

1 **Dossier: visualizing/ understanding decision choices in data analysis via**
2 **decision similarity**
3

4 **ANONYMOUS AUTHOR(S)**
5

6 Decision choices made during data analysis, along with the reasons motivating them, are central to how results are interpreted and to
7 comparisons across similar studies. However, such decisions – such as selecting the degree of freedom for a smoothing spline and the
8 rationale behind them – are rarely studied, since it is impractical to interview authors for all the alternatives and their motivations or
9 to rerun the analysis under different options. In this work, we propose a workflow to automatically extract analytic decisions from the
10 published literature and organize them into structured data using Large Language Models (Claude and Gemini). The pipeline then
11 calculates paper similarity based on the semantic similarity of these extracted decisions and their reasons, and visualizes the results
12 using clustering algorithms. We apply this workflow to a set of studies on the effect of particulate matter on mortality and hospital
13 admission, conducted by researchers worldwide, which naturally provide alternative analyses of the same question. Our approach
14 offers an efficient way to study decision-making practices and robustness in data analysis compared with traditional interviews or
15 author-focused sensitivity or multiverse analyses.
16

17 CCS Concepts: • **Applied computing** → *Document analysis*; • **Human-centered computing** → *Empirical studies in HCI*.
18

19 Additional Key Words and Phrases: Large language models
20

21 **ACM Reference Format:**
22

23 Anonymous Author(s). 2025. Dossier: visualizing/ understanding decision choices in data analysis via decision similarity. In *Proceedings*
24 of CHI Conference on Human Factors in Computing Systems (CHI'26). ACM, New York, NY, USA, 20 pages. <https://doi.org/XXXXXX>.
25 XXXXXX

26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45 Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not
46 made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components
47 of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to
48 redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.
49

50 © 2025 ACM.
51 Manuscript submitted to ACM
52 Manuscript submitted to ACM

53 1 Introduction

54 Decisions are made at every stage of data analysis: from initial data collection and pre-processing to modelling choices.
 55 Different decision choices can have a direct impact to the final results, which can lead to different interpretation and
 56 policy recommendations that follow. When independent analysts analyzing the same dataset even to answer the same
 57 research questions, through many-analysts experiments, they often arrive at markedly different conclusions [8, 19, 42].
 58 This variability in results can be attributed to the flexibility analysts have in making decisions throughout the data
 59 analysis process, which Gelman and Loken [18] describe as the “garden of forking paths”. When such flexibility is
 60 misused, data analysis can lead to p-hacking, selective reporting, inflated effect sizes, and other issues, undermining the
 61 quality and credibility of the findings.
 62

63 Multiple recommendations have been proposed to improve data analysis practices, such as pre-registration and
 64 multiverse analysis. Bayesian methods also offer a different paradigm to p-value driven inference for interpreting
 65 statistical evidence. Most empirical studies of data analysis practices focus on specially designed and simplified analysis
 66 scenarios. While informative, these setups may not adequately capture the complexity of the data analysis with
 67 significant policy implications. [In practice, studying the data analysis decisions with actual applications is challenging.]
 68 Analysts may no longer be available for interviews due to job changes, and even when they are, recalling the full set
 69 of decisions and thinking process made during the analysis is often infeasible. Moreover, only until the last decades,
 70 analysis scripts and reproducible materials were not commonly required by journals for publishing. [As a result, it
 71 remains challenging to study how analytical decisions are made.]

72 In this work, we develop a tabular format to record analytical decisions in data analysis and automate the extraction
 73 of these decisions from published papers using large language models (Gemini and Claude). The workflow also include a
 74 component to calculate paper similarity based on both the decisions and the semantic similarity of their rationales, and
 75 use clustering methods to visualize papers according to distance based on decision similarity. We apply this workflow to
 76 a set of 62 air pollution modelling studies estimating the effect size of particulate matter (PM2.5 or PM10) on mortality
 77 and hospital admissions, typically modeled using Poisson generalised linear models (GLMs) or generalized additive
 78 models (GAMs). Analysis of the extracted decisions reveals common choices in this type of analysis (number of knots
 79 or degree of freedom for smoothing methods for time, temperature and humidity) and find three distinct clusters
 80 corresponding to different smoothing methods (LOESS, natural spline, and smoothing spline) used in European and U.S.
 81 studies, consistent with findings from the APHENA project.
 82

83 The contribution of this work includes:

- 84 • A new approach to study data analysis decision choices through automatic extraction of decisions from scientific
 85 literature using LLMs,
- 86 • A dataset compiled from 62 papers to study decision-making in air pollution mortality modelling, and
- 87 • A method to construct similarities between papers based on decision similarities.

95 2 Related work

97 2.1 Decision-making in data analysis

98 A data analysis is a process of making choices at each step, from the initial data collection to model specification, and
 99 post-processing. Each decision represents a branching point where analysts choose a specific path to follow, and the
 100 vast number of possible choices analysts can take forms what Gelman and Loken [18] describe as the “garden of forking
 101 paths”. While researchers may hope their inferential results are robust to the specific path taken through the garden,
 102

in practice, different choices can lead to substantially different conclusions. This has been empirically demonstrated through “many analyst experiments”, where independent research groups analyze the same dataset to the same answer using their chosen analytic approach. A classic example is Silberzahn et al. [42], where researchers reported an odds ratio from 0.89 to 2.93 for the effect of soccer players’ skin tone on the number of red cards awarded by referees. Similar variability has been observed in structural equation modeling [40], applied microeconomics [22], neuroimaging [8], and ecology and evolutionary biology [19].

Examples above have rendered decision-making in data analysis as a subject to study in data science. To collect data on how analysts making decisions during data analysis, researchers have conducted interviews with analysts and researchers on data analysis practices [2, 24, 29], visualization of the decision process through the analytic decision graphics (ADG) [30]. Recently, Simson et al. [43] describes a participatory approach to decisions choices in fairness ML algorithms. Software tools have also developed to incorporate potential alternatives in the analysis workflow, including the DeclareDesign package [7] and the multiverse package [39]. The DeclareDesign package [7] introduces the MIDA framework for researchers to declare, diagnose, and redesign their analyses to produce a distribution of the statistic of interest, which has been applied in the randomized controlled trial study [6]. The multiverse package [39] provides a framework for researchers to systematically explore how different choices affect results and to report the range of plausible outcomes that arise from alternative analytic paths. Other systems have been developed to visualize multiverse analysis [31].

2.2 Visualization on scientific literature

Much of the work on IEEE visualizing scientific literature focuses on helping researchers stay aware of relevant publications, given the rapidly growing volume of scientific output and the difficulty of navigating it. Systems have been developed to support the discovery of relevant papers, where relevance is typically determined by keywords [23], citation information (e.g. citation list, co-citation) [13], or combinations with other relevant paper metadata (e.g. author, title) [5, 14, 17, 20]. More recent approaches incorporate text-based information from the abstract or sections of the paper to [obtain a better similar metric]. This includes using topic modelling [1], argumentation-based information retrieval [44], and text embedding [36]. While these metadata information and high level text-based information are valuable for discovering relevant papers, for data analysis, researchers need tools that help them *make sense* of the literature rather than simply *finding* it. Capturing the decisions and reasoning expressed during analyses within a similar theme can reveal common practices in the field and guide decisions choices in new applications. With recent advances in Large Language Models (LLMs), it has become possible to automatically extract structured information from unstructured text through prompting. This allows scientific literature to be clustered and visualized using information about the underlying decisions and reasoning made during analysis, providing a basis for studying analysts’ decision choices.

3 Methods

3.1 Decisions in data analysis

Decisions occur throughout the entire data analysis process – from the selection of variables and data source, to pre-processing steps to prepare the data for modelling, to the model specification and variable inclusion. In this work, we focus specifically on modelling decisions in the air pollution mortality modelling literature. These include the

choice of modelling approach, covariate inclusion and smoothing, and specifications of spatial and temporal structure. Consider the following excerpt from Ostro et al. [37]:

Based on previous findings reported in the literature (e.g., Samet et al. 2000), the basic model included a smoothing spline for time with 7 degrees of freedom (df) per year of data. This number of degrees of freedom controls well for seasonal patterns in mortality and reduces and often eliminates autocorrelation.

This sentence encode the following components of a decision:

- **variable:** time
- **method:** smoothing spline
- **parameter:** degree of freedom (df)
- **reason:** Based on previous findings reported in the literature (e.g., Samet et al. 2000); This number of degrees of freedom controls well for seasonal patterns in mortality and reduces and often eliminates autocorrelation.
- **decision:** 7 degrees of freedom (df) per year of data

The decision above is regarding a certain parameter in the statistical method, we categorize this as a “parameter” type decisions. Other types of decisions - such as spatial modelling structure or the inclusion of temporal lags - may not include an explicit method or parameter, but still reference a variable and rationale, which we will provide further examples below.

To record these decisions, we follow the tidy data principle [47], where each variable should be in a column, each observation in a row. In our context, each row represents a decision made by the authors of a paper and an analysis often include multiple decisions. To retain the original context of the decision, we extract the original text in the paper, without paraphrase or summarization, from the paper. Below we present an example of how to structure the decisions made in a paper, using the paper by Ostro et al. [37]:

Paper	ID	Model	variable	method	parameter	type	reason	decision
ostro	1	Poisson regression	temperature	smoothing spline	degree of freedom	parameter	NA	3 degree of freedom
ostro	2	Poisson regression	temperature	smoothing spline	degree of freedom	temporal	NA	1-day lag
ostro	3	Poisson regression	relative humidity	LOESS	smoothing parameter	parameter	to minimize Akaike's Information Criterion	NA
ostro	4	Poisson regression	model	NA	NA	spatial	to account for variation among cities	separate regression models fit in each city

209 Most decisions in the published papers are not explicitly stated, this could due to the coherence and conciseness of
210 the writing or authors' decision to include only necessary details. Here, we identify a few common anomalies where
211 decisions may be combined or omit certain fields:

- 212 1. **Authors may combine multiple decisions into a single sentence** for coherence and conciseness of the
213 writing. Consider the following excerpt from Ostro et al. [37]:

214 Other covariates, such as day of the week and smoothing splines of 1-day lags of average temperature
215 and humidity (each with 3 df), were also included in the model because they may be associated with
216 daily mortality and are likely to vary over time in concert with air pollution levels.

217 This sentence contains four decisions: two for temperature (the temporal lag and the smoothing spline parameter)
218 and two for humidity. These decisions should be structured as separate entries.

- 219 2. **The justification does not directly address the decision choice.** In the example above, the stated rationale
220 ("and are likely to vary over time in concert with air pollution levels") supports the general inclusion of temporal
221 lags but does not justify the specific choice of 1-day lag over alternatives, such as 2-day average of lags 0 and 1
222 (lag01) and single-day lag of 2 days (lag2). As such, the reason field should be recorded as NA.

