

META-ANALYSIS: A METHODOLOGY FOR RESEARCH SYNTHESIS

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1. The Knowledge Paradox in Scientific Analysis

The level of scientific knowledge has risen to an unprecedented degree in the post-war period: the cumulative stock of new knowledge has in the past **fifty** years far exceeded the total knowledge stock gathered by mankind during the previous centuries. Not surprisingly, our modern society is often referred to as a knowledge society. Notwithstanding this favourable picture, it is also increasingly recognized that the need for more information has almost risen limitlessly. From daily operational choices to long-term strategic decisions, the amount of information needed by decision-makers can hardly be satisfied or covered anymore. If thus seems that in a knowledge society the demand for scientific knowledge and information is even growing faster than the supply. This mismatch, called the **knowledge paradox**, prompts the question whether the balance between supply and demand can be restored.

A surprising feature of the abundance of scientific insights in our current knowledge society is the **lack of scientific synthesis**. The process of scientific knowledge gathering proceeds usually in a fragmented and individualised way, without due attention to research efforts made previously or elsewhere. This is clearly witnessed by the present popularity of and need for survey articles which aim to review concisely the state of affairs in a relevant area of scientific research. Most of these contributions - useful as they are - are however based on literary approaches, and certainly not on more rigorous approaches for comparative or synthesising analyses.

The fragmentation in the scientific knowledge acquisition process has led to the emergence of '**niches**' or '**islands**' of scientific knowledge, without a satisfactory - and fruitful - connection with scientifically related areas. Despite advances in artificial intelligence methods, cognitive evolutionary approaches and quantum computing, in many disciplines comprehensiveness has become an illusion, while even integration of knowledge cannot boost in high achievement. This observation holds certainly for interdisciplinary research, but even for intradisciplinary research addressing sometimes almost similar research questions the level of free communication and cooperation - leave aside integration - is feeble and problematic. This situation is not a coincidental development in the knowledge collection process, but is closely linked to the history of **science philosophy** in the western world.

In the past few centuries the major impact on the scientific research methodology has been exerted by Cartesian philosophy where **analysis** has become the central focus. Analysis means a breakdown of a complex reality into constituents which may be subjected to substantive and causal scientific investigation. The concentration on subsets of a complex constellation (made up of elements and relationships that exist in the real world) has certainly generated many important insights into separate phenomena (see Bal and Nijkamp 1999; Button et al. 1999). Remaining uncertainty was next tackled by a further fragmentation and analysis of relevant components of a phenomenon, without due attention to contextual factors which might have been identified through a consideration of related research efforts elsewhere. This ever **lasting** repetitive, deductive research methodology has led to a wealth of insights into details, but less so into major linkages within and between similar phenomena. As a consequence, a need has arisen to investigate the behaviour of complex systems by using principles from **synergetics**. This situation may also explain the current popularity of chaos theory which tries to study turbulence conditions in deterministic non-linear dynamic systems by infinitesimal changes in initial conditions (see also Nijkamp and Reggiani 1998). In any case, conclusive answers are usually difficult to find, and

beyond the horizon of a tentative finding on a fragment of reality, a new - usually even more detailed - research question appears to emerge.

In recent years, due to **improved communication** among scientists in a certain discipline (through professional networks, Internet, exchange of data bases) the perspective for a better exchange of knowledge has become more favourable, as the documentation, collection and retrieval of study results have become much easier. Nevertheless, the present situation still leaves much to be desired and inconsistencies - or large variations - between study findings are still more a rule than an exception. Hence, there is certainly a need for more context-specific research in a comparative sense, but this requires a serious effort and more research synthesis based on (quasi-) experimentation.

