Philosophy of Science

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Introduction

- Statistics is not just about *facts* and *math*.
- Statistics is a **direct extension of philosophy of science**.
- The numbers only make sense because of underlying (philosophical) arguments.
- Statistics is changing, cross-pollinating with data science: looking at the philosophy under the hood helps you navigate those changes
- Goal today: understand the main ideas that shape how we do statistics in the social sciences.

Paradigms (Kuhn, 1962)

- Thomas Kuhn introduced the idea of **paradigms**:
- Shared frameworks of concepts, methods, and assumptions that guide the production and interpretation of research.
- “Normal science” happens within paradigms: everyone knows the rules, and doesn’t question them so we can get down to business
- Paradigms are not eternal: they shift through **scientific revolutions**.
- Dominant paradigm in the social sciences is quantitative empiricism
- Things we are able to measure and count
- Things “in the world” that we can observe

The Empirical Cycle (De Groot, 1969)

- A model of cumulative knowledge acquisition through scientific research

1. **Observation** - of patterns in data (including naturalistic observtion).
2. **Induction** - generate hypotheses/theories to explain patterns.
3. **Deduction** - derive testable predictions.
4. **Testing** - test predictions in new data.
5. **Evaluation** - reflect back on theory based on results.

Deductive Reasoning

Deduction

- Often, but not always, from general to specific.
- Example:
- All men are mortal.
- Socrates is a man.
- Socrates is mortal.
- Truth-preserving: If premises are true, the conclusion *must* be true.
- Non-ampliative: Informative content of the conclusion does not exceed that of the premises
- No new knowledge

Inductive Reasoning

Induction

- Often, but not always, from specific to general.
- Example:
  - All swans I’ve seen are white.
  - Therefore, all swans are white.
- Conclusion does not follow logically from premises; it goes beyond them (ampliative)
- The conclusion is not *necessarily* true, even if the premises are

The Problem of Induction (Hume)

- David Hume: Induction cannot be logically justified.
- Past observations do not guarantee future truths.
- Example: The sun has risen every day until now; will it rise tomorrow?
- Pragmatic solution: Inductive reasoning works, because it has yielded true concusions in the past (= inductive)
- We may *believe* it will, but this belief is not based in logic.
- Not truth-preserving
- Ampliative: Conclusion is more informative than the premises

Induction vs Deduction in Statistics?

So… is statistics based on inductive or deductive reasoning?

Induction and Deduction in Statistics

- **Deduction in hypothesis testing**:
  - Theory -> Prediction.
  - Example: If studying causes better grades -> studying should be correlated with grades in dataset.
- **Induction in hypothesis testing**:
  - Statistical inference
  - Example: Observed nonzero correlation in sample -> infer nonzero correlation in population.
- Induction offers weaker support for the conclusion, but allows us to obtain new information not contained in the premises
- Science **cannot escape induction**, but it must acknowledge its limits.

Logic

- Study of valid reasoning
- Sub-area of philosophy, but also mathematics
- Focus on the form of the conclusions, regardless of truthfulness of the premises and the conclusion

Logic: Examples 1

- P: Socrates is a human being
- **C: Socrates is a multicellular organism**

  Conclusion C is true, but does not logically follow from the premise P (not valid)

Logic: Examples 2

- P: Socrates is a human being
- P: All human beings are multicellular organisms
- **C: Socrates is a multicellular organism**

  Conclusion C is true AND logically valid

Logic: Examples 3

- P: Socrates is a human being
- P: All human beings are bananas
- **C: Socrates is a banana**

Conclusion C is false because one of the premises is false BUT logically valid

Propositional Logic

If (it rains) then (the street is wet).

If (A) then (B)

A -> B

We can assign a truth value to A and B

Connectives

Symbol	Name	Meaning
∧	Conjunction	And
∨	Adjunction	Or (= and/or)
->	Implication	If -> Then
<>	Biconditional/Equivalence	Bidirectional implication; iff: if and only if
¬	Negation	Not

Truth Table

A	B	A ∧ B	A ∨ B	A -> B	A <> B
T	T	T	T	T	T
T	F	F	T	F	F
F	T	F	T	T	F
F	F	F	F	T	T

Truth Table Implications

A	B	A -> B	Implication
T	T	T	It rains and the street is wet
T	F	F	It rains and the street is not wet
F	T	T	It does not rain and the street is wet
F	F	T	It does not rain and the street is not wet

Valid Conclusions: Modus Ponens

$[(A \rightarrow B) \wedge A] \rightarrow B$

Two premises and a conclusion:

- If A, then B
- A
- Therefore, B
- P: If a child receives parental support, then they will develop secure attachment.
- P: This child received parental support.
- C: Therefore, this child is securely attached.

Valid argument, but both premises must be verifiably true for the conclusion to be true.

Truth Table Modus Ponens

A	B	A -> B
T	T	T
T	F	F
F	T	T
F	F	T

Modus Ponens for Hypothesis Test?

[(A -> B) ∧ A] -> B

Two premises and a conclusion:

- If A, then B
- A
- Therefore, B
- P: If my Theory is correct, then a predicted pattern will occur in the Data
- P: My Theory is correct
- C: Therefore the predicted pattern occurred in the Data

We’re assuming the very thing under question (A)

Fallacies: Denying the Antecedent

$[(A \rightarrow B) \land \neg A] \rightarrow \neg B$

- If A, then B
- Not A
- Therefore, not B

Invalid argument; no reason why the conclusion would follow from the premises, even if they are true.

