and choosing of correct models followed by heterogeneity test. The other group of methods are called as Advanced Meta-Analysis which helps in testing the validity and correctness of the calculated estimates (effect sizes) through methods such as Moderator analysis, Publication bias, Sensitivity analysis, Sub-group analysis, *etc.*

1. BASIC META-ANALYSIS

1.1 STATISTICAL POWER ANALYSIS

Statistical power analysis helps to determine if a given research question has enough published studies to warrant conducting a meta-analysis before the start of MA to know the feasibility of the analysis. In general, the number of studies recommended for inclusion is:

A. For a fixed-effects model, only two studies might be sufficient (Valentine *et al.,* 2009).
B. For a random-effects model, at least five studies are required (Jackson and Turner, 2017).

However, as the number of studies included for MA increases, the precision, reliability and quality of the analysis would also increase. The fixed-effects model assumes that the studies are sampled from population with fixed average effect sizes and hence the sample effect sizes are homogenous in nature. On the other hand, the random-effects model assumes that the studies are sampled from population with different effect sizes, which are in turn are sampled from a super-population. Hence the sample effect sizes under this model will be heterogeneous in nature.

1.2 CALCULATION OF EFFECT SIZES

Effect sizes are the standardized measure of the magnitude of observed effect of any intervention that enables for direct comparison as they are standardized. They represent the magnitude or size of the effect or impact of an intervention or treatment on the sample included for the analysis. Statistically, effect size refers to the mean differences between the control and treatment of any intervention. Effect sizes can be calculated using three parameters. **Pearson's correlation coefficient (r)** measures the strength of relationship between the variable and effect sizes. The inference based on r will be; small effect of the intervention on sample for r = 0.10, medium effect for r = 0.30 and large effect for r = 0.50. **Cohens'd** gives the standardized difference between two means of treatment and control from the included studies and is the most widely used measure. The inference represents small effect of the intervention for d = 0.30, medium effect for d = 0.50 and large effect for d = 0.80. **Odds ratio** is most widely used in medical sciences that represent the probability of occurrence of event in one group (treatment) compared to the other group (control). The odds ratio lies between zero to infinity and if the value equals to one, it indicates there is no effect of the intervention.

These effect sizes can be plotted graphically using forest plot (as in Figure 1) which represent the effect sizes and confidence interval for each study along with the overall effect sizes. Effect size and confidence interval for each study is represented and the overall total effect size also represented at the bottom of the graph in the shape of diamond. Forest plots can be created for both fixed and random effects model where the X-axis represent the Effect sizes and the Y-axis represent the included studies.

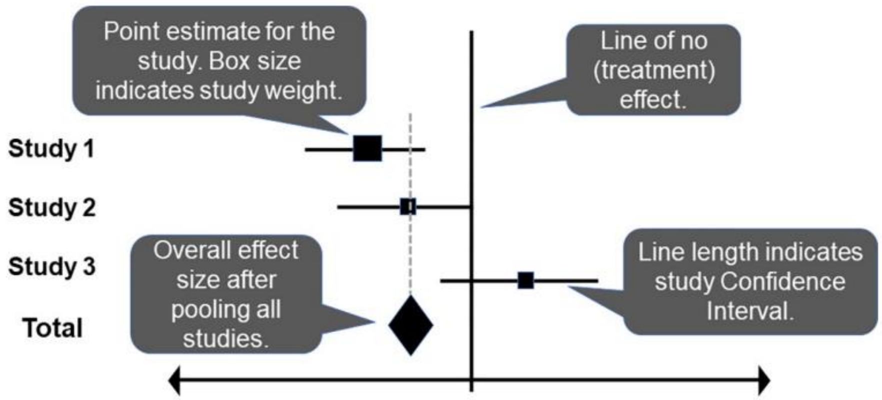


Figure 1. Description of a forest plot

1.3 HETEROGENEITY TESTS

MA employs various tests to know or check whether the effect sizes vary across the studies or not. There are three common tests of heterogeneity *viz.,* **Forest plot**, **Cochranes' Q statistic and Higgins' I^2 statistic.** If the forest plot of each study shows higher overlap between them, it indicates more homogeneous nature of effect sizes of all the included studies. The inference of p-values below 0.1 indicates statistical heterogeneity in Cochranes' Q statistic. The value of I^2 ranges from 0-100 per cent. The value of I^2 below 25 per cent, indicates strong homogeneity, 50 per cent indicates average heterogeneity or homogeneity and I^2 more than 75 per cent indicates strong heterogeneity.

2. ADVANCED META-ANALYSIS

2.1 MODERATOR ANALYSIS

The moderator analysis helps the researcher to know the reason behind the differences in the effect sizes across the research studies. It addresses the question of "Why the effect sizes vary across the studies?" by identifying the moderator variables. The moderator variables are the third variable that interacts with the independent variable and influence the dependent variable. It mediates the effect of the intervention or treatment on the sample or population under consideration. Through moderator analysis, the researcher can identify the variability among the studies, sub-groups and actual factors influencing the outcome.

2.2 PUBLICATION BIAS

Publication bias refers to the problem of not including those relevant studies that are not published due to the insignificancy in the results reported and occurs when only studies with significant results at 1 and 5 per cent level of significance are published and included for MA. It is also called as file-drawer problem and funnel-plot asymmetry, as the insignificant studies are always left in the file-drawer itself, never included in MA and it causes the effect size to be distributed asymmetrically around the funnel plot, respectively. **Funnel plot** is a graphical representation of effect sizes around the funnel or diagonal. It helps to determine the publication bias where if the points are clouded around the funnel, it indicates no bias. In the presence of publication bias, the plot will lack symmetry. If the true population effect size is nonzero, the part of the graph where the effects and the samples are both small is sparse.