- 223 3. **Some decisions may be omitted because they are data-driven.** For instance, Katsouyanni et al. [26] states:
224 The inclusion of lagged weather variables and the choice of smoothing parameters for all of the weather
225 variables were done by minimizing Akaike's information criterion.

226 In this case, while the method of selection (minimizing AIC) is specified, the actual degree of freedom used is not.
227 Such data-driven decisions may be recorded with "NA" in the decision field, but the reason field should still be recorded
228 as "by minimizing Akaike's information criterion"

- 229 4. **Information required to interpret the decision may be distributed across multiple sections.** In the
230 previous example, "weather variables" refers to mean temperature and relative humidity, as defined earlier in
231 the text. This requires cross-referencing across sections to identify the correct variables associated with each
232 modeling choice.

233 3.2 Automatic reading of literature with LLMs

234 **TODO:** Prompt engineering: these models may paraphrase or hallucinate unless explicitly told not to since it is
235 generative in nature based on the predicted probability of the next word from the text and the instruction

236 **TODO:** The Prompt Report: A Systematic Survey of Prompt Engineering Techniques <https://arxiv.org/pdf/2406.06608.pdf>
237 While decisions can be extracted manually from the literature, this process is labor-intensive and time-consuming.
238 Recent advances in Large Language Models (LLMs) have demonstrated potential for automating the extraction of
239 structured information from unstructured text [ref]. In this work, we use LLMs to automatically identify decisions
240 made by authors during their data analysis processes.

241 Text recognition from PDF document relies on Optical Character Recognition (OCR) to convert scanned images into
242 machine-readable text – capability currently offered by Anthropic Claude and Google Gemini. We instruct the LLM
243 to generate a markdown file containing a JSON block that records extracted decisions, which can then be read into
244 statistical software for further analysis. The exact prompt feed to the LLM is provided in the Appendix. The `ellmer`
245 package [48] in R is used to connect to the Gemini and Claude API, providing the PDF attachment and the prompt in a
246 markdown file as inputs.

261 3.3 Review the LLM output

- 262 • TODO something about result validation of LLM output: We also observe data quality with the extraction:
 263 for example in Lee et al. [28], the variable recorded is “smoothing parameter”. Authors are unclear about the
 264 delivery Specify how much of validation and review has been done.

265 The shiny app is designed to provide users a visual interface to review and edit the decisions extracted by the LLM
 266 from the literature. The app allows three actions from the users: 1) *overwrite* – modify the content of a particular
 267 cell, equivalently `dplyr::mutate(xxx = ifelse(CONDITION, "yyy" , xxx))`, 2) *delete* – remove a particular cell,
 268 `dplyr::filter(!(CONDITION))`, and 3) *add* – manually enter a decision, `dplyr::bind_rows()`. Figure 1 illustrates
 269 the *overwrite* action in the Shiny application, where users interactively filter the data and preview the rows affected by
 270 their edits—in this case, changing the model entry from “generalized additive Poisson time series regression” to the
 271 less verbose “Poisson regression”. Upon confirmation, the corresponding tidyverse code is generated, and users can
 272 download the edited table and incorporate the code into their R script.
 273

paper	id	model	variable	method	parameter	type	reason	decision
anderson2008size	1	generalized additive Poisson time series regression	temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	2	generalized additive Poisson regression	deep-point temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	3	generalized additive Poisson regression	calendar time	smoothing spline	degrees of freedom per year	parameter	NA	3, 4 or 5
anderson2008size	4	generalized additive Poisson time series regression	pollutant concentrations	NA	NA	temporal	NA	log 0-5 days examined
barrett2004air	1	cose-crossover model	model	NA	NA	temporal	NA	use fixed 20-day seasonal changes, no re-parameterization by design
barrett2004air	2	cose-crossover model	temperature	NA	NA	temporal	NA	to control for weather extremes of hot and cold
barrett2004air	3	cose-crossover model	temperature extremes	percentile	75 and 99th percentiles	parameter	NA	use constant estimates across cities using multi-level analysis
barrett2004air	4	random effects meta-analysis model	model	NA	NA	spatial	NA	combine estimates across cities using multi-level analysis
barrett2004air	5	cose-crossover model	air pollutants	NA	NA	temporal	NA	use average of previous day's day exposure
bel2003seasonal	1	2-stage Bayesian hierarchical model	temperature	natural cubic spline	6 degrees of freedom	parameter	NA	6 degrees of freedom
bel2003seasonal	2	2-stage Bayesian hierarchical model	deep point temperature	natural cubic spline	6 degrees of freedom	parameter	NA	3 degrees of freedom

1

paper	id	model	variable	method	parameter	type	reason	decision
anderson2008size	1	Poisson regression	temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	2	Poisson regression	deep-point temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	3	Poisson regression	calendar time	smoothing spline	degrees of freedom per year	parameter	NA	3, 4 or 5
anderson2008size	4	Poisson regression	pollutant concentrations	NA	NA	temporal	NA	log 0-5 days examined
barrett2004air	1	cose-crossover model	model	NA	NA	temporal	NA	to control for 20-day seasonal changes, no re-parameterization by design
barrett2004air	2	cose-crossover model	temperature	NA	NA	temporal	NA	to control for weather extremes of hot and cold
barrett2004air	3	cose-crossover model	temperature	percentile	75 and 99th percentiles	parameter	NA	use constant estimates across cities using multi-level analysis
barrett2004air	4	random effects meta-analysis model	model	NA	NA	spatial	NA	use average of previous day's day exposure
barrett2004air	5	cose-crossover model	air pollutants	NA	NA	temporal	NA	use average of previous day's day exposure
bel2003seasonal	1	2-stage Bayesian hierarchical model	temperature	natural cubic spline	6 degrees of freedom	parameter	NA	6 degrees of freedom
bel2003seasonal	2	2-stage Bayesian hierarchical model	deep point temperature	natural cubic spline	3 degrees of freedom	parameter	NA	3 degrees of freedom
bel2003seasonal	3	2-stage Bayesian hierarchical model	time	natural cubic spline	6 degrees of freedom	parameter	NA	8 degrees of freedom per year
bel2003seasonal	4	2-stage Bayesian hierarchical model	time by age	natural cubic spline	6 degrees of freedom per year	parameter	NA	1 degree of freedom per year

2

paper	id	model	variable	method	parameter	type	reason	decision
anderson2008size	1	Poisson-regression	temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	2	Poisson-regression	deep-point temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	3	Poisson-regression	calendar time	smoothing spline	degrees of freedom per year	parameter	NA	3, 4 or 5
anderson2008size	4	Poisson-regression	pollutant concentrations	NA	NA	temporal	NA	log 0-5 days examined
barrett2004air	1	cose-crossover model	model	NA	NA	temporal	NA	use fixed 20-day seasonal changes, no re-parameterization by design
barrett2004air	2	cose-crossover model	temperature	NA	NA	temporal	NA	to control for weather extremes of hot and cold
barrett2004air	3	cose-crossover model	temperature	percentile	75 and 99th percentiles	parameter	NA	use constant estimates across cities using multi-level analysis
barrett2004air	4	random effects meta-analysis model	model	NA	NA	spatial	NA	use average of previous day's day exposure
barrett2004air	5	cose-crossover model	air pollutants	NA	NA	temporal	NA	use average of previous day's day exposure
bel2003seasonal	1	2-stage Bayesian hierarchical model	temperature	natural cubic spline	6 degrees of freedom	parameter	NA	6 degrees of freedom
bel2003seasonal	2	2-stage Bayesian hierarchical model	deep point temperature	natural cubic spline	3 degrees of freedom	parameter	NA	3 degrees of freedom
bel2003seasonal	3	2-stage Bayesian hierarchical model	time	natural cubic spline	6 degrees of freedom	parameter	NA	8 degrees of freedom per year
bel2003seasonal	4	2-stage Bayesian hierarchical model	time by age	natural cubic spline	6 degrees of freedom per year	parameter	NA	1 degree of freedom per year

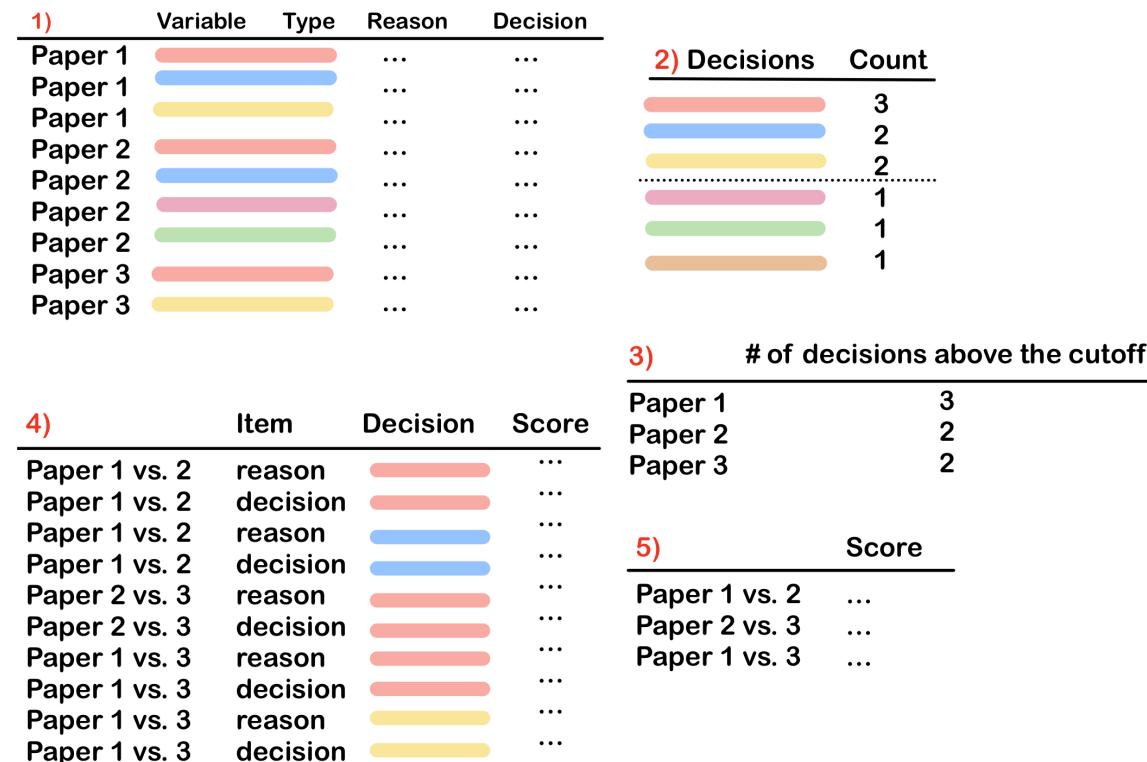
3

4

304 Fig. 1. The Shiny application interface for editing Large Language Model (LLM)-generated decisions (overwrite, delete, and add). (1) the default interface after loading the input CSV file. (2) The table view will update interactively upon the user-defined filter condition – expressed using `dplyr::filter()` syntax (e.g., `paper == anderson2008size`), (3) The user edits the model column to “Poisson
 305 regression” and applies the change by clicking the Apply changes button. The table view updates to reflect the changes (4) After
 306 clicking the Confirm button, the corresponding tidyverse code is generated, and the table view returns to its original unfiltered view.
 307 The edited data can be downloaded by clicking the Download CSV button.
 308

313 3.4 Calculating paper similarity

314 Once the decisions have been extracted and validated, this opens up a structured data for analyzing these information.
 315 For example, we can compare whether author's choices at different times changes, or across decisions varies at different
 316 regions. In this section, we present a method to calculate paper similarity based on the decisions shared in the paper
 317 pairs. The goal is to construct a distance metric based on similarity of the decision choice among papers that could
 318 be further used for clustering paper based on choices made by different authors in the literature. An overview of the
 319 method is illustrated in Figure 2.



