Strategic Decision Making in the 3D Printing Industry

A Robust Decision Making (RDM) analysis

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2018 DMDU Annual Meeting, California, US

November 14, 2018

The 3D Printing Industry

3D printing, the manufacturing of parts by adding layers of material, is gaining importance not only for prototyping but also for finished parts production.

Additive Manufacturing (AM) holds the potential to impact production systems by:

- Streamlining supply chains;
- Enabling economic manufacturing of customized parts;
- Allowing the production of more efficient technical parts with highly complex geometry.

Conventional vs 3D Printed Part

Image Source: metal-am.com

Challenges to AM Systems Manufacturers

These are a few of the key deeply uncertain factors Challenging AM Systems Manufacturer's Strategy:

- **Pace of R & D and Tech. Improvement**: Will our competitors develop the next technological breakthrough in AM?
- **Patent Dynamics and Expiration**: Can we leverage the benefits of our technology before the patent expires? (e.g.: FDM in 2009).
- **Open Source Players**: Will other major players engage in open source technologies or platforms? (e.g.: Prusa).
- **Aggressive Competition and new entrants**: To what extent can we deter new players from aggressively entering the field?

New Product Diffusion Models

There is a broad range of models portraying new product diffusion and technological substitutions, beyond the basic Bass Diffusion Model (Bass 1969):

- **New Product Launch Strategy** and Timing Between Successive Product Generations (Mahajan and Muller 1996);
- **Social Factors** (e.g. Reference Users and Opinion Leaders - GE in the case of AM) (Dattée and Birdseye Weil 2007);
- **Competition** Among Players and Substitution Between Product Generations (Maier 1998);
- **Market Uncertainty** (Cui, Zhao, and Ravichandran 2011);
- **Competition, Learning Curves, diffusion dynamics, Pricing and Capacity Strategies** (Sterman et al. 2007).

X - Uncertainties

This study analyzed **parametric uncertainty** present in the professional AM market, represented by 35 model parameters, including:

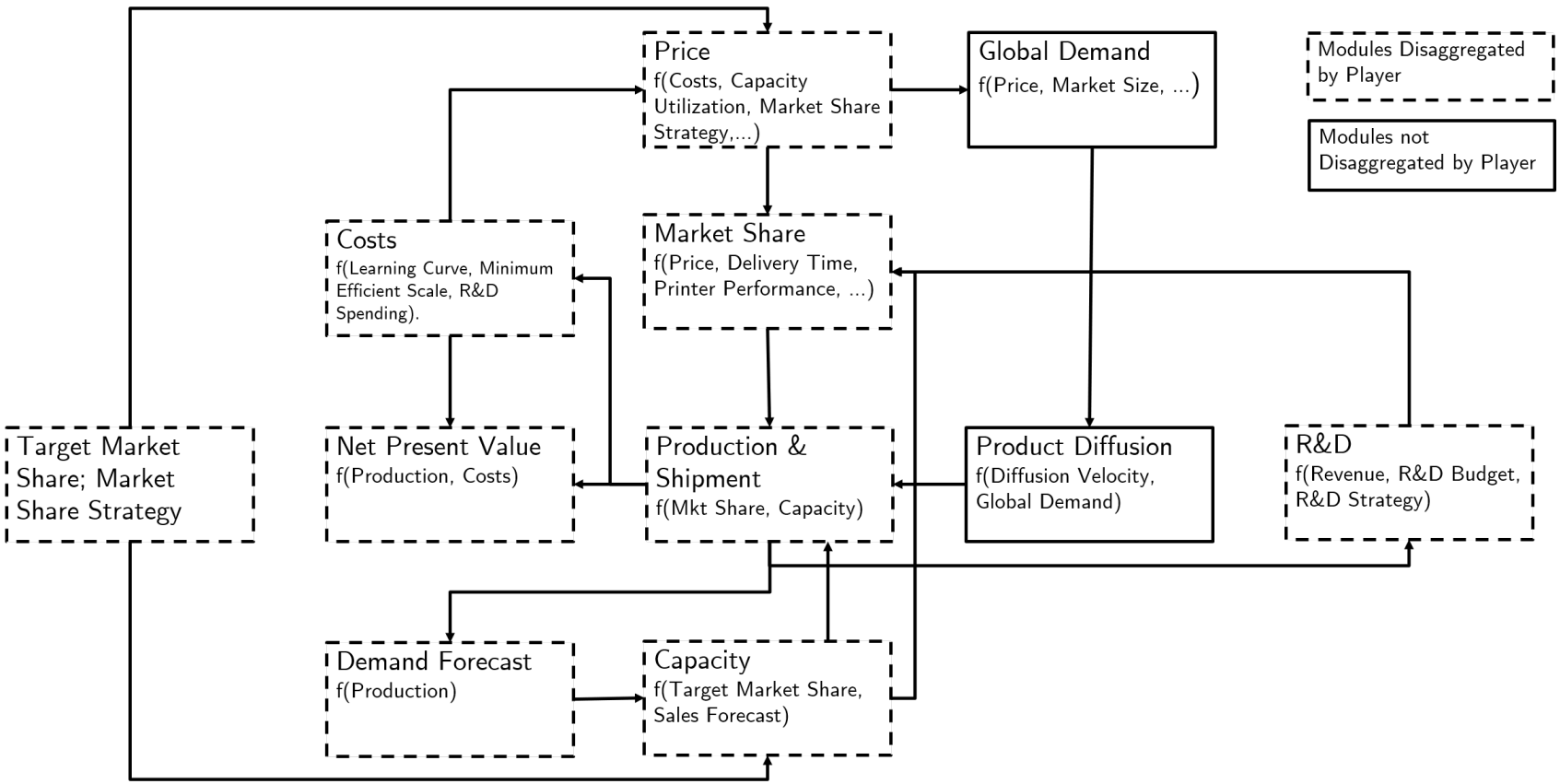
- **Diffusion Dynamics parameters**:how fast and to what extent the industrial-grade 3D printing market might grow;
- **Opponent's Strategies**: The strategy of the opponents manufacturers are also defined as uncertain;
- **Market Share**: To what extent the market will prioritize 3D printer performance rather than its cost.

L - Levers

The AM Systems Manufacturer is allowed to use four levers:

1. **Pricing and Capacity Strategy**: Aggressive vs Conservative;
2. **Target Market Share**: 20%, 30% or 40%;
3. **R & D Budget**: 5%, 10% or 15%;
4. **% of Open Source R & D**: 0%, 50%, 90%.

Relationships - Sterman et al. (2007) expanded model



Relationships - A glimpse* into the model

- Product Diffusion:

$$A_t = A_{t_0} + \int_{t_0}^{t} MAX\left(0, N\left(\alpha + \beta \frac{A}{POP}\right)\right); A_{t_0} = \theta A^*$$

- Patent Dynamics (added to the model):

$$dT^o/dt = \sum_i \left[\kappa_i * (1-\psi) * T_i^r/\upsilon^a\right] - T^o/\upsilon^e$$

*Link to Full documentation, and parameters ranges provided on the final slide.