In empirical research, **we** may also often observe **statistical biases** emerging from small samples, measurement errors and biased data, so that indeed empirical research synthesis on distinct case studies may suffer **from** biases too. The only meaningful ways to overcome this cumbersome situation is to develop a proper - preferable quantitatively-oriented - methodology for a systematic comparison and synthesis of previously obtained analytical knowledge from in-depth (case-) studies. Against this background, **meta-analytical methods** may offer a promising new departure (see Van den Bergh et al. 1997). Such an effort may lead to a more satisfactory performance of research approaches, as it may be helpful to distinguish between phenomenon-intrinsic factors (e.g., behavioural response) and context-specific or moderator factors (e.g. site-specific and time-specific impacts, research methods).

Research synthesis does not only have a science-intrinsic benefit; it may also lead to major efficiency gains in empirical research through the possibility of (partial) **transferability** of practical results, e.g. for economic assessment or macro-economic forecasting. Knowledge transfer may essentially be conceived of as conditional forecasting where the parameters used for inferring statements on future states of a phenomenon under investigation are derived from information synthesis (e.g. **meta-analytical** experiments). Recent applications in this field can in particular be found in environmental economics, viz. benefit transfer or value transfer (see Button and Nijkamp 1999; Johnson and Button 1997; Loomis 1992).

In the light of the above background remarks, the aim of the present paper is to offer a further reflection on research synthesis by addressing the potential of **meta-analysis** (Section 2). Next, we will give a concise introduction into some operational meta-analytical methods and empirical applications (Section 3). The paper will be concluded with an outlook for further research.

2. The Potential of Meta-analysis

How much scientific effort is needed to reach a certain goal? It is surprising that in basic research this question is hardly raised nor answered. But essentially this is an economic question, where the allocation of scarce human resources is at stake. Against this background, it does not seem unrealistic to seek for an optimal level of scientific effort in a research process. In principle, one would have to look for an optimal control model with learning effects. In other words, we may investigate whether it is possible to infer certain scientific conclusions while **economising** on the input side of scarce intellect or creativity during a research process. It is by no means certain that more studies will ultimately lead to more or better insights, as there may be

decreasing (or even negative) marginal benefits (due to diseconomies and redundancy). In a statistical sense this question is often referred to as optimal data sampling, but especially in a more general sense this question is very intriguing. Do additional studies add to a better understanding of largely similar phenomena? Or in economic terms: do the additional scientific benefits of an extra case study outweigh the marginal costs?

This can be exemplified by referring to Columbus. When he asked Queen Isabella for financial support for this exploration of the New World, he needed to justify why he wanted three ships. He could convincingly argue that one ship would be too risky, whereas twenty ships would create serious logistic management problems. Thus, out of a set of rivalry hypotheses on the size of this research endeavour, he had to identify the optimal fleet size (see Van Doren 1991).

Another illustration can be found in Jane Jacobs' fascinating study on 'The Death and Life of Great American Cities' (1961). Her book addresses survival conditions of American cities, but in her empirical case it sufficed to address mainly New York City as the archetype of other American cities. Thus, although her analysis centered around New York City, she offered the building blocks for a comprehensive general theory on urban dynamics. Her analysis of the critical success and survival conditions of modern cities - sometimes in an anecdotal way - would most likely not have gained so much momentum and conviction, if she would have studied all American cities.

Clearly, case study research is essentially research focussing on the inference of general or transferable findings and is thus also a matter of optimal experimentation (see for details Yin 1994). A major problem inherent in social science research however, is lack of controlled experimentation in empirical investigations. A common design of case studies in different countries is mostly lacking. This is clearly exemplified by the varying *ceteris paribus* conditions assumed in distinct case studies. At best, case studies may address the same phenomenon, use more or less the same research methodology or employ to a large extent similar data. This makes of course a rigorous synthesis difficult, while also the degree of transferability may sometimes be questionable. This holds in particular when case studies are pooled which were never meant to be integrated in a meta-analytical experiment.

The conditions for a proper application of conventional statistical **meta-analysis** are fairly stringent. After its genesis in medicine and the natural sciences, meta-analysis was introduced in social science research in the 1970s to overcome common application problems such as the lack of large data sets in order to derive general results and the problem of uncertainty of information and of data values. **Meta-analysis** is a systematic framework which synthesises and compares past studies and extends and re-examines the results of the available data to produce more general results than earlier attempts have been able to do, by focussing on a joint kernel of previously undertaken research.

