Finetuning and Free Parameters

Richard Dawid
Stockholm University

- The problem of finetuning (FT).
- FT and the need for a prospect of an underlying theory.
- The case of ST.

Finetuning as an Indicator

There is a fairly widespread, though not uncontested, understanding that FT arguments are heuristically important:

If a parameter value looks finetuned in our theory, we should search for a new theory that explains this.

Today we know two types of possible explanation:

1. Naturalness explanation: A new principle establishes a structure that enforces or makes probable the specific values in the effective theory without finetuned parameters.
   - Atoms enforce multiple proportions in chemistry (FT towards integers)
   - Inflation explains isotropy and flatness of the universe.
2. Anthropic reasoning: Physics implies a vast number of parameter values that exist in different parts of the universe and only some finetuned of those allow for our existence.
   - Λ? …

Naturalness and anthropic arguments

- Note that naturalness and anthropic reasoning are not strictly opponents.

- To the extent anthropic reasoning is predictive, this is based on the degree of finetuning necessary from an anthropic perspective.

- Weinberg's prediction regarding the cosmological constant states the anthropically required degree of finetuning.

- But this relies on a naturalness assumption: there won't be any further FT finetuning beyond the anthropic requirement.

Problems of Finetuning Arguments

Specific:

- Which Parameters should be subjected to FT analysis?
  - Why bare parameters?
- What is the right measure?

General:

- Why rule out that natural laws are finetuned?

➢ It has been suggested that FT is in essence a esthetical argument, comparable to simplicity or elegance.

Finetuning arguments in physics as a category mistake?

- If we observe some finetuned state in our neighborhood, we are right to infer that there probably is an explanation.

If I observe twelve parallel and equally distanced matches on a table, I assume that there is a reason (someone will have put them there deliberately.)

But this is an issue of the known dynamics governed by natural laws that determines the probabilities of specific outcomes.

=> they provide a measure fore assessing the degree of FT.

- FT of a fundamental physical constant:
  - no framework that gives me any probabilistic understanding.
  - Not all small numbers incur the same intuition: did atomism pose an FT problem because space is nearly empty?

$\Rightarrow$ Do FT arguments just amount to an misguided esthetic preference learned in another context where it had a physical basis?

But it often works also in physics

- **The early naturalness problem of the heliocentric model.**
- As observers did not find stellar parallaxes, the heliocentric model implied huge distances to the stars.
- The FT argument suggests that one should look for an explanation of the missing parallaxes that gets rid of the FT.
- And that worked: modern astrophysics can explain the decoupling of the typical dimension of solar systems from distances between stars and therefore establish the naturalness of what we observe.

- People defending the geocentric view based on naturalness were not wrong in using a naturalness argument!
- They were wrong in holding a no alternatives claim about geocentrism.

Some messages from the heliocentricity example

I. A naturalness argument for a specific theory involves two elements:
   1. The claim that FT needs to be explained
   2. The claim that the present theory is one of very few that do the job.

II. The idea that FT needs to be explained in the given case does not fail as soon as the first candidate explanation turns out to be inadequate.

III. If an explanation is found, what used to be an initial condition or free parameter often turns into a matter of a new theory's dynamics.

=> ex post, we do have the "matches scenario".

And how about classical probabilistic physics?

Kinetic gas theory makes statistical predictions. It predicts that the laws of thermodynamics hold.

- If a deviation from those predictions were observed, that might be explained by a FT of initial conditions. (atypicality)

- But initial conditions that are ad hoc finetuned to break the statistical predictions in accordance with observations would not be accepted as legitimate scientific choices.
- If they were, science would be in serious danger since such ad hoc FTs would eradicate large parts of predictability and therefore testability.

  (If FT of initial conditions was adopted, one would need a physical principle that guides it.)

➢ Typicality assumptions behave rather like a part of the theory than like a mere esthetic prejudice.

➢ But they are external to the laws involved, nothing in the them enforces a certain typicality measure,….

QM tells a nicer story

Once QM is involved, we see a different story.

- Much of what seemed deducible from initial conditions before, now turns into a consequence of quantum processes.
  - Outcomes of scattering processes in particle collisions
  - Galaxy distributions

➢ the initial conditions turn into part of the dynamics.

$\Rightarrow$ statistical analysis is directly confronted with the natural laws.

$\Rightarrow$ Deviation from statistical predictions are in direct contradiction to the theory.

$\Rightarrow$ Finetuning initial conditions by hand is no way out.

➢ Natural approach to the FT of parameter values:

“Internalize” those parameters in a similar way.

A Lakatossian remark

"If a parameter value looks finetuned in our theory, we should search for a new theory that explains this."

Lakatos:

- theories get rejected not based on anomalies but based on better alternatives. (IBE kind of use.)
- "Protective belt" that shields a theory from refutation in the absence of better theories.
  - Questioning of empirical results
  - Hope for future solutions within the same theoretical framework.
  - …
- In effect, anomalous data suggests search for better theories rather than theory rejection in itself.