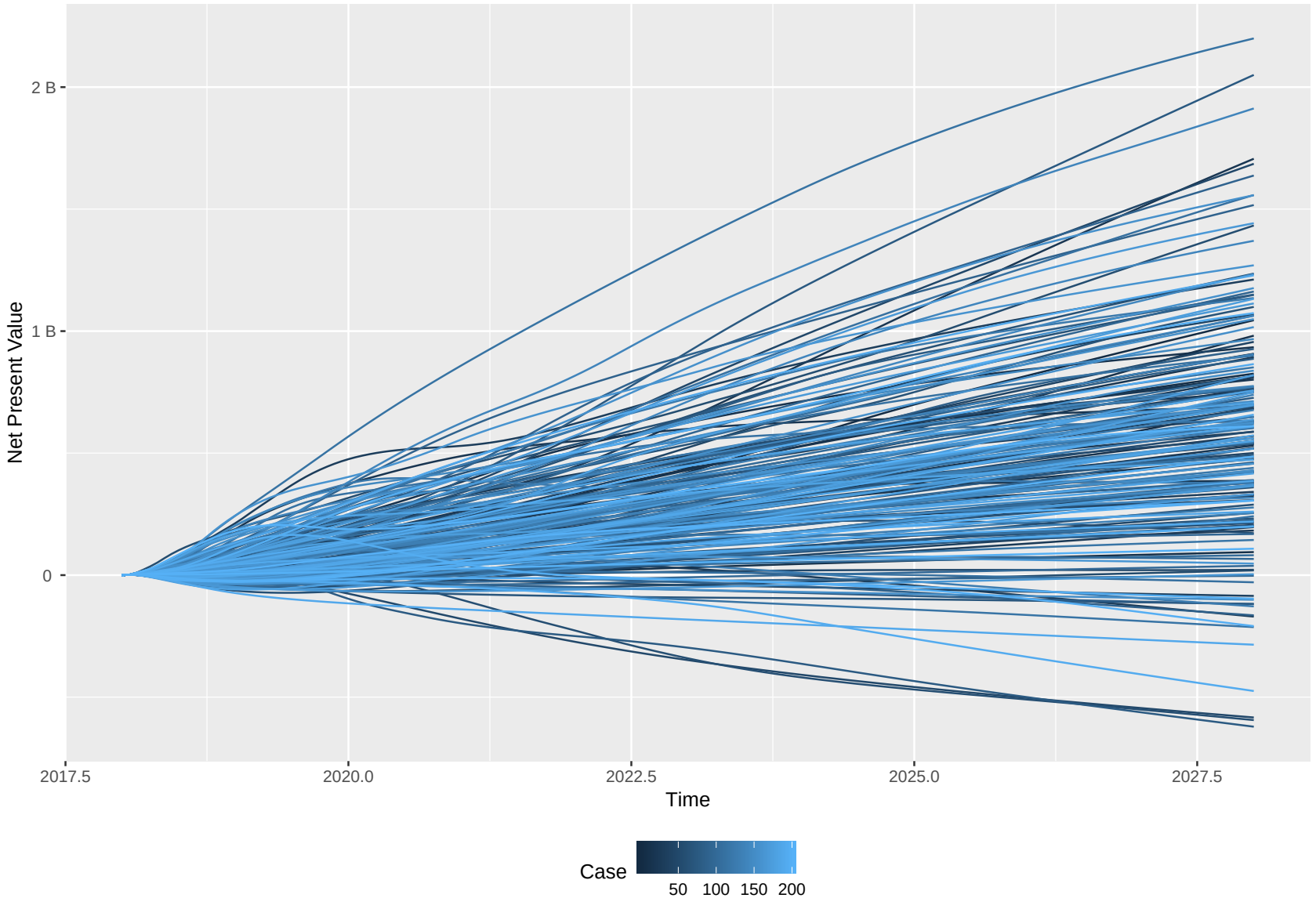
Metrics

We use the **Absolute Regret** of the Playerâ€™s 1 Net Present Value as the metric to compare different alternatives.