350 Fig. 2. Workflow for calculating paper similarity based on decision choices: (1) standardize variable names, (2) identify most frequent
 351 variable-type decisions across all papers, (3) identify papers with at least x identified decisions, (4) calculate decisions similarity
 352 score on the *decision* and *reason* fields using transformer language models, e.g. BERT, (5) calculate paper similarity score based on
 353 aggregating decision similarity scores.

- 355 • TODO some discussion on what it means by for two papers to be similar based on decisions.

356 The calculation of paper similarity is based on the similarity of decisions shared by each paper pair. A decision
 357 comparable in two papers are the ones that share the same variable and type, e.g. temperature and parameter (a decisions
 358 on the choosing the statistical method *parameter* for the *temperature* variable), or humidity and temporal (any *temporal*
 359 treatment, e.g. choice of lag value for the *humidity* variable). While many decisions share a similar variable, different
 360 authors may refer to them with slightly different names, such as "mean temperature" and "average temperature", hence
 361 variable names are first standardized to a common set of variable names. For example, "mean temperature" and "average
 362

temperature” are both standardized to “temperature”. Notice that “dewpoint temperature” is standardized into “humidity” since it is a proxy of temperature to achieve a relative humidity (RH) of 100%. For literature with a common theme, there is usually a set of variables that shared by most papers and additional variables are justified in individual research. For our air pollution mortality modelling literature, we standardize the following variable names:

- **temperature**: “mean temperature”, “average temperature”, “temperature”, “air temperature”, “ambient temperature”
- **humidity**: “dewpoint temperature” and its hyphenated variants, relative humidity”, “humidity”
- **PM**: “pollutant”, “pollution”, “particulate matter”, “particulate”, “PM10”, “PM2.5”
- **time**: “date”, “time”, “trends”, “trend”

Depending on the specific pairs, papers have varied number of decisions that can be compared and aggregated. While paper similarities can be computed for all paper pairs, using the similarity of one or two pair of decisions to represent paper similarity is less ideal. Hence, before calculating the text similarity of decisions, we also include two optional steps to identify and subset the most frequent decisions across papers, and to retain only papers that report more than a certain number of frequent decisions. Research questions in different fields may have different levels of homogeneity, depending on the maturity of the field and for air pollution mortality modelling, it is helpful to focus on decisions and papers that share a substantial number of decisions.

To assign numerical value for the similarity of reason, we use a transformer language model, such as BERT, to measure the semantic text similarity between the decision itself and its justification. The decision similarity is calculated by comparing the *decision* and *reason* fields of the decisions in each paper pair. To obtain paper similarity, we average the decision similarities across all decisions in each paper pair and other method can be customized for aggregation. The resulting paper similarity score can be used as a distance matrix to cluster papers based on their decision choices to understand the common practices in the investigated literature.

4 Results

From the 56 studies examining the effect of particulate matters (PM₁₀ and PM_{2.5}) on mortality, we focus on the baseline model reported in each paper, excluding secondary models (e.g. lag-distributed models) and sensitivity analysis. We also exclude decisions on other pollutants, such as nitrogen dioxide (NO₂). This yields 242 decisions extracted using Gemini, averaging approximately 4 decisions per paper. Table 2 summarizes the number of edits made during the review process using the Shiny app. [details]

Table 3 summarizes the missingness of the decisions and reason. While most papers report their decision choices (e.g. use of five degree of freedom), 55% of decisions lack a stated rationale for the choice. Table 4 lists the eight most frequently reported decision: parameter and temporal choice for time, PM, temperature, and humidity.

Table 2. tsdjflkajsldf.

Reason	Count
Irrelevant decisions, e.g. other pollutants, sensitivity analysis	50
Recode for secondary LLM processing for standardization	45
Decision captured not correct	11
Duplicates	9
General statements without specific decision, e.g. minimum of 1 df per year was required	6

417 Table 3. Missingness of decision and reason fields in the Gemini-extracted decisions. Most decisions report the choice (35.5 + 57.1 =
 418 92%), but 57.1% lacks a stated reason.

Decision		
Reason	Non-missing	Missing
Non-missing	90 (37.2%)	14 (5.8%)
Missing	134 (55.4%)	4 (1.7%)

426
427 Table 2. tsdjflkajksldf.
428

Reason	Count
Definition of variables, e.g. season	5
Total	126

435 Table 4. Count of variable-type decisions in the Gemini-extracted decisions. The most commonly reported decision are the parameter
 436 choices and temporal lags for time, PM, temperature, and humidity.

Variable	Type	Count
time	parameter	44
PM	temporal	39
temperature	parameter	35
humidity	parameter	25
temperature	temporal	23
humidity	temporal	19
PM	parameter	9
time	temporal	3

452 Table 5 reports the parameter-related decisions captured in the literature. They refer to the number of knots or degree
 453 of freedom for spline methods (natural and smoothing spline) applied to variable time, humidity and temperature. For
 454 consistency, all values have been converted to a *per year* scale. The selection of knot for natural spline has less variation
 455 than the degree of freedom choices for smoothing spline. Choices for temperature and humidity tend to be close, given
 456 they are both weather related variables, while the choices for time are more varied inherently. This tabulation offers a
 457 reference set for potential options for future studies and help to identify anomalies and special treatment in practice.
 458 Notable example includes the use of 7.7 degree of freedom in Castillejos et al. [12], and highly flexible choices of 30 and
 459 100 in Moolgavkar [34] and Moolgavkar [35], respectively. While most papers choice to report the smoothing parameter
 460 as a constant value, Schwartz [41] specifies it as a proportion of the data (“5% of the data” and “5% of the data”).

461 For temporal decisions, after an initial review, we observed that decisions are still highly varied. The decisions can
 462 be divided into two groups: multi-day lags include expressions such as “6-day average”, “3-d moving average”, “mean of
 463 lags 0+1”, and “cumulative lags, mean 0+1+2”, and single-day lags include “lagged exposure up to 6 days”, “lag days from
 464 0 to 5” among others. To standardize these entries, we applied a secondary LLM process (claude-3-7-sonnet-latest) and
 465

469 converted them into a consistent format: multi-day: lag [start]-[end] and single-day: lag [start], . . .
 470 lag [end]. Table ?? summarizes the temporal lag choices for PM, temperature, and humidity. Both single and multiple
 471 day lags are generally considered up to five days prior (lag 5). [TODO: check multi-day starts from one].
 472

473 Table 5. Options captured for parameter choices for time, humidity, and temperature variables in the Gemini-extracted decisions.
 474 The choices for natural spline knots are generally less varied than the degree of freedom choices for smoothing spline. Choices for
 475 temperature and humidity tend to be close, given they are both weather related variables, while the choices for time are more varied
 476 inherently.
 477

Method	Variable	Decision
natural spline	humidity	3, 4
natural spline	temperature	3, 4, 6
natural spline	time	1, 1.5, 3, 4, 6, 7, 8, 12, 15, 30, NA
smoothing spline	humidity	2, 3, 4, 6, 8, 50
smoothing spline	temperature	2, 3, 4, 6, 8, 50
smoothing spline	time	1, 3, 4, 5, 6, 7, 7.7, 8, 9, 10, 12, 30, 100, NA

488 For computing the decision similarity score, we include the first 6 most common variable-type decisions as suggested
 489 in Table 4. Figure 4 shows the clustering of the 48 papers based on the decision similarity scores. The dendrogram is
 490 generated using hierarchical clustering, and the labels are colored according to the most common smoothing method
 491 used in each paper. The clustering reveals three distinct groups of papers, which reflect the modelling strategies differ
 492 in the European (LOESS) and U.S. (...) studies [more on the APHENA].
 493

494 5 Discussion

495 In this section, we examine the reproducibility for using LLMs for text extraction tasks in Section 5.1, discrepancies
 496 between different LLM models: Gemini (gemini-2.0-flash) and Claude (claude-3-7-sonnet-latest) in Section 5.2,
 497 and the sensitivity of our paper similarity calculation pipeline to the choice of text model used for computing decision
 498 similarity scores in Section 5.3.

503 5.1 LLM reproducibility

504 For our text extraction task, we test the reproducibility of Gemini (gemini-2.0-flash) by repeating the text extraction
 505 task 5 times for each of the 62 papers. For each of the 31 papers, five runs yield $5 \times 4/2 = 10$ pairwise comparisons per
 506 field and including both the “reason” and “decision” fields results in a total of $31 \times 10 \times 2 = 620$ pairs. We exclude the
 507 pairs that have different number of decisions since it would require manually align the decision to compare and this left
 508 us with 449 out of 620 (72%) pairwise comparisons. Table 6 shows an example of such comparison in Andersen et al. [3],
 509 where all the four reasons are identical among the two runs, hence a zero number of difference.
 510

511 Table 6. An example of comparing the text extraction in decisions in Andersen 2008.
 512

513 Variable	Run1	Run2
514 NCtot	6day average (lag 05)	6day average (lag 05)

521
522
523
524
525
526
527
528
Table 6. An example of comparing the text extraction in decisions in Andersen 2008.
529
530
531
532
533
534