The meta-analysis approach thus offers a series of techniques on measurable phenomena that permit a quantitative aggregation of results across different studies. In so doing, it may, for instance, help to more clearly generate numerical values of the economic costs and benefits from the available data. It can also act as a supplement to more common literary-type approaches when reviewing the usefulness of parameters derived from prior studies and help direct new research to related areas. And finally, it may also help to understand the robustness of certain findings by referring to research synthesis as a kind of sensitivity analysis.

The introduction of meta-analysis as a formal procedure for analysing problems has emerged from the necessity to summarise and induce general results from studies already developed on similar problems. Meta-analysis is therefore concerned with the synthesis of results and findings from scientific studies. Glass, who in 1976 coined the term meta-analysis, provides a simple definition of this approach: "*Meta-analysis refers to the statistical analysis of a large collection of results from individual studies for the purpose of integrating the findings. It connotes a rigorous alternative to the casual, narrative discussions of research studies which typify our attempt to make sense of the rapidly expanding research literature*".

A commonly used method in social science research is meta-regression analysis. Such a statistical technique has been widely applied in biometrics and sociometrics with rather successful results. Since this approach uses a statistical tool, the input data must be quantitative data. The primary characteristics of a meta-regression analysis are the same as those used in standard regression analysis, i.e., the statistical linkage between one of the variables (the dependent variable) by means of other variables (the independent variables). The main problem is of course here the variance in the original underlying case study data.

Let us for the sake of illustration consider a number of studies which have addressed a common research problem, be it in different contexts and with different data. For instance, we may address the problem of congestion in commuting traffic. We may then consider studies on transport congestion which have been conducted in various countries at different times and with different samples. In general, the application of the meta-analysis methodology is used when there is a small set of case studies in which a general conclusion is difficult to obtain. Therefore, we combine different studies on the same topic in order to reach a more general conclusion. We can, so to speak, conceive of meta-analysis as a puzzle where each piece does not give the idea of the entire figure, but altogether the pieces make up an integral picture. This picture may of course be more cohesive, if the phenomena under investigation are not extremely study-specific. In addition, in a policy problem, for example, meta-analysis can be applied to reach a balanced decision in the present based upon prior decisions made in the past or elsewhere. To do so, it tries to define the relationship between cause and effect in the problem under investigation. The general form of a statistical meta-analytical problem will then be as follows:

$$Y = f(P, X, R, T, L) + \text{error}$$

where:

- Y is the variable under study which has been the focal point of the prior studies under scrutiny;
- P is what we consider to be the set of causes of the outcome Y;
- X represents the characteristics of the set of objects under examination affected by P in order to determine the outcome Y;
- R represents the characteristics of the research methods used in each study (e.g. econometric analysis or survey analysis), and the data (e.g., time series or cross sectional);
- T indicates the time period covered by each study in order to examine time dependency;
- L expresses the location where each study has been carried out.

In relation to the types of studies considered here, all of these variables are supposed to have a relative importance in our analysis. For instance, in the field of medical studies where the majority of the studies are experiments in a closed system with the same methodology, attention is mainly focused on the variables P and X.

The application of a meta-regression analysis - addressing average values of parameter values originating from different studies - can then generate meaningful comparative results we want to achieve in our survey analysis. After having obtained the regression results, we must carry out various tests that may verify the correctness of our results. Such tests generally try to assess the effect sizes in the study examined and the accuracy of the results. For instance, we can test how the indicator, chosen to reveal the effects of the problem under scrutiny, depends upon the design of the research, or how different estimates can be combined into one estimate of the effect size. The most frequently used statistical tests are the following:

- (1) **estimation of individual effect sizes:** this is an examination of the correlation of the 'policy' applied and the observed effect;
- (2) **vote-counting:** this is a procedure which assesses whether a specific effect does exist or not;
- (3) **combined significance:** this test aims to reach a conclusion concerning the existence for the effect under scrutiny;
- (4) **combining effect sizes and a test on homogeneity:** in this test, attention is given to the question of how different estimates can be combined into one estimate of the effect size;
- (5) **analysing effect sizes:** in this test, the variations among the estimated effect sizes are estimated.