- P: If Theory X is correct, then a predicted pattern will occur in the Data
- P: Theory X is not correct
- C: Therefore, the predicted pattern will *not* occur in the Data

The pattern could occur for OTHER reasons

Fallacies: Affirming the Consequent

$[(A \rightarrow B) \wedge B] \rightarrow A$

- If A, then B
- B
- Therefore, A
- P: If Theory X is correct, then a predicted pattern will occur in the Data
- P: The predicted pattern occurred in the Data
- C: Therefore, Theory X is correct

The pattern could occur for OTHER reasons

Valid Conclusions: Modus Tollens

$[(A \rightarrow B) \land \neg B] \rightarrow \neg A$

- If A, then B
- Not B
- Therefore, not A
- P: If my Theory is correct, then a predicted pattern will occur in the Data
- P: The predicted pattern did *not* occur in the Data
- C: Therefore, the Theory is not correct

Truth Table Modus Tollens

A	B	A -> B
T	T	T
T	F	F
F	T	T
F	F	T

Falsificationism (Popper)

- Karl Popper: we cannot prove theories true
- Collecting white swans would be affirming the consequent,
- We can only **falsify**: search for black swan is modus tollens.
- Science should focus on **rejecting** theories.
- There is no “scientific proof”; the best theories are those that are “not yet falsified”
- Related to Demarcation: distinguishing science from pseudoscience
- Pseudoscientific claims cannot be falsified
- “All swans are white” is falsifiable (find one black swan).

Science or Pseudoscience?

- Vaccines cause autism
- Chinese restaurant disease
- Homeopathy (like cures like)
- Anthropogenic emissions cause climate change

Falsificationism and Hypothesis Testing

- Dominant paradigm in social sciences: **Null-Hypothesis Significance Testing (NHST)**.
- Steps:

1. True belief: alternative hypothesis H_a
2. Create zero null hypothesis H_0
3. Calculate probability of observing sample statistic if H_0 were true
4. If this probability is low, reject H_0
5. Conclude that results are *consistent* with H_a

- Criticism: This is **fake falsificationism**.
  - H_0 is a “straw man” with no substantive meaning
  - H_a remains underspecified
  - True falsification would test the *actual* theory

Limitations of Hypothesis Testing

- Modus tollens does not straightforwardly apply to probabilistic statements
- Rejecting H_0 does *not* confirm H_a.
- Finding a lack of (significant) evidence in a sample can happen due to chance
- Thus, finding "no evidence" could happen because the hypothesis is false, OR because the test failed (e.g., due to small sample, violation of assumptions)
- Moreover, if the test DOES find an effect, this does not "prove" the hypothesis

Underdetermination of Theory by Evidence

Duhem-Quine-Thesis:

- It’s impossible to conclusively falsify a hypothesis
- Every central hypothesis relies on “auxiliary hypotheses” which we must assume to be correct
  - Measurement, method, statistical assumptions
- Falsifying evidence COULD be due to a problem with the central hypothesis, OR with any of the auxiliary hypotheses

Solutions

- Accept that science has no purely logical-deductive inference
- Or accept that auxiliary assumptions must be made somewhere
- Kuhn: Paradigm provides widely shared auxiliary assumptions
- Lakatos: Hard core and protected by auxiliary hypotheses; only auxiliary hypotheses can be falsified

Feyerabend

- Book “Against Method”: critique of ALL methodological rules
- Actual research determines the scientific method and rarely follows prescribed methods
- Rhetoric, propaganda, beauty, personal preference, and social factors play a larger role than rational argument and empiricism
- There are no generally useful and exceptionless methodological rules
- Logical empiricism and Popper’s critical rationalism would inhibit scientific progress
- Epistemological anarchy: “Anything goes”

Where Does This Leave Us?

- Science is messy.
- The problem of induction always pops up if you try to learn general principles from specific observations
- Statistics is no magic bullet
- While the hypothetico-deductive paradigm is based on legitimate philosophy of science, there are also ritualistic mis-applications (Gigerenzer: Null ritual)
- As future researchers:
  - Use statistics critically.
  - Be mindful of assumptions.
  - Acknowledge limitations of your conclusions, while also remaining assured that no other approach has contributed so consistently to the accumulation of knowledge and practical improvements as the scientific method (see: The Knowledge Machine)

Causality

- Scientists and policymakers care about **causal effects**
- Any time you want to *intervene*, make a change, explain, understand
- Three criteria for causality:

1. **Association** - X and Y are related.
2. **Temporal precedence** - cause before effect.
3. **Non-spuriousness** - alternative explanations ruled out.

- Methods:
- **Randomized controlled experiments**: ensure all three criteria
- **Causal inference methods**: if you assume that these criteria are met

Further Reading

Godfrey-Smith, P. (2009). Theory and reality: An introduction to the philosophy of science. In Theory and reality. University of Chicago Press.

Strevens, M. (2020). The knowledge machine: How an unreasonable idea created modern science. Penguin UK.

Debora Mayo: Statistical Inference as Severe Testing: How to Get Beyond the Statistics Wars, Cambridge University Press, 2018 ISBN 978-1107664647

Richard McElreath: Statistical Rethinking: A Bayesian Course with Examples in R and Stan. Chapman & Hall, 2015 ISBN 978-1482253443

Speaker notes