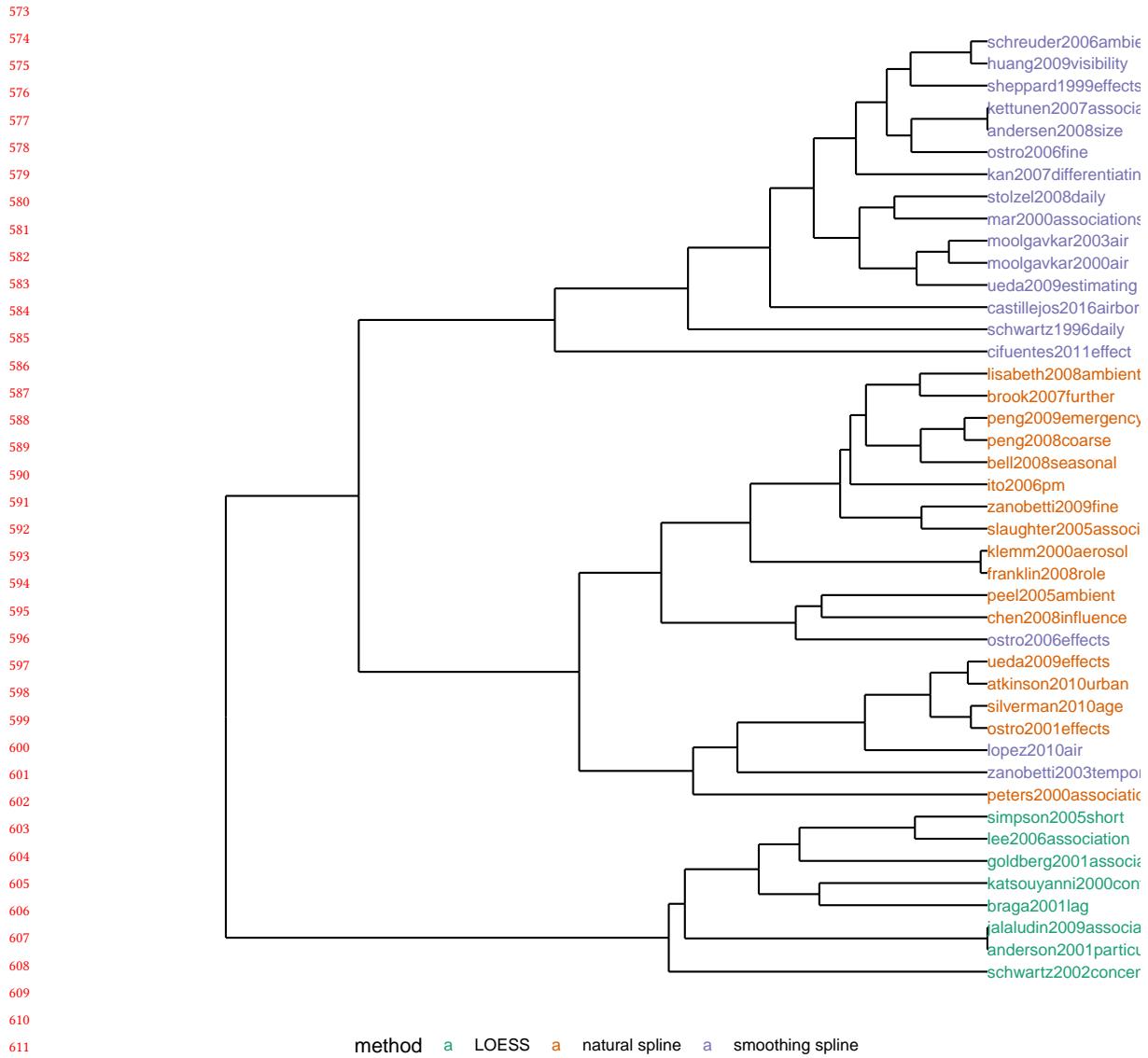
Variable	Run1	Run2
calendar time	3 4 or 5 dfyear	3 4 or 5 dfyear
dew-point temperature	4 or 5 df	4 or 5 df
temperature	4 or 5 df	4 or 5 df

535
536
537
538
539
540
541
542
543
544
545
546
Table 7 summarizes the number of differences observed in each pairwise comparison. Among all comparisons, 80%
produce the identical text in reason and decision. The discrepancies come from the following reasons:

- Gemini extracted different length for the same decision, e.g. in Kan et al. [25], some runs may extract “singleday lag models underestimate the cumulative effect of pollutants on mortality 2day moving average **of current and previous day concentrations** (lag=01)”, while others extract “singleday lag models underestimate the cumulative effect of pollutants on mortality 2day moving average (lag=01)”. Similarly, for decisions, some runs may yield “10 df for total mortality”, while other runs yield “10 df”. Similar extraction appears in Breitner et al. [9].
- Gemini fails to extract reasons in some runs but not others, e.g. in Burnett et al. [10], the first run generates NAs in the reasons, but the remaining four runs are identical. In Ueda et al. [46] and Castillejos et al. [12] , runs 1 and 5 fail to extract the reasons and produce the same incomplete version, whereas runs 2, 3, and 4 produce accurate versions with reasons populated.

550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
Table 7. Number of differences in the reason and decision fields across Gemini runs for papers with consistent number of decisions across runs.

Num. of difference	Count	Proportion (%)
0	358	79.73
1	12	2.67
2	8	1.78
3	0	0.00
4	24	5.35
5	12	2.67
6	3	0.67
7	0	0.00
8	10	2.23
9	6	1.34
10	10	2.23
11	6	1.34
Total	449	100.00



613 Fig. 3. The dendrogram (left) and multi-dimensional scaling (MDS) (right) based on paper similarity distance for 62 air pollution
 614 mortality modelling literature. The papers are colored by the most common smoothing method used. The MDS reveals the three
 615 distinct groups of papers. This grouping corresponds to the modelling strategies differ in the European and U.S. studies, documented
 616 in ALPHENA.

617

618

619 5.2 LLM models

620

621

622

623

624 Reading text from PDF document requires Optical Character Recognition (OCR) to convert images into machine-readable text, which currently is only supported by Antropic Claude (`claude-3-7-sonnet-latest`) and Google Gemini (`gemini-2.0-flash`).

624

Manuscript submitted to ACM

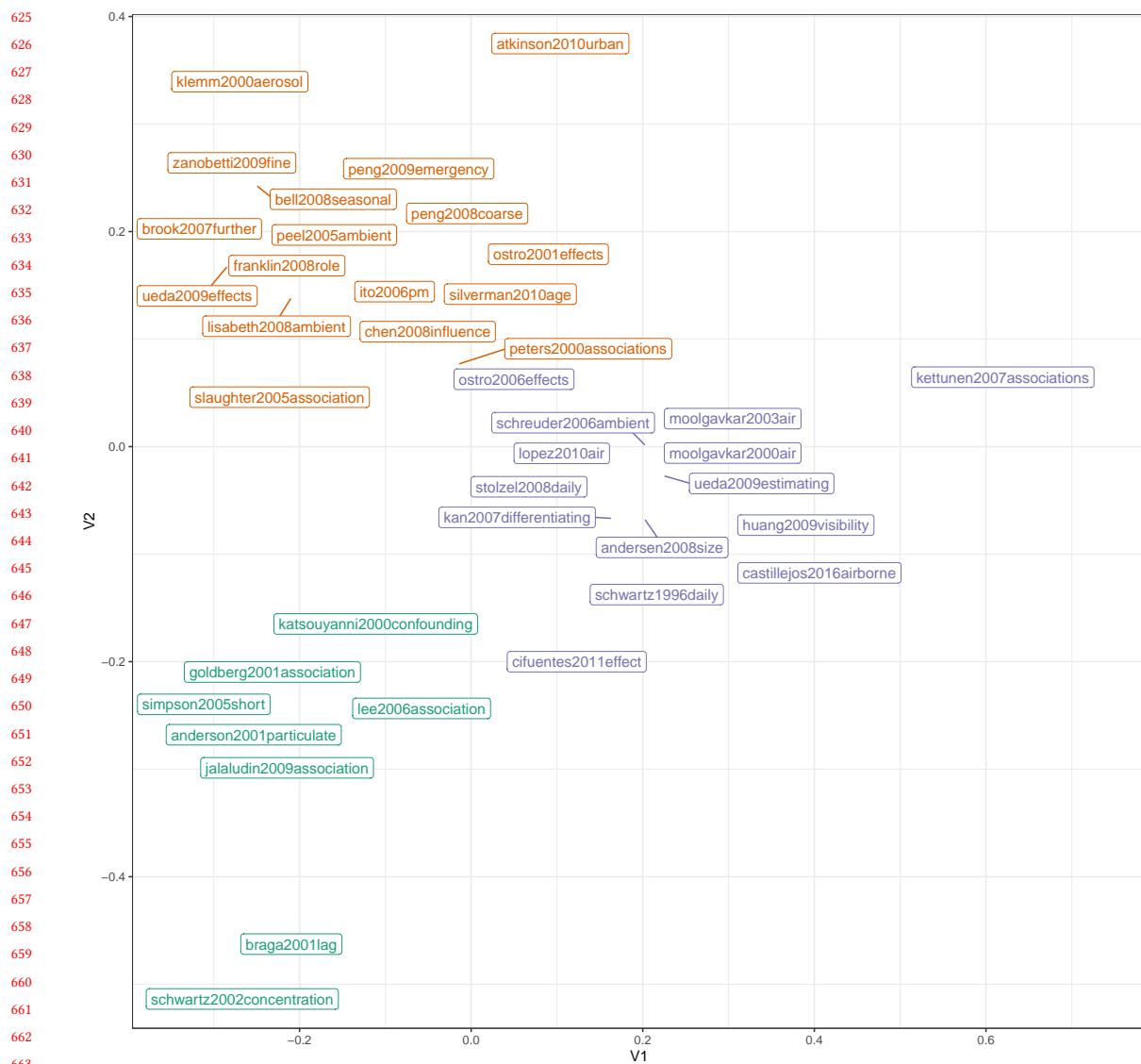


Fig. 4. The dendrogram (left) and multi-dimensional scaling (MDS) (right) based on paper similarity distance for 62 air pollution mortality modelling literature. The papers are colored by the most common smoothing method used. The MDS reveals the three distinct groups of papers. This grouping corresponds to the modelling strategies differ in the European and U.S. studies, documented in ALPHENA.

We compare the number of decisions extracted by Claude and Gemini across all 62 papers in `?@fig-claude-gemini`. Each point represents a paper, with the x- and y-axes showing the number of decisions extracted by Claude and Gemini, respectively. The dashed 1:1 line marks where both models extract the same number of decisions. Most points fall below this line, indicating that Claude extracts more decisions – often from data pre-processing or secondary data analysis

677 steps requiring more manual validation – whereas Gemini focuses more on modelling choices relevant to our analysis.
678 Some of these decisions captured by Claude are
679

- 680 • the definition of “cold day” and “hot day” indicators in Dockery et al. [16] (“defined at the 5th/ 95th percentile”),
- 681 • the choice to summarize NO₂, O₃, and SO₂ using a “24 hr average on variable” in Huang et al. [21], and
- 682 • the definition of black smoke and in Katsouyanni et al. [26] for secondary analysis (“restrict to days with BS
- 683 concentrations below 150 $\mu\text{g}/\text{m}^2$ ”).

684 Gemini sometimes also include irrelevant decisions, such as in Mar et al. [33], where secondary analysis choices like
685 “0-4 lag days” for air pollution exposure variables (CO, EC, K_S, NO₂, O₃, OC, Pb, S, SO₂, TC, Zn) are captured. However,
686 these cases are less frequent, resulting in outputs with less noise overall.