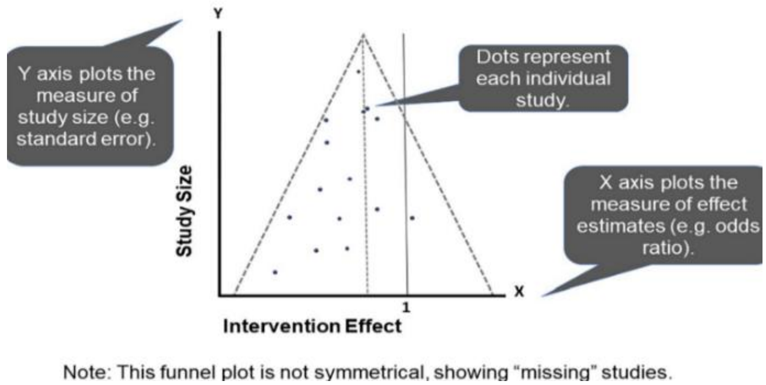


Figure 2. Description of asymmetrical funnel plot

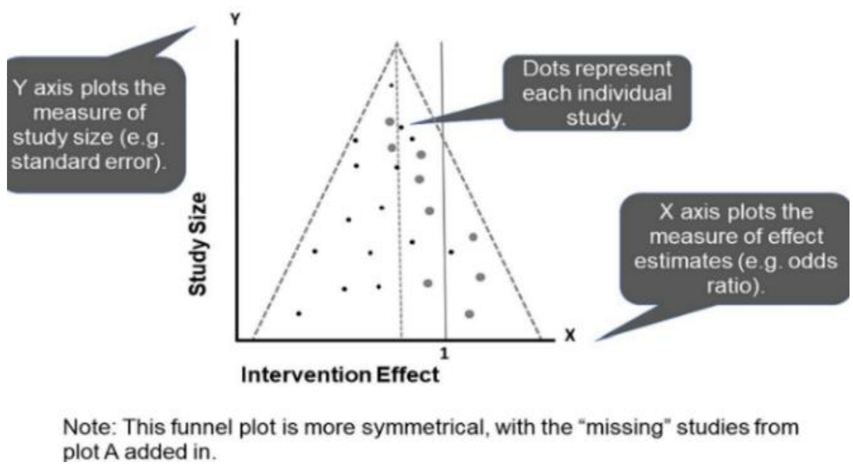


Figure 3. Description of symmetrical funnel plot

Source: Carlson et al., 2023

2.3 SENSITIVITY ANALYSIS

The sensitivity analysis helps the researcher to identify whether the effect sizes are sensitive to any changes made in the Meta-Analysis in terms of number of studies (sample size). This address the question of "Are the findings robust to the decisions made in the process of obtaining them?" The contribution of each individual study to the MA results and the change in the results by removing any of these studies is studied through sensitivity analysis. Hence, it helps to identify the influence of study bias by knowing the quality of studies included for MA.

APPLICATION OF MA IN AGRICULTURE

Meta-analysis in agriculture is a powerful tool used to synthesize research findings from multiple studies and provide a comprehensive understanding of specific agricultural phenomena. It involves the statistical analysis of results from different studies to derive pooled estimates of effects, identify patterns and provide evidence-based conclusions.

- MA helps in identifying the most effective, successful and sustainable agricultural practices.
- It identifies trends and projections of food availability across various climate scenarios, land use changes or economic conditions by combining various primary studies.
- MA provides reliable and evidence-based recommendations by aggregating data.
- It assesses the pooled impact of an intervention on the sample by comparing control vs treatment.
- MA helps to identify adxaptive strategies for different regions/crops to mitigate climate change.
- Policy or decision making is made more holistic by consolidate research as it compares genetically modified (GM) crops with conventional crops/ Traditional Vs Organic farming, *etc.*

APPLICATIONS OF MA IN ECONOMICS AND AGRICULTURAL ECONOMICS

1. Effects of immigration on wages
2. Impact of interventions in fisheries' co-management in developing countries
3. Impact of technical barriers to trade
4. Energy consumption and economic growth
5. Effect of currency unions on trade
6. Market structure and price transmission in agro-food sector
7. Income inequality and economic growth
8. Price and income elasticity of demand for meat, alcohol, cigarettes
9. Exchange rate volatility and trade
10. Debt and economic growth
11. Impact of Welfare policy on food security
12. Economic performance of organic vis-à-vis conventional farming

ADVANTAGES OF MA	LIMITATIONS OF MA
Improve precision as it has greater statistical power and hence provides a confirmatory data analysis and is an evidence-based source.	Resource intensive, time-consuming process as it may take at least a year and requires advanced statistical techniques.
MA helps in answering questions that are not posed by the individual studies.	Inadequacy in data for inclusion and analysis and if low-quality studies are included, the results will be biased and incorrect.
Settle controversies between conflicting studies and helps in generating a new hypotheses.	Heterogeneity of study populations as the treatment effects may vary.
Greater ability to extrapolate to general population affected.	Publication bias might overestimate actual effect magnitude.

CONCLUSION

Meta-analysis is an advanced reviewing methodology that employ quantitative methods to analyze various primary studies that answers a single or same research question. The quantitative estimation through MA provides an estimate that helps to identify the impact or effect of an intervention or a treatment on the sample or population under the research. There exists various methods of MA to study the reliability of the estimate and hence the methodology as a whole is a prominent technique for policy making. The scope of MA, especially for social scientists, is envisaged to be expanding owing to its prominence in policy making. This can be attributed to the greater statistical power of MA and the increased precision of the estimates.

Hence, the role of social scientists in policy making necessitates the upgrading of methodological skills among them for providing empirical evidences for policy making.

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