Robust Decarbonization Policies

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Economics and Management of Climate Change: Linking Adaptation and Mitigation

Michel De Lara – Nicolas Schlegel

Cermics, École des Ponts ParisTech, France

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Introduction

- Adaptation and mitigation to climate change require to make decisions "here and now", considering future uncertainties (market, climate, technologies, policies)

- Stochastic optimization allows to design decisions now, that are prepared for an array of future uncertainties weighted by their probabilities

- We present here a case about decarbonization of the economy, and compare — on a toy problem — solutions given
  - either by a single future uncertainty (deterministic)
  - or by an array of future uncertainties (stochastic)

A linear problem in a deterministic framework

Two (normalized) actions x_1, x_2 of decarbonization, with

- $(x_1, x_2) \in \Delta = \{(x_1, x_2) \,|\, 0 \leq x_1, x_2 \;,\;\; x_1 + x_2 \leq 1\}$ (simplex) (third action $x_3 \geq 0$ corresponds to the statu quo, with $x_1 + x_2 + x_3 = 1$)
- respective unitary costs c_1, c_2
- respective unitary emissions reductions e_1, e_2
- emissions reduction target $e^{\#}$

$$\min_{(x_1, x_2) \in \Delta} \quad c_1 x_1 + c_2 x_2$$

$$\text{s.t.} \qquad e_1 x_1 + e_2 x_2 \geq e^{\#} \qquad \text{(emissions reductions)}$$

For instance, in a taxi company, x_1 and x_2 represent fractions of vehicles switched from thermal to electric or hybrid

Solutions (extreme) of the deterministic approach

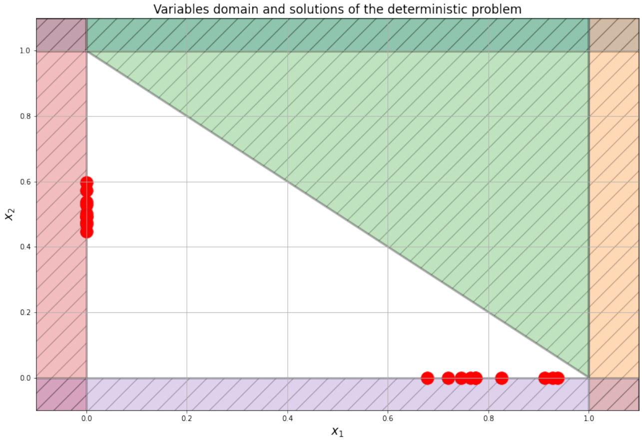

Figure: Variables domain and solutions of the deterministic approach

Fomulation of the multi-scenario approach

- We consider
  - a finite set $\mathbb{S}$ of scenarios (future uncertainties)
  - a family $\{e_1^s, e_2^s, c_1^s, c_2^s, p^s\}_{s \in S}$ of possible values for unitary emissions reduction factors e_1^s, e_2^s, unitary costs c_1^s, c_2^s, and for the price p^s of CO_2 emission rights
  - a family $\{\pi^s\}_{s \in S}$ of nonnegative numbers summing to one, where π^s represents the probability of the scenario s
- and we set the stochastic optimization problem, with a new recourse decision variable q^s, representing buying emission rights after uncertainty is resolved

$$
\begin{aligned}
\min_{(x_1,x_2)\in\Delta,\{q^s\}_{s\in S}\in\mathbb{R}_+^S} \quad & \sum_{s\in\mathbb{S}} \pi^s [c_1^s x_1 + c_2^s x_2 + p^s \overbrace{q^s}^{\text{emission rights}}] \\
\text{s.t.} \quad & e_1^s x_1 + e_2^s x_2 + q^s \geq e^{\#} \ , \quad \forall s \in \mathbb{S}
\end{aligned}
$$

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$$\min_{(x_1,x_2)\in\Delta,\{q^s\}_{s\in S}\in\mathbb{R}_+^S} \sum_{s\in\mathbb{S}} \pi^s [c_1^s x_1 + c_2^s x_2 + p^s \overbrace{q^s}^{\text{emission rights}}]$$

$$\text{s.t.} \quad e_1^s x_1 + e_2^s x_2 + q^s \geq e^{\#} , \quad \forall s \in \mathbb{S}$$

$$\Updownarrow$$

$$\min_{(x_1,x_2)\in\Delta} \bar{c}_1 x_1 + \bar{c}_2 x_2 + \sum_{s\in\mathbb{S}} \pi^s p^s \overbrace{[e^{\#} - e_1^s x_1 - e_2^s x_2]_+}^{\text{convexification term}}$$

Solution (inner) of the stochastic approach

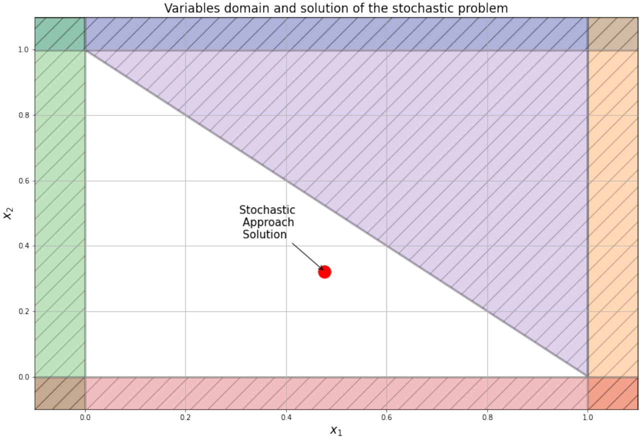

Figure: Variables domain and solution of the stochastic approach

Comparison of costs histograms

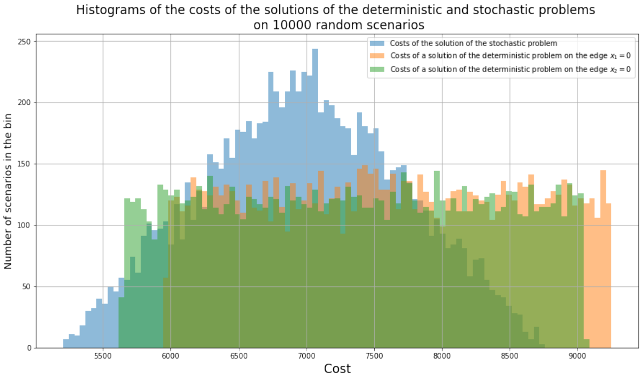

Figure: Histograms of the costs for two "deterministic" solutions and the "stochastic" solution

Conclusion

- With solutions obtained by deterministic approach, we are not sure to satisfy the emission reduction constraints, in case of uncertainties
- By contrast, the robust/stochastic approach provides a solution which is "prepared" for multiple scenarios, and satisfies the emission reduction constraints by means of a recourse variable (buying emission rights)

Stochastic optimization appears as a suitable tool to design robust policies under uncertainty about the future, taking into account the adaptation to uncertainty

Future developments encompass

- industrial cases (decarbonization of mobility)
- multistage approaches