687 For both Claude and Gemini, we find they fail to link the general term “weather variables” to the specific weather
688 variables. For example Gemini misses this link in Dockery et al. [16] and Burnett et al. [11], while Claude does so in
689 Dockery et al. [16] and Katsouyanni et al. [26]. Although our prompt specified that some decisions may require linking
690 information across sentences and paragraphs to identify the correct variable, this instruction doesn’t appear to be
691 applied consistently.

692 5.3 Text model

693 We have conducted sensitivity analysis on the text model for obtaining the decision similarity score from the Gemini
694 outputs. The tested language models tested include

- 695 1) BERT by Google [15],
- 696 2) RoBERTa by Facebook AI [32], trained on a larger dataset (160GB v.s. BERT’s 15GB),
- 697 3) XLNet by Google Brain [49], and
- 698 two domain-trained BERT models:
- 699 4) sciBERT [4], trained on scientific literature, and
- 700 5) bioBERT [27], trained on PubMed and PMC data.

701 Figure 5 presents the distribution of the decision similarity (left) and paper similarity (right) for each text model.
702 At decision level, the BERT model produces the widest variation across all five models, while the similarity scores
703 from XLNet are all close to 1. These scores are not comparable across models since the difference of the underlying
704 transformer architecture. However, the paper similarity scores from each model are comparable and Figure 6 shows the
705 multi-dimensional scaling (MDS) of the paper similarity scores from each text model: all showing a similar clustering
706 pattern of the three main smoothing methods.

707 5.4 Others

708 There are other decisions in an analysis that are worth comparing and documenting. For example data pre-processing
709 decisions, e.g. how pollutant series are defined and collected, treatment on missing values, etc. Again, for a complete
710 review of the field, these decisions ideally would be included, but for our demonstration of idea, we focus on the modelling
711 decisions. Spatial decisions are generally not well captured because it often conducted uniformly as estimating the city
712 individually to accommodate city heterogeneity. Some papers only consider a handful of cities, while in larger studies
713 the individual city effects are then pooled together using random effect.

714 The variation in the choice of parameters degree of freedom or knot for smoothing can motivate separate investigation
715 on the sensitivity analysis. For instance, parameters that exhibit a wide range of choices across studies may indicate

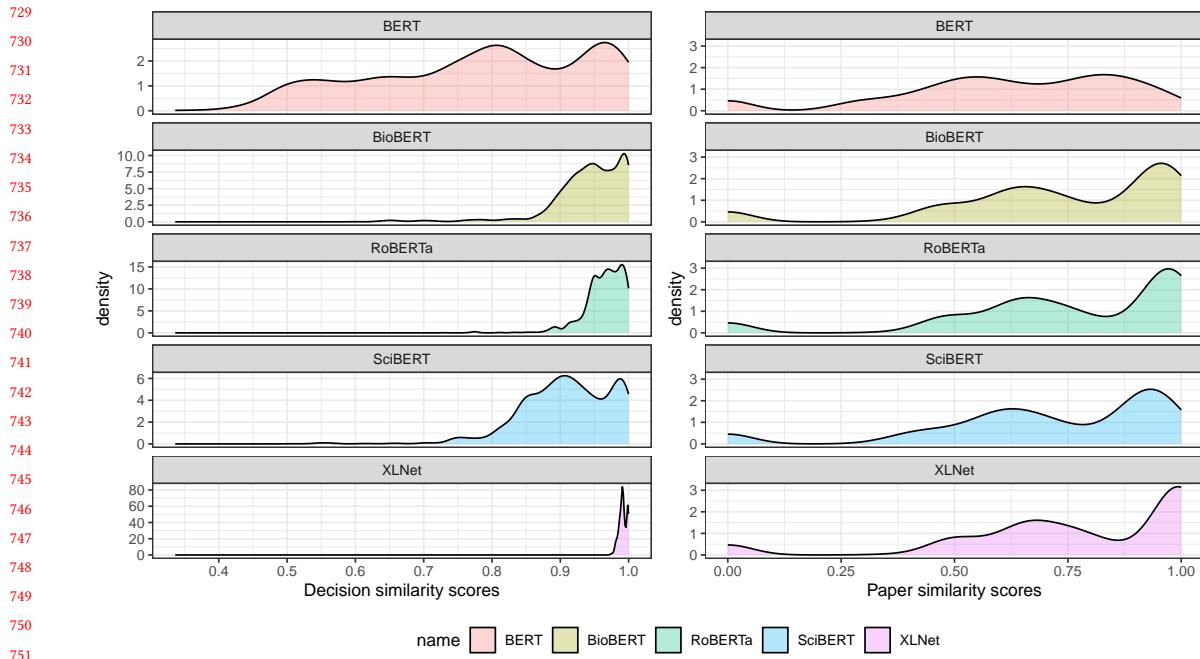


Fig. 5. Distribution of decision similarity (left) and paper similarity (right) scores for five different text models (BERT, BioBERT, RoBERTa, SciBERT, and XLNet). The default language model, BERT, produces the widest variation across the five models, while the similarity scores form XLNet are all close to 1. The model BioBERT, RoBERTa, and SciBERT yield decision similar scores mostly between 0.7 to 1.

areas of uncertainty or debate within the field, suggesting that further investigation is needed to assess their impact on study outcomes [38, 45].

With LLMs, the extraction of decisions from literature could be largely automated, but manual review is still needed to ensure the quality of the extracted decisions. We also find secondary LLMs can be used to standardize the extracted decisions, such as for temporal lag choices from text expressing this decision in various ways. In this work, we use prompt engineering to optimize the prompt for extracting decisions from general LLMs (Claude and Gemini). Fine-tuning a local model is an alternative approach for a locally-trained model. While it could potentially yield more accurate extraction and hence less manual review, for a systematic literature review, it would require substantially more training efforts and a labelled decision dataset. We also find sometimes the prompt is not fully followed throughout the extraction (example). Claude and Gemini...

Currently, only one model per paper - some have comparison of GLM and GAM, compare different pollutants, stratify by

With the advocacy for reproducibility in science, it is expected that more papers will share their code and data. The availability of the code could be a supplementary source for understanding the decisions made in the analysis and cross comparison of the manuscript with the code. However, given the lack of comments in the current practice, we are not there to extract reasons for the decisions encoded in the script.

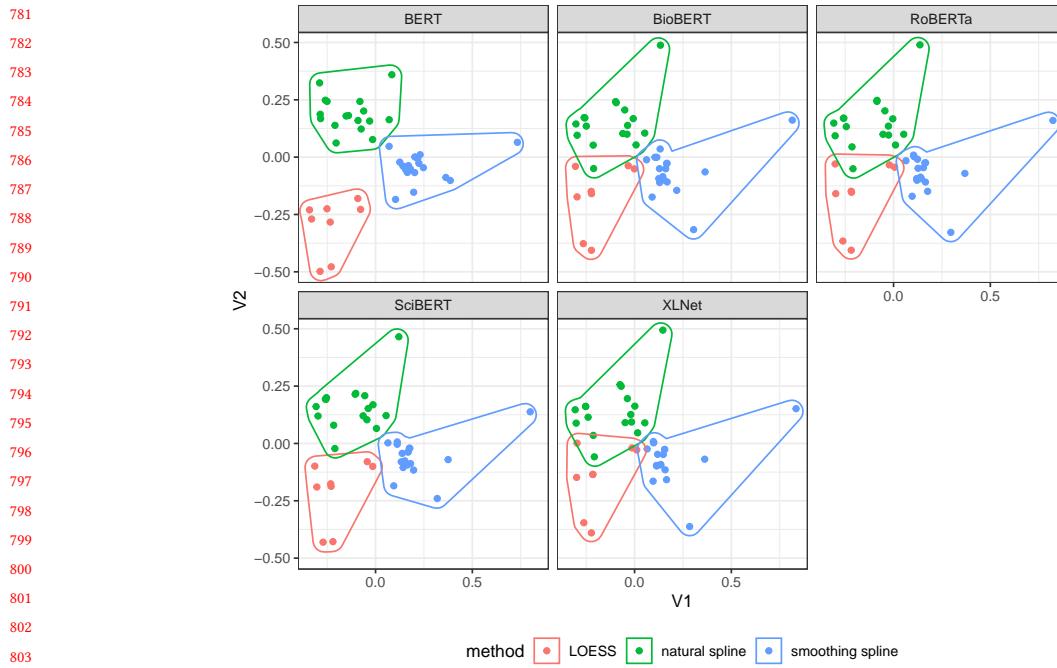


Fig. 6. The multi-dimensional scaling (MDS) of the paper similarity scores from each text model: all showing a similar clustering pattern of the three main smoothing methods. The points are colored by the most common method used in the paper, and the hulls are drawn around each method group.

6 Conclusion

In this paper, [we study how decisions are made in practical data analysis]. We developed a pipeline for automatically extracting decisions using LLMs (Claude and Gemini) and introduced a method for calculating paper similarity through decision similarity. This enables us to cluster papers by their decision choices and visualization through hierarchical clustering and multidimensional scaling. We applied this pipeline to mortality/ hospital admission – PM modelling literature. We extracted key modelling decisions, such as the choice of smoothing methods and parameters for time, temperature, and humidity, and revealed paper clusters that correspond to different modelling strategies, as documented in the APHENA project.

While sensitivity analyses are commonly used to assess the robustness of findings to different analytical choices, the set of choices tested is often limited and selected subjectively by the authors. Our approach offers a new perspective by pooling decisions made in analyses across studies in the fields. This allows for a holistic account on the alternatives in the field and identification of both consensus and divergence within the field, providing insights for future research and methodological development.

References

- [1] Eric Alexander, Joe Kohlmann, Robin Valenza, Michael Witmore, and Michael Gleicher. 2014 ieee conference on visual analytics science and technology (vast). pages 173–182, 10 2014. doi: 10.1109/VAST.2014.7042493. URL <https://ieeexplore.ieee.org/document/7042493>.