After having calculated these tests, we will not only have a response to the assessment problem concerned, but also a more comprehensive understanding of the characteristics and limitations of the methodology adopted.

In the case of a (statistically-based) meta-regression analysis, the data that need to be collected must be quantitative data. Given this condition, a general guideline for deciding whether or not a particular study should be considered in a meta-analytical formulation is based on commonality in research issues. Therefore, a meta-regression analysis rests upon the following general rules: the study to be included must focus on the same phenomenon; it must use the same outcome measure and the same population characteristics, and finally, it must have a similar research objective. The problem of the selection of the studies is closely linked to the selection criteria that are needed to identify relevant studies. With regard to these criteria for the selection, particular care must be taken to ensure similarity among the studies. Moreover, we need to verify uniformity and standardisation in order to minimise possible errors in the calculation. To avoid this problem it may be necessary to conduct further experiments or to carry out new elaborations and estimations of the data presented in the individual studies (see Van den Bergh et al. 1997).

Due to its specific synthesis potential, a statistical meta-analysis approach may be a useful and rigorous substitute for the standard type of literature review of distinct case studies. Therefore, it can assume a relevant role in an initial phase of a study, because such a technique has the capacity to pinpoint aspects of a problem not immediately evident from a cursory examination of data. In the next section we will offer a broader scope for meta-analysis by emphasizing its potential in comparative studies.

3. Meta-analytical Methods and Applications

There are various methods for research synthesis and comparison. It is increasingly recognized that meta-analysis is not a single statistical method, but a mode of thinking (on research) in order to bring together research findings from different studies with a view to comparison, synthesis, knowledge acquisition, transferability or generalisation. Meta-regression is only one such method, but in practice there is a variety of approaches possible. We will offer a concise overview here.

In case of **nominal** information (i.e., the lowest measurement level), the variable under consideration from different studies do not have a numerical meaning, but we can count the frequency of occurrence of certain attributes and link them to other attributes. In this context, contingency table analysis and log-linear modelling may offer meaningful analytical assistance. Verbal and substantive information synthesis is, for instance, done in content analysis, **often** deployed in communication and media studies (see Hogenraad 1989).

If **we** have **categorical** information (e.g., from surveys,), then standard approaches such as **logit** analysis may be used to infer statistically valid results from a comparative analysis of case studies. Clearly, the sample should be sufficiently large to warrant this approach. Otherwise, soft-modelling approaches would have to be applied (see Nijkamp et al. 1984).

Next, the outcomes of various previous case studies may also be measured as **ordinal** rankings. In such cases, rank correlation analysis may be helpful and - if the sample size is sufficiently large - also ordinal meta-regression analysis. An alternative way of comparing ordinal outcomes of different case studies is the use of qualitative multi-criteria analysis, e.g., concordance analysis or regime analysis (see for a survey Nijkamp et al. 1992).

If the study findings of previous investigations are measured in a **cardinal** metric (either on an interval scale or a ratio scale), then the above mentioned meta-regression analysis may be a meaningful method. If the sample of case studies is not large enough, one may also employ normal correlation analysis or discriminant analysis.

Finally, there may also be cases where the outcomes of case studies are only linguistically measured, e.g., as a **fuzzy** expression. In that case, the use of fuzzy set analysis, in particular if a distinct classification with a numerical meaning of the variables (or classes) concerned can be made. For a further discussion on fuzzy set analysis is for comparative purposes we refer to Munda (1996). Finally, there is also the possibility that the performance of case studies is measured as class information, with distinct class sizes. In such cases **rough set analysis** appears to be a very **powerful** tool. For application of rough set analysis we refer to Van den Bergh et al. (1997) and Nijkamp and Ursem (1999).