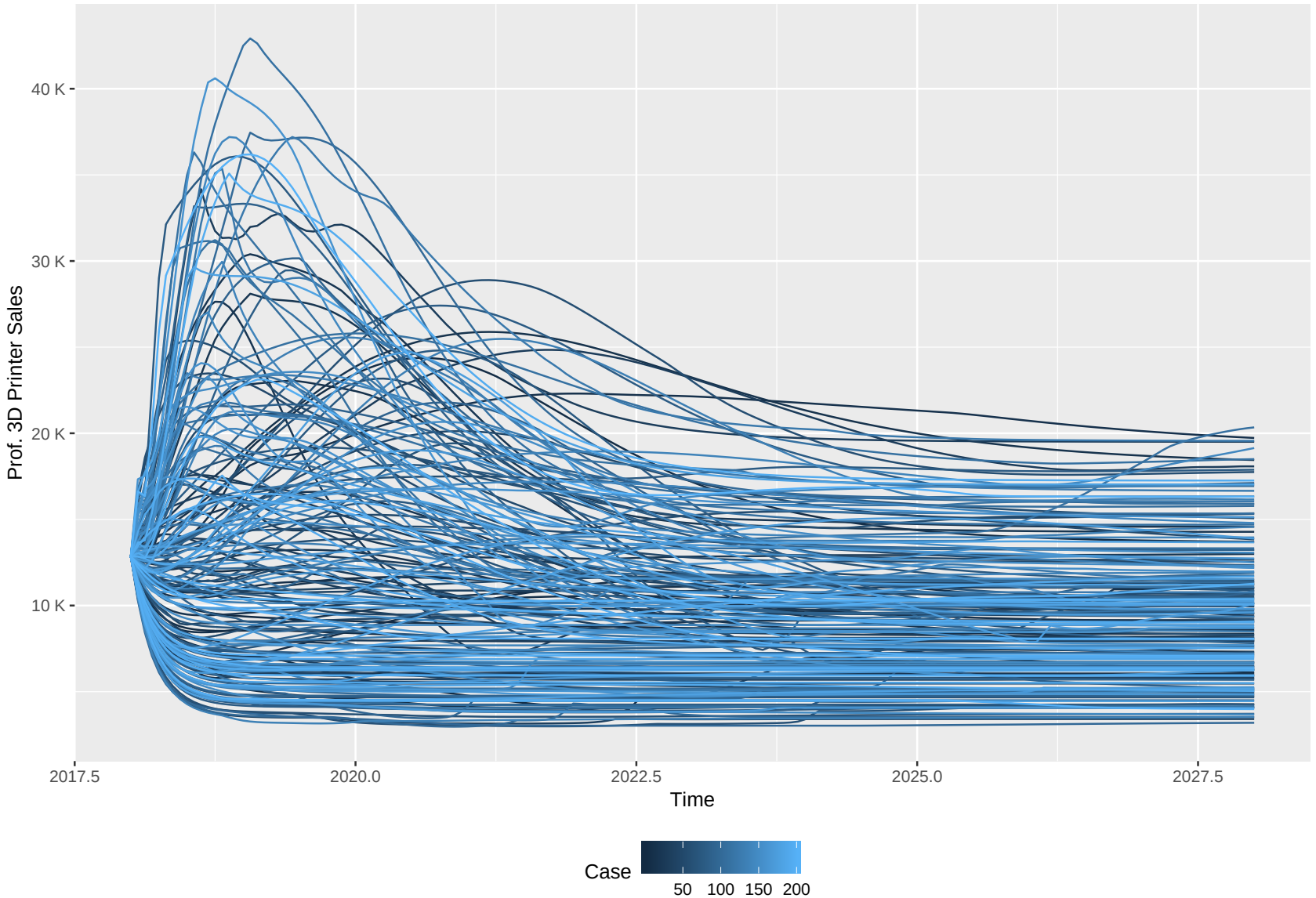
Scenario Ensemble

- **Experimental Design**: 54 strategies were obtained through a full-factorial design of the levers and their levels.
- **Results Database:** The simulation results database contains 10.800 runs (54 strategies X 200 scenarios obtained from LHS of the 35 uncertain parameters).
- **Time-frame:** 10 years.