- [2] Sara Alspaugh, Nava Zokaei, Andrea Liu, Cindy Jin, and Marti A. Hearst. Futzling and moseying: Interviews with professional data analysts on exploration practices. *IEEE Transactions on Visualization and Computer Graphics*, 25(1):22–31, 01 2019. doi: 10.1109/TVCG.2018.2865040. URL <https://ieeexplore.ieee.org/document/8440815>.
- [3] Z. J. Andersen, P. Wahlin, O. Raaschou-Nielsen, M. Ketzel, T. Scheike, and S. Loft. Size distribution and total number concentration of ultrafine and accumulation mode particles and hospital admissions in children and the elderly in copenhagen, denmark. *Occupational and Environmental Medicine*, 65(7):458–466, 07 2008. doi: 10.1136/oem.2007.033290. URL <https://oem.bmjjournals.org/content/65/7/458>. Publisher: BMJ Publishing Group Ltd Section: Original article PMID: 17989204.
- [4] Iz Beltagy, Kyle Lo, and Arman Cohan. Proceedings of the 2019 conference on empirical methods in natural language processing and the 9th international joint conference on natural language processing (emnlp-ijcnlp). pages 3613–3618, Hong Kong, China, 2019. Association for Computational Linguistics. doi: 10.18653/v1/D19-1371. URL <https://www.aclweb.org/anthology/D19-1371>.
- [5] Steven Bethard and Dan Jurafsky. Cikm '10: International conference on information and knowledge management. pages 609–618, Toronto ON Canada, 10 2010. ACM. doi: 10.1145/1871437.1871517. URL <https://dl.acm.org/doi/10.1145/1871437.1871517>.
- [6] Dorothy V. M. Bishop and Charles Hulme. When alternative analyses of the same data come to different conclusions: A tutorial using declaredesign with a worked real-world example. *Advances in Methods and Practices in Psychological Science*, 7(3):25152459241267904, 07 2024. doi: 10.1177/25152459241267904. URL <https://doi.org/10.1177/25152459241267904>. Publisher: SAGE Publications Inc.
- [7] Graeme Blair, Jasper Cooper, Alexander Coppock, and Macartan Humphreys. Declaring and diagnosing research designs. *American Political Science Review*, 113(3):838–859, 08 2019. doi: 10.1017/S0003055419000194. URL https://www.cambridge.org/core/product/identifier/S0003055419000194/type/journal_article.
- [8] Rotem Botvinik-Nezer, Felix Holzmeister, Colin F. Camerer, Anna Dreber, Juergen Huber, Magnus Johannesson, Michael Kirchler, Roni Iwanir, Jeanette A. Mumford, R. Alison Adcock, Paolo Avesani, Blazej M. Baczkowski, Aahana Bajracharya, Leah Bakst, Sheryl Ball, Marco Barilar, Nadège Bault, Derek Beaton, Julia Beitner, Roland G. Benoit, Ruud M. W. J. Berkers, Jamil P. Bhanji, Bharat B. Biswal, Sebastian Bobadilla-Suarez, Tiago Bortolini, Katherine L. Bottenhorn, Alexander Bowring, Senne Braem, Hayley R. Brooks, Emily G. Brudner, Cristian B. Calderon, Julia A. Camilleri, Jaime J. Castrellon, Luca Cecchetti, Edna C. Cieslik, Zachary J. Cole, Olivier Collignon, Robert W. Cox, William A. Cunningham, Stefan Czoschke, Kamalaker Dadi, Charles P. Davis, Alberto De Luca, Mauricio R. Delgado, Lysia Demetriou, Jeffrey B. Dennison, Xin Di, Erin W. Dickie, Ekaterina Dobryakova, Claire L. Donnat, Juergen Dukart, Niall W. Duncan, Joke Durnez, Amr Eed, Simon B. Eickhoff, Andrew Erhart, Laura Fontanesi, G. Matthew Fricke, Shiguang Fu, Adriana Galván, Remi Gau, Sarah Genon, Tristan Glatard, Enrico Gleean, Jelle J. Goeman, Sergej A. E. Golowin, Carlos González-García, Krzysztof J. Gorgolewski, Cheryl L. Grady, Mikella A. Green, João F. Guassi Moreira, Olivia Guest, Shabnam Hakimi, J. Paul Hamilton, Roeland Hancock, Giacomo Handjaras, Bronson B. Harry, Colin Hawco, Peer Herholz, Gabrielle Herman, Stephan Heunis, Felix Hoffstaedter, Jeremy Hogeveen, Susan Holmes, Chuan-Peng Hu, Scott A. Huettel, Matthew E. Hughes, Vittorio Iacobella, Alexandru D. Iordan, Peder M. Isager, Ayse I. Isik, Andrew Jahn, Matthew R. Johnson, Tom Johnstone, Michael J. E. Joseph, Anthony C. Juliano, Joseph W. Kable, Michalis Kassinopoulos, Cemal Koba, Xiang-Zhen Kong, Timothy R. Koscik, Nuri Erkut Kucukboyaci, Brice A. Kuhl, Sebastian Kupek, Angela R. Laird, Claus Lamm, Robert Langner, Nina Lauharatanahirun, Hongmi Lee, Sangil Lee, Alexander Leemans, Andrea Leo, Elise Lesage, Flora Li, Monica Y. C. Li, Phui Cheng Lim, Evan N. Lintz, Schuyler W. Liphardt, Annabel B. Losecaat Vermeer, Bradley C. Love, Michael L. Mack, Norberto Malpica, Theo Marins, Camille Maumet, Kelsey McDonald, Joseph T. McGuire, Helena Melero, Adriana S. Méndez Leal, Benjamin Meyer, Kristin N. Meyer, Glad Mihai, Georgios D. Mitsis, Jorge Moll, Dylan M. Nelson, Gustav Nilsson, Michael P. Notter, Emanuele Olivetti, Adrian I. Onicas, Paolo Papale, Kaustubh R. Patil, Jonathan E. Peelle, Alexandre Pérez, Doris Pischedda, Jean-Baptiste Poline, Yanina Prystauka, Shruti Ray, Patricia A. Reuter-Lorenz, Richard C. Reynolds, Emiliana Ricciardi, Jenny R. Rieck, Anais M. Rodriguez-Thompson, Anthony Romyn, Taylor Salo, Gregory R. Samanez-Larkin, Emilio Sanz-Morales, Margaret L. Schlichting, Douglas H. Schultz, Qiang Shen, Margaret A. Sheridan, Jennifer A. Silvers, Kenny Skagerlund, Alec Smith, David V. Smith, Peter Sokol-Hessner, Simon R. Steinkamp, Sarah M. Tashjian, Bertrand Thirion, John N. Thorp, Gustav Tinghög, Loreen Tisdall, Steven H. Tompson, Claudio Toro-Serey, Juan Jesus Torre Tresols, Leonardo Tozzi, Vuong Truong, Luca Turella, Anna E. van 't Veer, Tom Verguts, Jean M. Vettel, Sagana Vijayarajah, Khoi Vo, Matthew B. Wall, Wouter D. Weeda, Susanne Weis, David J. White, David Wisniewski, Alba Xifra-Porxas, Emily A. Yearling, Sangsuk Yoon, Rui Yuan, Kenneth S. L. Yuen, Lei Zhang, Xu Zhang, Joshua E. Zosky, Thomas E. Nichols, Russell A. Poldrack, and Tom Schonberg. Variability in the analysis of a single neuroimaging dataset by many teams. *Nature*, 582(7810):84–88, 06 2020. doi: 10.1038/s41586-020-2314-9. URL <https://www.nature.com/articles/s41586-020-2314-9>. Publisher: Nature Publishing Group.
- [9] Susanne Breitner, Matthias Stölzel, Josef Cyrys, Mike Pitz, Gabriele Wölke, Wolfgang Kreyling, Helmut Küchenhoff, Joachim Heinrich, H.-Erich Wichmann, and Annette Peters. Short-term mortality rates during a decade of improved air quality in erfurt, germany. *Environmental Health Perspectives*, 117(3):448–454, 03 2009. doi: 10.1289/ehp.11711. URL <https://ehp.niehs.nih.gov/doi/10.1289/ehp.11711>. Publisher: Environmental Health Perspectives.
- [10] Richard T. Burnett, Sabit Cakmak, Mark E. Raizenne, David Stieb, Renaud Vincent, Daniel Krewski, Jeffrey R. Brook, Owen Philips, and Haluk Ozkaynak. The association between ambient carbon monoxide levels and daily mortality in toronto, canada. *Journal of the Air & Waste Management Association*, 48(8):689–700, 08 1998. doi: 10.1080/10473289.1998.10463718. URL <https://www.tandfonline.com/doi/full/10.1080/10473289.1998.10463718>.
- [11] Richard T. Burnett, Stieb ,Dave , Brook Jeffrey R. , Cakmak ,Sabit , Dales ,Robert , Raizenne ,Mark , Vincent ,Renaud , , and Tom Dann. Associations between short-term changes in nitrogen dioxide and mortality in canadian cities. *Archives of Environmental Health: An International Journal*, 59(5):228–236, 05 2004. doi: 10.3200/AEOH.59.5.228-236. URL <https://doi.org/10.3200/AEOH.59.5.228-236>. Publisher: Routledge _eprint: <https://doi.org/10.3200/AEOH.59.5.228-236> PMID: 16201668.

