Beyond Risk: Robust Policy Assessment and Intertemporal Valuation

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National Academies Wisdom?

2017 Recommendation for updating estimation of the Social Cost of Carbon. Four distinct modules:

1. socioeconomic
   ↓
2. climate
   ↓
3. damage
   ↓
4. discounting

Integrated science?

Haunted by Hayek's forewarning

"Even if true scientists should recognize the limits of studying human behaviour, as long as the public has expectations, there will be people who pretend or believe that they can do more to meet popular demand than what is really in their power."

From Hayek's Nobel address (1974)

Evidence-based policy?

- The challenges of economics policy are often dynamic in nature.
- Empirical researchers and applied statisticians gravitate toward problems with data richness.
- But the data tend not to be rich along all of the relevant directions for policy.
- Model-based approaches remain essential with important subjective inputs needed to fill knowledge gaps.

How could uncertainty matter?

- Should we be more or less proactive?
- How should we reduce future exposure to uncertainty?

The answers depend in part on how much or little confidence decision-makers have in their baseline probabilistic predictions.

What do uncertainty considerations bring to the table?

Two key uncertainty trade-offs:

- How much weight do we assign to:
  - best guesses
  - potentially bad outcomes
- Do we act now, or do we wait until we learn more?

Remaining talk outline

- decision theory under uncertainty
- uncertainty-adjusted probability distribution
- intertemporal social valuation

References

- Hansen & Sargent, (2022). Structured ambiguity and model misspecification. *JET*.
- Carreia-Vioglio, Hansen, Maccheroni, and Marinacci, (2025). Making decisions under model misspecification. *ReStud*.
- Hansen & Souganidis, (2025). Stochastic responses and marginal valuation. *PNAS*.
- Barnett, Brock, Hansen, & Zhang, H. (2026). Uncertainty, social valuation, and climate change policy. *SSRN working paper*.

Incorporate advances in decision theory under uncertainty

Decision theory aims to develop and justify approaches that are "rational," or more appropriately, "prudent," offering a broad perspective on uncertainty.

Do not know:

- outcomes but probabilities are known - risk
- which among multiple probability models is best - model ambiguity
- ways in which a model might give flawed probabilistic predictions - model misspecification

We endow our policy maker with preferences that encode aversions to these uncertainties. We explore sensitivities to these aversions.

Robust policy problem

- Formulate a recursive max-min game where we:
  - minimize over the possible alternative probability distributions subject to penalization
  - maximize over the possible decision processes.
- As external analysts, we explore sensitivity of the minimizing distributions to the magnitude of the penalizations.

Risk components in our protype economy

- Brownian (normally distributed) shocks
- Poisson (big) events, two types:
  - reveal damage uncertainty represented by alternative damage function curves for larger values of warming - intensity depends on the temperature anomaly
  - discover a new technology that eliminates the need for the dirty energy input - intensity depends on a knowledge stock

Relax full confidence (explore sensitivity to ambiguity and misspecification)

Uncertainty quantification

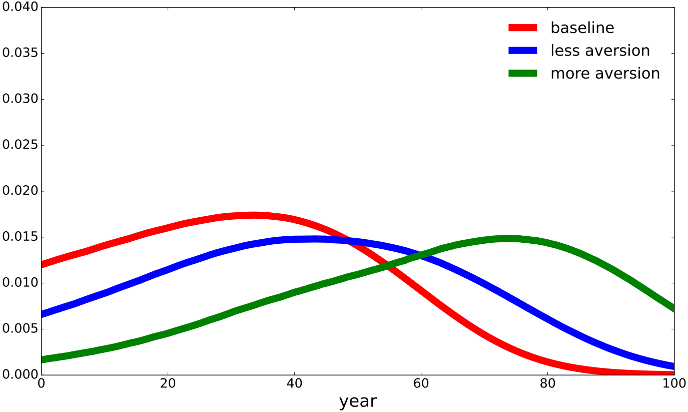
Two questions:

- How much uncertainty aversion should we impose?
  - trace through sensitivity to the choice of penalty parameters or constraints;
  - inspect the impact on the implied worst-case distributions of the min-max problem.
- Which source of uncertainty matters the most?

Uncertainty-adjusted probabilities

- Deduced from robust policy problem
- Draw insights from robust Bayesian theory and derivative claims pricing to:
  - derive a "worst-case" probability distribution isolating where potential misspecification is most concerning;
  - this "uncertainty-adjusted probability" is not intended to be the beliefs of the policy maker
  - nevertheless, we use the adjusted probability to represent the marginal valuation.

Illustration of uncertainty-adjusted probabilities



Jump-time densities for the technology jump only model

Why intertemporal marginal valuations?

They:

- help to navigate movements from suboptimal allocations to more efficient alternatives;
- provide interpretations of first-order conditions for optimal policies, including dynamic investment choice;
- support the implementation of an optimal policy or a robust counterpart;
- are proportional to derivatives of values with respect to endogenous state variables.