Recently, also attempts have been made to identify commonalities and differences between case study results and to transfer results for predictive purposes - especially in the **framework** of land use planning, tourism and environmental management - by using **geographic information systems** (GIS). We refer to **Bateman** et al. (1998) for further details.

In conclusion, there is a wide variety of meta-analytical approaches. All of them aim to shed light on the key findings of various studies in order to synthesise the most

prominent results from earlier research work. In recent years, we have seen a steady growth in meta-analytical studies in economics, in particular in the area of regional, transportation and environmental economics. We will exemplify here the research potential of meta-analysis by referring to various studies undertaken in the above fields.

In the area of **regional economics**, meta-analytical studies have been undertaken inter alia in the assessment of regional tourist multipliers with the aim to derive the best possible estimate of a regional tourist income multiplier for a given tourist area on the basis of empirically estimated multiplier values for various other tourist destinations; (see Baaijens and Nijkamp 1998) and the identification of critical success factors for spatial sustainability policy (with the aim to identify the most important impediments and opportunities of urban environmental sustainability initiatives; see Nijkamp and Pepping 1998a). Techniques used in these applications were inter alia meta-regression analysis, discrete choice modelling, and rough set theory.

In the **transportation** field also various meta-analytical applications can be found. Examples are the estimation of the variance in public transport demand elasticities in various European countries (based on a synthesis of previously undertaken case studies; see Nijkamp and Pepping 1998b) and studies on congestion policy (based on an assessment of the effectiveness of traffic restraint policies; see Button and Kerr 1996). The meta-analytical methods used in these studies comprise again meta-regression analysis, correlation analysis and rough set theory.

Finally, in **environmental economic** research, we have witnessed a great variety of meta-analytical studies. Examples are the evaluation of contingent valuation methods for air pollution (see Smith and Huang 1995) and noise nuisance (see Button 1995). Also the methods deployed were meta-regression analysis and correlation analysis.

The field of meta-analytical research is a rapidly rising field, and in the final section we will offer some prospective remarks.

4. Prospect of Meta-analysis

Meta-analysis has turned into a research style which aims to combine generality and specificity (cf. Espey 1996). It may be a cost-effective and expeditious way of **economising** on research efforts through the focus on main determinants of a phenomenon, seen from a comparative perspective. The same applies to value and benefit transfer studies. Clearly, there is need for some caution: the moderator variables have to be carefully investigated and proper care for study- and **context**-specificity is warranted. Against this background, also the use of the ceteris paribus clause deserves due attention, as this is essentially a non-controlled black box (see Bal and Nijkamp 1999; **Persky** 1990).

A new field where meta-analysis may likely play an interesting role is **micro**-based survey research. To some extent, the collection and description of the attributes of a given individual may be conceived of as a detailed case study **focussed** on one person. By combining the survey results on multiple persons • while addressing the same research issues across the entire sample of individuals -, the response variables can be treated and ‘explained’ in the same way as in a standard meta-analysis (including the correction for context-specific factors etc.).

Another area where meta-analysis can usefully be deployed is a review of reviews; in other words, a **meta** study on meta-analyses. This requires of course a

sufficiently large sample of meta-studies, but in some disciplines such meta-studies do exist, e.g., in educational sciences. A good example can be found in Becker (1998), who classified meta-studies systematically into instructional books, methodological books and application-oriented books. Each of these classes of meta-studies was next investigated in more detail albeit only in a literary form.

And finally, there may be new perspectives for meta-analysis by linking it to Bayesian statistics. By regarding previous case studies as sources of prior information, adjusted Bayesian tools may be applied (see e.g. Lubbe 1998).

In combination with large data bases and improved access to computerized information systems, meta-analysis will most likely become an important tool in normal research practice. In addition to a synthesis of knowledge, it will increasingly be used in a deductive science methodology as well as in the applied field of forecasting with a view to the identification of bandwidths in the variation of phenomena.

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