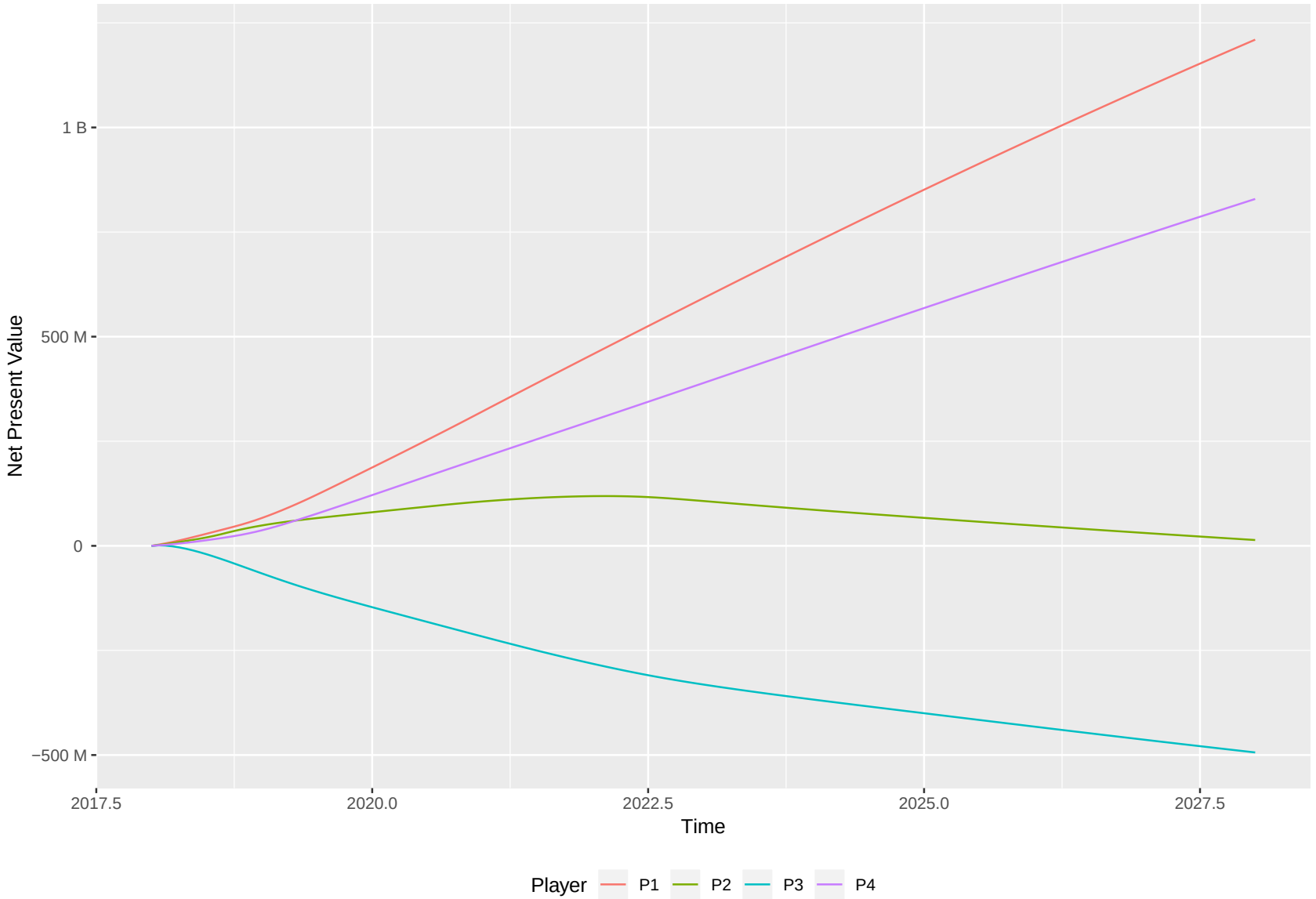
Candidate Strategy NPV across scenarios



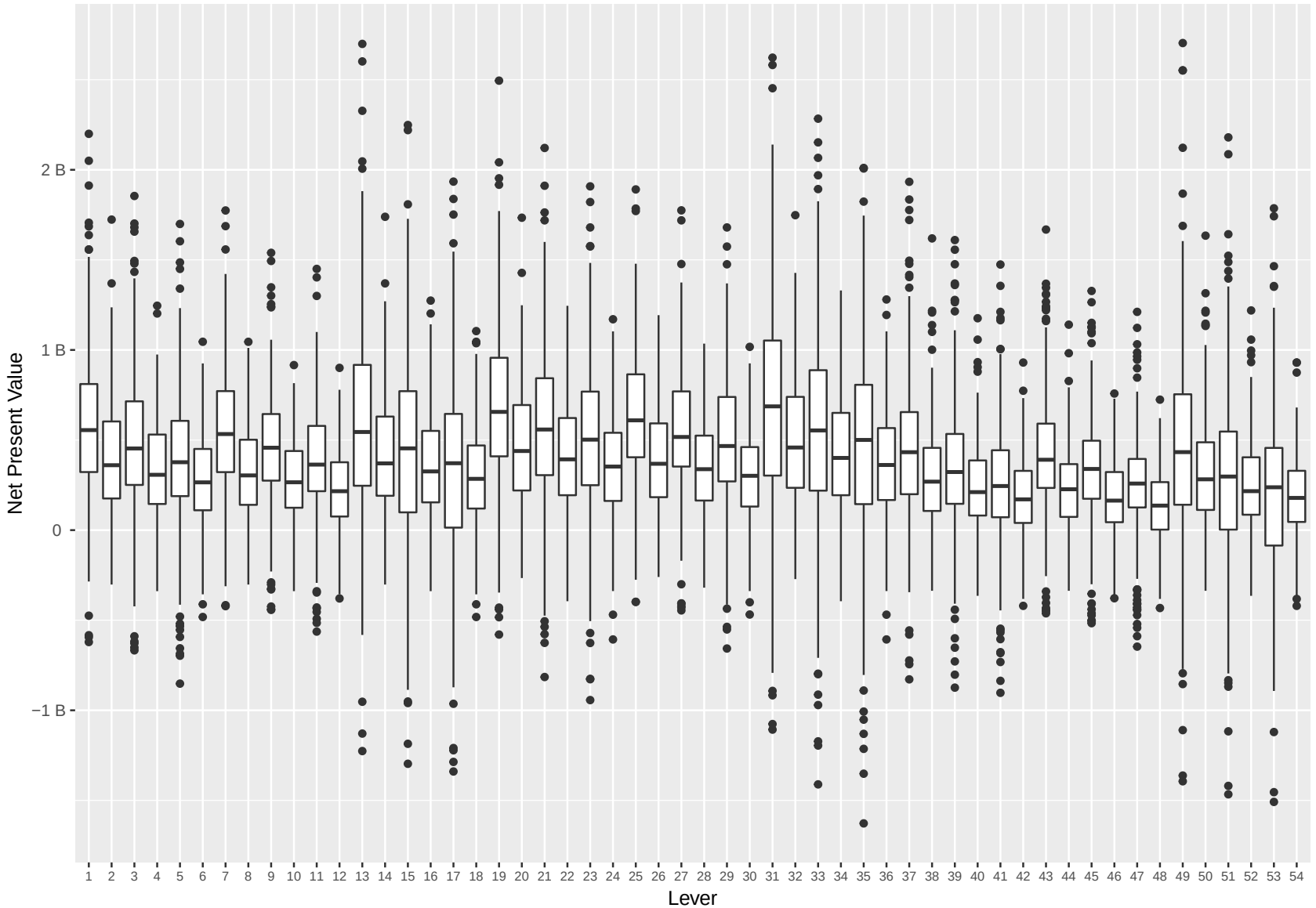