We provide formulas for intertemporal marginal valuation that deconstruct the valuations into alternative interpretable components.

Ingredients

- start with a value function, V,
  - impose the controls (investments and other actions): do not have to be optimal
  - characterize explicitly the state variable interactions
- form stochastic (nonlinear) impulse responses
- deduce an asset pricing-type formula with marginal utility adjustments
- model infrequent big changes as Poisson jumps
- construct an altered probability measure that adjusts for uncertainty aversion
- deduce additive decompositions of the contributions to the marginal valuations

Observation: the approach is different from solving a vector system of co-states forward.

Stochastic state evolution

Initially, consider diffusion dynamics:

$$dX_t = \mu(X_t)dt + \sigma(X_t)dW_t$$

where X is a Markov diffusion and W is a multivariate standard Brownian motion.

We will construct a stochastic impulse response to measure the impact of a marginal change in a state.

Stochastic responses

- Form the vector stochastic response process, Λ, that gives the marginal impact on future X's of a marginal change in one of the initial states.
- Initialize the process at one of the coordinate vectors to specify the initial state of interest.
- Observe that the stochastic evolution that depends on X.

Characterizing Λ

- The process Λ^i evolves as:

$$d\Lambda_t^i = (\Lambda_t)' \frac{\partial \mu_i}{\partial x}(X_t)dt + (\Lambda_t)' \frac{\partial \sigma_i}{\partial x}(X_t)dW_t.$$

  where Λ^i is the i^{th} component of Λ.
- Stack all of the Λ^i's and study the joint dynamics (X, Λ).
- Linear VAR (vector autoregression) counterpart is obtained with a drift $\mu(x)$ that is linear in x and a Brownian exposure matrix σ that is constant. Λ not stochastic.
- Λ is stochastic in general.

Intertemporal valuation

- Consider a value function, V, associated with a discounted objective with discount rate δ and utility contribution U by:
  - imposing the maximizing controls (investments and emissions) and the minimizing probability measure;
  - characterizing its dependence on state variables.
- Investigate marginal values computed as partial derivatives that capture small changes in the endogenous state variables including temperature, the stock of capital, and the stock of knowledge.

Note that under diffusion dynamics, a value function solves a Feynmann-Kac equation.

An initial pricing formula

Represent the partial derivatives as asset prices:

$$\frac{\partial V}{\partial x}(X_0) \cdot \Lambda_0$$
$$= \delta \int_0^\infty \exp(-\delta t) E \left[\frac{\partial U}{\partial x}(X_t) \cdot \Lambda_t \mid X_0, \Lambda_0 \right] dt.$$

where δ is the subjective rate of discount and U is the utility contribution to the value function.

- Initializing Λ_0 at alternative coordinate vectors gives the derivatives of interest.
- $\frac{\partial U}{\partial x}(X_t)$ is marginal utility contribution in the future.
- Λ is the vector of stochastic impulse responses.

Adding in jumps

Analyze the problem from a "pre-jump" perspective.

- Let $\mathcal{J}^\ell(x)$ denote the jump intensity to jump type ℓ, for $\ell = 1, 2, ..., L$.
- Let V^ℓ denote the state dependent continuation value for type ℓ.

We are particularly interested in the case in which the jumps depend on endogenous state variables.

Jump contributions

- Alter discount rate to adjust for potential Poisson jumps:

$$\delta + \sum_{\ell=1}^{L} \mathcal{J}^{\ell}(X_t).$$

- Incorporates two additional flows:
  - marginal impact of a jump:

$$\Lambda_t \cdot \sum_{\ell=1}^{L} \left[\frac{\partial \mathcal{J}^{\ell}}{\partial x}(X_t) \right] \left[V^{\ell}(X_t) - V(X_t) \right];$$

  - marginal impact when you jump:

$$\Lambda_t \cdot \sum_{\ell=1}^{L} \mathcal{J}^{\ell}(X_t) \left[\frac{\partial V^{\ell}}{\partial x}(X_t) \right].$$

Uncertainty quantification and and model deconstrution

We use the policy problem to add structure to uncertainty quantification by:

- depicting prudent decisions as dependent on marginal valuations.
- representing marginal valuations as asset prices with uncertain social/economic payoffs.
- partitioning marginal valuations into distinct components based on alternative contributions to the payoffs.

In the case of climate change, (at least) three marginal valuations are relevant:

- social cost of global warming
- social value of research and development.
- social value of capital

Partitioning valuations into alternative components:

- additive state decompositions: changing a state today impacts other states in the future - state feedback effects;
- additive jump contributions: changing a state today impacts the alternative jump intensities and continuation values as they depend on these states.

For our prototype model, the technology jump contribution is critical to understanding why R&D investment increases with uncertainty aversion.