- [885] [12] Margarita Castillejos, Borja-Aburto ,Victor H. , Dockery ,Douglas W. , Gold ,Diane R. , , and Dana Loomis. Airborne coarse particles and mortality. *Inhalation Toxicology*, 12(sup1):61–72, 01 2000. doi: 10.1080/0895-8378.1987.11463182. URL <https://doi.org/10.1080/0895-8378.1987.11463182>. Publisher: Taylor & Francis _eprint: <https://doi.org/10.1080/0895-8378.1987.11463182>.
- [886]
- [887]
- [888] [13] Chaomei Chen. Citespace ii: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, 57(3):359–377, 2006. doi: 10.1002/asi.20317. URL <https://onlinelibrary.wiley.com/doi/abs/10.1002/asi.20317>. _eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1002/asi.20317>.
- [889]
- [890]
- [891] [14] J. K. Chou and C. K. Yang. Papervis: Literature review made easy. *Computer Graphics Forum*, 30(3):721–730, 2011. doi: 10.1111/j.1467-8659.2011.01921.x. URL <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8659.2011.01921.x>. _eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-8659.2011.01921.x>.
- [892]
- [893] [15] Jacob Devlin, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. Naacl-hlt 2019. page 4171–4186, Minneapolis, Minnesota, 06 2019. Association for Computational Linguistics. doi: 10.18653/v1/N19-1423. URL <https://aclanthology.org/N19-1423>.
- [894]
- [895] [16] Douglas W. Dockery, Joel Schwartz, and John D. Spengler. Air pollution and daily mortality: Associations with particulates and acid aerosols. *Environmental Research*, 59(2):362–373, 12 1992. doi: 10.1016/S0013-9351(05)80042-8. URL <https://www.sciencedirect.com/science/article/pii/S0013935105800428>.
- [896]
- [897]
- [898] [17] Marian Dörk, Nathalie Henry Riche, Gonzalo Ramos, and Susan Dumais. Pivotpaths: Strolling through faceted information spaces. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2709–2718, 12 2012. doi: 10.1109/TVCG.2012.252. URL <https://ieeexplore.ieee.org/document/6327277>.
- [899]
- [900] [18] Andrew Gelman and Eric Loken. The statistical crisis in science. *American Scientist*, 102(6):460–465, 12 2014. URL <https://www.proquest.com/docview/1616141998/abstract/5E050DCE82414037PQ/1>. Num Pages: 6 Place: Research Triangle Park, United States Publisher: Sigma XI-The Scientific Research Society.
- [901]
- [902] [19] Elliot Gould, Hannah S. Fraser, Timothy H. Parker, Shinichi Nakagawa, Simon C. Griffith, Peter A. Veski, Fiona Fidler, Daniel G. Hamilton, Robin N. Abbey-Lee, Jessica K. Abbott, Luis A. Aguirre, Carles Alcaraz, Irith Aloni, Drew Altschul, Kunal Arekar, Jeff W. Atkins, Joe Atkinson, Christopher M. Baker, Meghan Barrett, Kristian Bell, Suleiman Kehinde Bello, Iván Beltrán, Bernd J. Berauer, Michael Grant Bertram, Peter D. Billman, Charlie K. Blake, Shannon Blake, Louis Blairst, Andrea Bonisolí-Alquati, Timothée Bonnet, Camille Nina Marion Bordes, Aneesh P. H. Bose, Thomas Botterill-James, Melissa Anna Boyd, Sarah A. Boyle, Tom Bradfer-Lawrence, Jennifer Bradham, Jack A. Brand, Martin I. Brengdahl, Martin Bulla, Luc Bussière, Ettore Camerlenghi, Sara E. Campbell, Leonardo L. F. Campos, Anthony Caravaggi, Pedro Cardoso, Charles J. W. Carroll, Therese A. Catanach, Xuan Chen, Heung Ying Janet Chik, Emily Sarah Choy, Alec Philip Christie, Angela Chuang, Amanda J. Chunco, Bethany L. Clark, Andrea Contina, Garth A. Covernton, Murray P. Cox, Kimberly A. Cressman, Marco Crotti, Connor Davidson Crouch, Pietro B. D'Amelio, Alexandra Allison de Sousa, Timm Fabian Döbert, Ralph Dobler, Adam J. Dobson, Tim S. Doherty, Szymon Marian Drobniak, Alexandra Grace Duffy, Alison B. Duncan, Robert P. Dunn, Jamie Dunning, Trishna Dutta, Luke Eberhart-Hertel, Jared Alan Elmore, Mahmoud Medhat Elsherif, Holly M. English, David C. Ensminger, Ulrich Rainer Ernst, Stephen M. Ferguson, Esteban Fernandez-Juricic, Thalita Ferreira-Arruda, John Fieberg, Elizabeth A. Finch, Evan A. Fiorenza, David N. Fisher, Amélie Fontaine, Wolfgang Forstmeier, Yoan Fourcade, Graham S. Frank, Cathryn A. Freund, Eduardo Fuentes-Lillo, Sara L. Gandy, Dustin G. Gannon, Ana I. García-Cervigón, Alexis C. Garretson, Xuezhen Ge, William L. Geary, Charly Géron, Marc Gilles, Antje Girndt, Daniel Glikman, Harrison B. Goldspiel, Dylan G. E. Gomes, Megan Kate Good, Sarah C. Goslee, J. Stephen Gosnell, Eliza M. Grames, Paolo Gratton, Nicholas M. Grebe, Skye M. Greenler, Maaike Griffioen, Daniel M. Griffith, Frances J. Griffith, Jake J. Grossman, Ali Güncan, Stef Haesen, James G. Hagan, Heather A. Hager, Jonathan Philo Harris, Natasha Dean Harrison, Sarah Syedia Hasnain, Justin Chase Havird, Andrew J. Heaton, María Laura Herrera-Chaustré, Tanner J. Howard, Bin-Yan Hsu, Fabiola Iannarilli, Esperanza C. Iranzo, Erik N. K. Iverson, Saheed Olaide Jimoh, Douglas H. Johnson, Martin Johnsson, Jesse Jorna, Tommaso Jucker, Martin Jung, Ineta Kačergytė, Oliver Kaltz, Alison Ke, Clint D. Kelly, Katharine Keegan, Friedrich Wolfgang Keppeler, Alexander K. Killion, Dongmin Kim, David P. Kochan, Peter Korsten, Shan Kothari, Jonas Kuppler, Jillian M. Kusch, Małgorzata Lagisz, Kristen Marianne Lalla, Daniel J. Larkin, Courtney L. Larson, Katherine S. Lauck, M. Elise Lauterbur, Alan Law, Don-Jean Léandri-Breton, Jonas J. Lembrechts, Kiara L'Herpiniere, Eva J. P. Lievens, Daniela Oliveira de Lima, Shane Lindsay, Martin Luquet, Ross MacLeod, Kirsty H. Macphie, Kit Magellan, Magdalena M. Mair, Lisa E. Malm, Stefano Mammola, Caitlin P. Mandeville, Michael Manhart, Laura Milena Manrique-Garzon, Elina Mäntylä, Philippe Marchand, Benjamin Michael Marshall, Charles A. Martin, Dominic Andreas Martin, Jake Mitchell Martin, April Robin Martinig, Erin S. McCallum, Mark McCauley, Sabrina M. McNew, Scott J. Meiners, Thomas Merkling, Marcus Michelangeli, Maria Moiron, Bruno Moreira, Jennifer Mortensen, Benjamin Mos, Taofeek Olatunbosun Muraina, Penelope Wrenn Murphy, Luca Nelli, Petri Niemelä, Josh Nightingale, Gustav Nilsonne, Sergio Nolazco, Sabine S. Nooten, Jessie Lanterman Novotny, Agnes Birgitta Olin, Chris L. Organ, Kate L. Ostevik, Facundo Xavier Palacio, Matthieu Paquet, Darren James Parker, David J. Pascall, Valerie J. Pasquarella, John Harold Paterson, Ana Payo-Payo, Karen Marie Pedersen, Grégoire Perez, Kayla I. Perry, Patrice Pottier, Michael J. Proulx, Raphaël Proulx, Jessica L. Pruitt, Veronarindra Ramananjato, Finaritra Tolotra Randimbirison, Onja H. Razafindratsima, Diana J. Rennison, Federico Riva, Sepand Riyahi, Michael James Roast, Felipe Pereira Rocha, Dominique G. Roche, Cristian Román-Palacios, Michael S. Rosenberg, Jessica Ross, Freya E. Rowland, Deusdedit Rudemalila, Avery L. Russell, Suvi Ruuskanen, Patrick Saccone, Asaf Sadeh, Stephen M. Salazar, Kris Sales, Pablo Salmóñ, Alfredo Sánchez-Tójár, Leticia Pereira Santos, Francesca Santostefano, Hayden T. Schilling, Marcus Schmidt, Tim Schmoll, Adam C. Schneider, Allie E. Schrock, Julia Schroeder, Nicolas Schtickzelle, Nick L. Schultz, Drew A. Scott, Michael Peter Scroggie, Julie Teresa Shapiro, Nitika Sharma, Caroline L. Shearer, Diego Simón, Michael I. Sitvarin, Fabricio Luiz Skupien, Heather Lea Slinn, Grania Polly Smith, Jeremy A. Smith, Rahel Sollmann, Kaitlin Stack Whitney, Shannon Michael Still, Erica F. Stuber, Guy F. Sutton, Ben Swallow, Conor Claverie Taff, Elina Takola, Andrew J. Tanentzap, Rocío Tarjuelo, Richard J. Telford, Christopher J. Thawley, Hugo Thierry, Jacqueline Thomson, Svenja Tidau, Emily M. Tompkins, Claire Marie Tortorelli, Andrew Trlica, Biz R. Turnell, Lara Urban, Stijn Van de Vondel, Jessica Eva Megan van der Wal, Jens Van Eeckhoven, Francis van Oordt, K. Michelle Vanderwel, Mark C.
- [935]
- [936]