➢ Reminiscent of the fine-tuning case.

➢ Even the impact of anomalous empirical data on theory assessment has a considerable pragmatic element.

A Lakatossian remark

- Difference to the FT case:
  - No-one doubts that data is epistemically crucial.
  - no tolerance for “final” empirical anomalies.

- ➢ Lakatos’ point is just methodological.
- ➢ The FT issue is about whether the idea that there are no FT parameters is reflected in nature.

In Lakatos’ picture, we can only understand why anomalies give reason to look for alternatives because we expect that there is an empirically adequate theory.

$\Rightarrow$ Something comparable would be needed in the case of FT.

Raw induction

- It would be possible in principle to apply raw induction in order to justify an expectation that the next FT will find an explanation based on the observation that this was the case in previous examples.
- If so, no need to worry about the measure problem, since it is "bridged" by the inductive argument.
- But (see Norton), raw induction is difficult to gauge in thin air.
- It is also quite doubtful whether induction can work here, given the substantial unsolved finetuning problems.

- It seems that one needs a more nuanced approach.

The role of expectation

Suggestion:

Understanding a FT problem implicitly relies on a vague understanding of what a more fundamental theory might look like. That theory may be expected to turn it into a question of dynamics.

$\Rightarrow$ The finetuning argument is driven by the understanding that the parameter will not remain fundamental.

$\Rightarrow$ the fundamental theory is expected to offer a probability distribution (or deductive explanation) for the given parameter value.

- A FT problem then amounts to the understanding that a straightforward “dynamization” that keeps the measure one intuitively applies in the effective theory would make the value improbable.

- The aim then is to find a theory where the value looks natural on its basis.

A shift of emphasis

- Observing FT is not in itself is used to infer that there needs to be a deeper explanation of that parameter value.

- Rather the argument works the other way: If theoretical background knowledge suggests that there may be a deeper explanation of the parameter value, FT constrains the ways in which this can be expected to play out.

? But why should one expect that parameters don’t remain fundamental?

String Theory

- String theory has no free parameters at a fundamental level.
- Parameter values of low energy effective theories must correspond to ground states of ST.

- Two possibilities in principle:

  a. Consistency enforces one or a few specific groundstates. Popular idea in the 20th century.

  b. Modern understanding based on flux compactification (Bousso, Polchinski 2000, KKLT 2003…) : a huge spectrum of groundstates (landscape)

How the two Possibilities answer to FT

- If a.: ST enforces (and thereby explains) the parameter value, be it finetuned or not.
  - Extreme exemplification of naturalness.
  - Note that it would **not** explain the remarkable improbable outcome that a fundamental theory implies precisely the finetuned valued we need in order to live.

  But then, again, what would be the right measure for that improbability?

- If b.: Naturalness would require that the outcome is not overly improbable within the theory's framework.
  - Specific mechanisms could imply distributions of solutions.
    - Example CKM matrix: entries seem to show a logarithmic distribution. A suggested mechanism that selects values with linear distribution would seem odd.
  - Anthropic reasoning could explain FT in a multiverse setting.

Internalizing the FT Argument

- All FT that occurs in effective theories will eventually be turned into a matter of dynamics.
- The dynamics (hopefully) provides the correct probability measure.
- All effective FT must at a fundamental level be explained by
  - being deducible from first principles or
  - being a typical outcome of a statistical process or
  - Anthropic reasoning.

- If a probability measure can be extracted, observing our parameter values turns into a way of empirically testing the theory.
- It is not quite significance testing, since we just have one shot.
- But it seems difficult to deny its relevance.

- If no probability measure to be had, we are back to square one.

A specific constellation

What makes the case specific is the peculiar blend of knowledge and lacunae.

- One knows: no free parameters in ST.
- One does not know: how the theory plays out at low energies:
  - Mechanisms that may affect the distribution of ground states in terms of parameter values are not known.

- There is a fundamental theory but a missing understanding of the mechanism it implies with respect to FT at low energies.
  - ? Separation of Planck scale from EW scale?
  - ? Generation of entries in the CKM matrix?

- The framework is there to render FT an internal issue. The measure will be provided by the mechanism.
- But we don't know the mechanism.

How about the initial understanding of FT?

Let's assume that ST is viable and everyone knows it (without fully understanding its implications).

There would still be FT arguments.

But the old understanding:

"If a parameter value is finetuned in our theory, we should search for a new theory that explains this."

would not make any sense any more.

We would know anyway that ANY fundamental parameter must be explained, be it finetuned or not.

$\Rightarrow$ The only way to understand the role of a FT argument then would be:

FT constrains the ways in which the so far unknown fundamental explanation of a given parameter value can be expected to play out.

Conclusion

- Sceptics of FT arguments are right that those arguments don't work in "thin air".
- But FT arguments can make sense if they are embedded in vague "bets" on the future of physics.
- Once one acknowledges the serious possibility that there is a fundamental theory without free parameters, FT arguments are an essential part of interpreting the data.