- 937 Vanderwel, Karen J. Vanderwolf, Juliana Vélez, Diana Carolina Vergara-Florez, Brian C. Verrelli, Marcus Vinícius Vieira, Nora Villamil, Valerio
938 Vitali, Julien Vollering, Jeffrey Walker, Xanthe J. Walker, Jonathan A. Walter, Paweł Waryszak, Ryan J. Weaver, Ronja E. M. Wedegärtner, Daniel L.
939 Weller, and Shannon Whelan. Same data, different analysts: variation in effect sizes due to analytical decisions in ecology and evolutionary biology.
940 *BMC Biology*, 23(1):35, 02 2025. doi: 10.1186/s12915-024-02101-x. URL <https://doi.org/10.1186/s12915-024-02101-x>.
- 941 [20] Florian Heimerl, Qi Han, Steffen Koch, and Thomas Ertl. Citerivers: Visual analytics of citation patterns. *IEEE Transactions on Visualization and*
942 *Computer Graphics*, 22(1):190–199, 01 2016. doi: 10.1109/TVCG.2015.2467621. URL <https://ieeexplore.ieee.org/document/7192685/authors>.
- 943 [21] Wei Huang, Jianguo Tan, Haidong Kan, Ni Zhao, Weimin Song, Guixiang Song, Guohai Chen, Lili Jiang, Cheng Jiang, Renjie Chen, and Bingheng
944 Chen. Visibility, air quality and daily mortality in shanghai, china. *Science of The Total Environment*, 407(10):3295–3300, 05 2009. doi: 10.1016/j.
945 scitotenv.2009.02.019. URL <https://linkinghub.elsevier.com/retrieve/pii/S004896970900165X>.
- 946 [22] Nick Huntington-Klein, Andreu Arenas, Emily Beam, Marco Bertoni, Jeffrey R. Bloem, Pralhad Burli, Naibin Chen, Paul Grieco, Godwin
947 Ekpe, Todd Pugatch, Martin Saavedra, and Yaniv Stopnitzky. The influence of hidden researcher decisions in applied microeconomics.
948 *Economic Inquiry*, 59(3):944–960, 2021. doi: 10.1111/ecin.12992. URL <https://onlinelibrary.wiley.com/doi/abs/10.1111/ecin.12992>. _eprint:
949 <https://onlinelibrary.wiley.com/doi/pdf/10.1111/ecin.12992>.
- 950 [23] Petra Isenberg, Tobias Isenberg, Michael Sedlmair, Jian Chen, and Torsten Möller. Visualization as seen through its research paper keywords. *IEEE*
951 *Transactions on Visualization and Computer Graphics*, 23(1):771–780, 01 2017. doi: 10.1109/TVCG.2016.2598827. URL <https://ieeexplore.ieee.org/document/7539364>.
- 952 [24] Alex Kale, Matthew Kay, and Jessica Hullman. Decision-making under uncertainty in research synthesis: Designing for the garden of forking
953 paths. *CHI ’19*, page 1–14, New York, NY, USA, 05 2019. Association for Computing Machinery. doi: 10.1145/3290605.3300432. URL <https://dl.acm.org/doi/10.1145/3290605.3300432>.
- 954 [25] Haidong Kan, Stephanie J. London, Guohai Chen, Yunhui Zhang, Guixiang Song, Naiqing Zhao, Lili Jiang, and Bingheng Chen. Differentiating the
955 effects of fine and coarse particles on daily mortality in shanghai, china. *Environment International*, 33(3):376–384, 04 2007. doi: 10.1016/j.envint.
956 2006.12.001. URL <https://www.sciencedirect.com/science/article/pii/S0160412006002108>.
- 957 [26] Klea Katsouyanni, Giota Touloumi, Evangelia Samoli, Alexandros Gryparis, Alain Le Tertre, Yannis Monopolis, Giuseppe Rossi, Denis Zmirou,
958 Ferran Ballester, Azedine Boumghar, Hugh Ross Anderson, Bogdan Wojtyniak, Anna Paldy, Rony Braunstein, Juha Pekkanen, Christian Schindler,
959 and Joel Schwartz. Confounding and effect modification in the short-term effects of ambient particles on total mortality: Results from 29 european
960 cities within the aphe2 project. *Epidemiology*, 12(5):521, 09 2001. URL https://journals.lww.com/epid/fulltext/2001/09000/confounding_and_effect_modification_in_the_11.aspx.
- 961 [27] Jinhyuk Lee, Wonjin Yoon, Sungdong Kim, Donghyeon Kim, Sunkyu Kim, Chan Ho So, and Jaewoo Kang. Biobert: a pre-trained biomedical
962 language representation model for biomedical text mining. *Bioinformatics*, 36(4):1234–1240, 02 2020. doi: 10.1093/bioinformatics/btz682. URL
963 <https://academic.oup.com/bioinformatics/article/36/4/1234/5566506>.
- 964 [28] S. L. Lee, W. H. S. Wong, and Y. L. Lau. Association between air pollution and asthma admission among children in hong kong. *Clinical & Experimental*
965 *Allergy*, 36(9):1138–1146, 2006. doi: 10.1111/j.1365-2222.2006.02555.x. URL <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2222.2006.02555.x>. _eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2222.2006.02555.x>.
- 966 [29] Jiali Liu, Nadia Boukhelifa, and James R. Eagan. Understanding the Role of Alternatives in Data Analysis Practices. *IEEE Transactions on Visualization*
967 *and Computer Graphics*, 26(1):66–76, January 2020. ISSN 1941-0506. doi: 10.1109/TVCG.2019.2934593. URL <https://ieeexplore.ieee.org/document/8805460/>.
- 968 [30] Yang Liu, Tim Althoff, and Jeffrey Heer. Paths explored, paths omitted, paths obscured: Decision points & selective reporting in end-to-end
969 data analysis. *CHI ’20*, page 1–14, New York, NY, USA, 04 2020. Association for Computing Machinery. doi: 10.1145/3313831.3376533. URL
970 <https://dl.acm.org/doi/10.1145/3313831.3376533>.
- 971 [31] Yang Liu, Alex Kale, Tim Althoff, and Jeffrey Heer. Boba: Authoring and visualizing multiverse analyses. *IEEE Transactions on Visualization and*
972 *Computer Graphics*, 27(2):1753–1763, 02 2021. doi: 10.1109/TVCG.2020.3028985. URL <https://ieeexplore.ieee.org/document/9216579/>.
- 973 [32] Yinhan Liu, Myle Ott, Naman Goyal, Jingfei Du, Mandar Joshi, Danqi Chen, Omer Levy, Mike Lewis, Luke Zettlemoyer, and Veselin Stoyanov.
974 Roberta: A robustly optimized bert pretraining approach. doi: 10.48550/arXiv.1907.11692.
- 975 [33] T F Mar, G A Norris, J Q Koenig, and T V Larson. Associations between air pollution and mortality in phoenix, 1995–1997. *Environmental*
976 *Health Perspectives*, 108(4):347–353, 04 2000. doi: 10.1289/ehp.00108347. URL <https://ehp.niehs.nih.gov/doi/abs/10.1289/ehp.00108347>. Publisher: Environmental Health Perspectives.
- 977 [34] Suresh H. Moolgavkar. Air pollution and hospital admissions for diseases of the circulatory system in three u.s. metropolitan areas. *Journal of the Air &*
978 *Waste Management Association*, 50(7):1199–1206, 07 2000. doi: 10.1080/10473289.2000.10464162. URL <https://doi.org/10.1080/10473289.2000.10464162>. Publisher: Taylor & Francis.
- 979 [35] Suresh H. Moolgavkar. Air pollution and daily mortality in two u.s. counties: Season-specific analyses and exposure-response relationships.
980 *Inhalation Toxicology*, 15(9):877–907, 01 2003. doi: 10.1080/08958370390215767. URL <https://doi.org/10.1080/08958370390215767>. Publisher: Taylor &
981 Francis.
- 982 [36] Arpit Narechania, Alireza Karduni, Ryan Wesslen, and Emily Wall. Vitality: Promoting serendipitous discovery of academic literature with
983 transformers & visual analytics. *IEEE Transactions on Visualization and Computer Graphics*, 28(1):486–496, 01 2022. doi: 10.1109/TVCG.2021.3114820.
984 URL <https://ieeexplore.ieee.org/document/9552447/>.

- [37] Bart Ostro, Rachel Broadwin, Shelley Green, Wen-Ying Feng, and Michael Lipsett. Fine particulate air pollution and mortality in nine California counties: Results from CalFINE. *Environmental Health Perspectives*, 114(1):29–33, 01 2006. doi: 10.1289/ehp.8335. URL <https://ehp.niehs.nih.gov/doi/10.1289/ehp.8335>. Publisher: Environmental Health Perspectives.
- [38] Roger D. Peng, Francesca Dominici, and Thomas A. Louis. Model choice in time series studies of air pollution and mortality. *Journal of the Royal Statistical Society Series A: Statistics in Society*, 169(2):179–203, 03 2006. doi: 10.1111/j.1467-985X.2006.00410.x. URL <https://doi.org/10.1111/j.1467-985X.2006.00410.x>.
- [39] Abhraneel Sarma, Alex Kale, Michael Moon, Nathan Taback, Fanny Chevalier, Jessica Hullman, and Matthew Kay. multiverse: Multiplexing alternative data analyses in R notebooks (version 0.6.2). *OSF Preprints*, 2021. URL <https://github.com/MUCollective/multiverse>.
- [40] Marko Sarstedt, Susanne J. Adler, Christian M. Ringle, Gyeongcheol Cho, Adamantios Diamantopoulos, Heungsun Hwang, and Benjamin D. Liengaard. Same model, same data, but different outcomes: Evaluating the impact of method choices in structural equation modeling. *Journal of Product Innovation Management*, 41(6):1100–1117, 2024. doi: 10.1111/jpim.12738. URL <https://onlinelibrary.wiley.com/doi/abs/10.1111/jpim.12738>. _eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/jpim.12738>.
- [41] Joel Schwartz. The distributed lag between air pollution and daily deaths. *Epidemiology*, 11(3):320–326, 2000. URL <https://www.jstor.org/stable/3703220>. Publisher: Lippincott Williams & Wilkins.
- [42] R. Silberzahn, E. L. Uhlmann, D. P. Martin, P. Anselmi, F. Aust, E. Awtrey, Š. Bahník, F. Bai, C. Bannard, E. Bonnier, R. Carlsson, F. Cheung, G. Christensen, R. Clay, M. A. Craig, A. Dalla Rosa, L. Dam, M. H. Evans, I. Flores Cervantes, N. Fong, M. Gamez-Djokic, A. Glenz, S. Gordon-McKeon, T. J. Heaton, K. Hederos, M. Heene, A. J. Hofelich Mohr, F. Höglund, K. Hui, M. Johannesson, J. Kalodimos, E. Kaszubowski, D. M. Kennedy, R. Lei, T. A. Lindsay, S. Liverani, C. R. Madan, D. Molden, E. Molleman, R. D. Morey, L. B. Mulder, B. R. Nijstad, N. G. Pope, B. Pope, J. M. Prenoveau, F. Rink, E. Robusto, H. Roderique, A. Sandberg, E. Schlueter, F. D. Schönbrodt, M. F. Sherman, S. A. Sommer, K. Sotak, S. Spain, C. Spörlein, T. Stafford, L. Stefanutti, S. Tauber, J. Ullrich, M. Vianello, E.-J. Wagemakers, M. Witkowiak, S. Yoon, and B. A. Nosek. Many analysts, one data set: Making transparent how variations in analytic choices affect results. *Advances in Methods and Practices in Psychological Science*, 1(3):337–356, 09 2018. doi: 10.1177/2515245917747646. URL <https://doi.org/10.1177/2515245917747646>. Publisher: SAGE Publications Inc.
- [43] Jan Simson, Fiona Draxler, Samuel Mehr, and Christoph Kern. Preventing harmful data practices by using participatory input to navigate the machine learning multiverse. CHI '25, page 1–30, New York, NY, USA, 04 2025. Association for Computing Machinery. doi: 10.1145/3706598.3713482. URL <https://dl.acm.org/doi/10.1145/3706598.3713482>.
- [44] Imad Tbahrifti, Christine Chichester, Frédérique Lisacek, and Patrick Ruch. Using argumentation to retrieve articles with similar citations: An inquiry into improving related articles search in the Medline digital library. *International Journal of Medical Informatics*, 75(6):488–495, 06 2006. doi: 10.1016/j.ijmedinf.2005.06.007. URL <https://www.sciencedirect.com/science/article/pii/S1386505605000894>.
- [45] G. Touloumi, E. Samoli, M. Pipikou, A. Le Tertre, R. Atkinson, and K. Katsouyanni. Seasonal confounding in air pollution and health time-series studies: effect on air pollution effect estimates. *Statistics in Medicine*, 25(24):4164–4178, 2006. doi: 10.1002/sim.2681. URL <https://onlinelibrary.wiley.com/doi/abs/10.1002/sim.2681>. _eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1002/sim.2681>.
- [46] Kayo Ueda, Nitta ,Hiroshi , Ono ,Masaji , , and Ayano Takeuchi. Estimating mortality effects of fine particulate matter in Japan: A comparison of time-series and case-crossover analyses. *Journal of the Air & Waste Management Association*, 59(10):1212–1218, 10 2009. doi: 10.3155/1047-3289.59.10.1212. URL <https://doi.org/10.3155/1047-3289.59.10.1212>. Publisher: Taylor & Francis _eprint: <https://doi.org/10.3155/1047-3289.59.10.1212>.
- [47] Hadley Wickham. Tidy data. *Journal of Statistical Software*, 59:1–23, 09 2014. doi: 10.18637/jss.v059.i10. URL <https://doi.org/10.18637/jss.v059.i10>.
- [48] Hadley Wickham, Joe Cheng, and Aaron Jacobs. *ellmer: Chat with Large Language Models*, 2025. URL <https://CRAN.R-project.org/package=ellmer>. R package version 0.1.1.
- [49] Zhilin Yang, Zihang Dai, Yiming Yang, Jaime Carbonell, Ruslan Salakhutdinov, and Quoc V. Le. Xlnet: Generalized autoregressive pretraining for language understanding. doi: 10.48550/arXiv.1906.08237.