Global Demand across scenarios



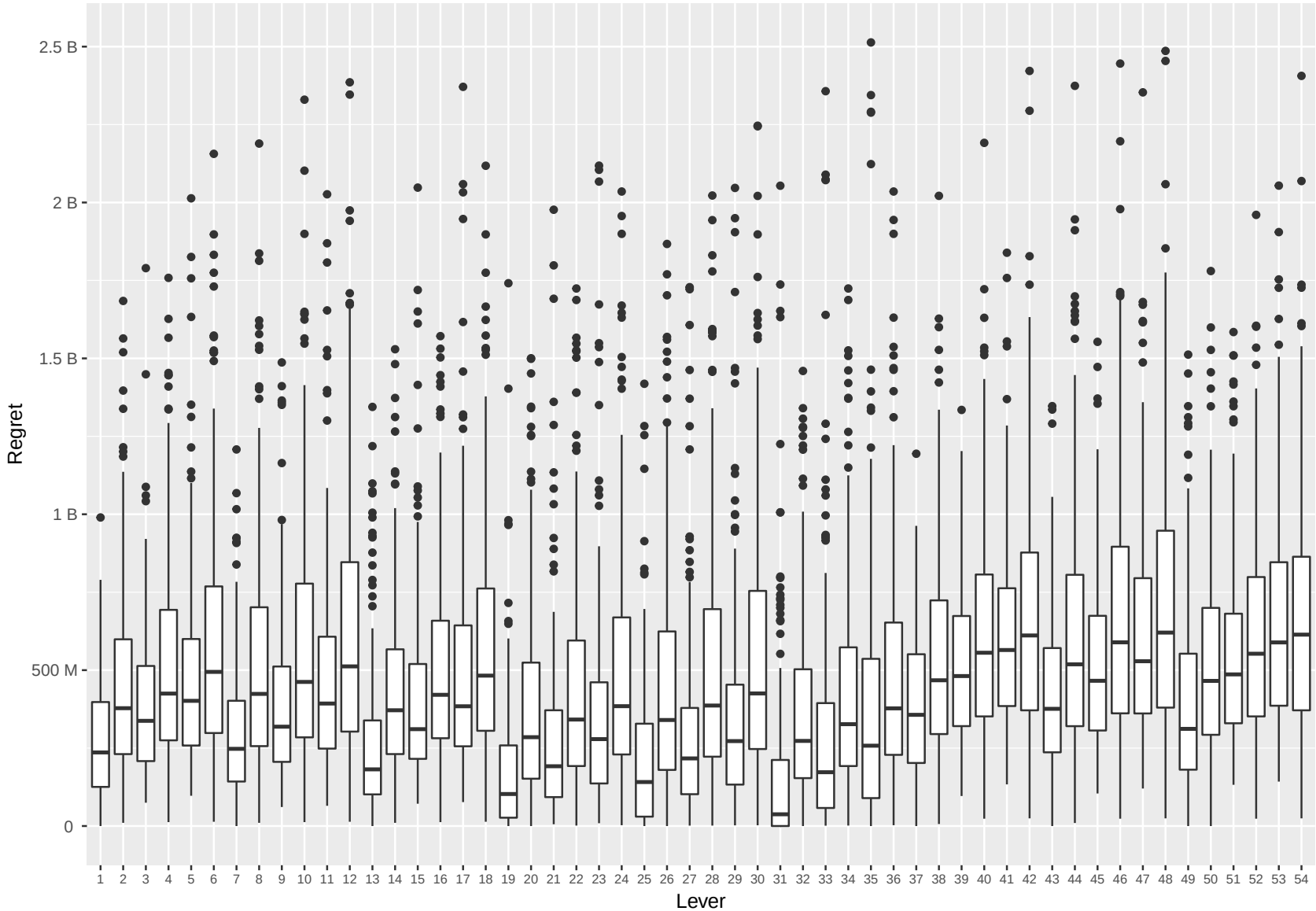
4 Players Net Present Value in a given scenario



Net Present Value across strategies and Scenarios



Regret across strategies and Scenarios



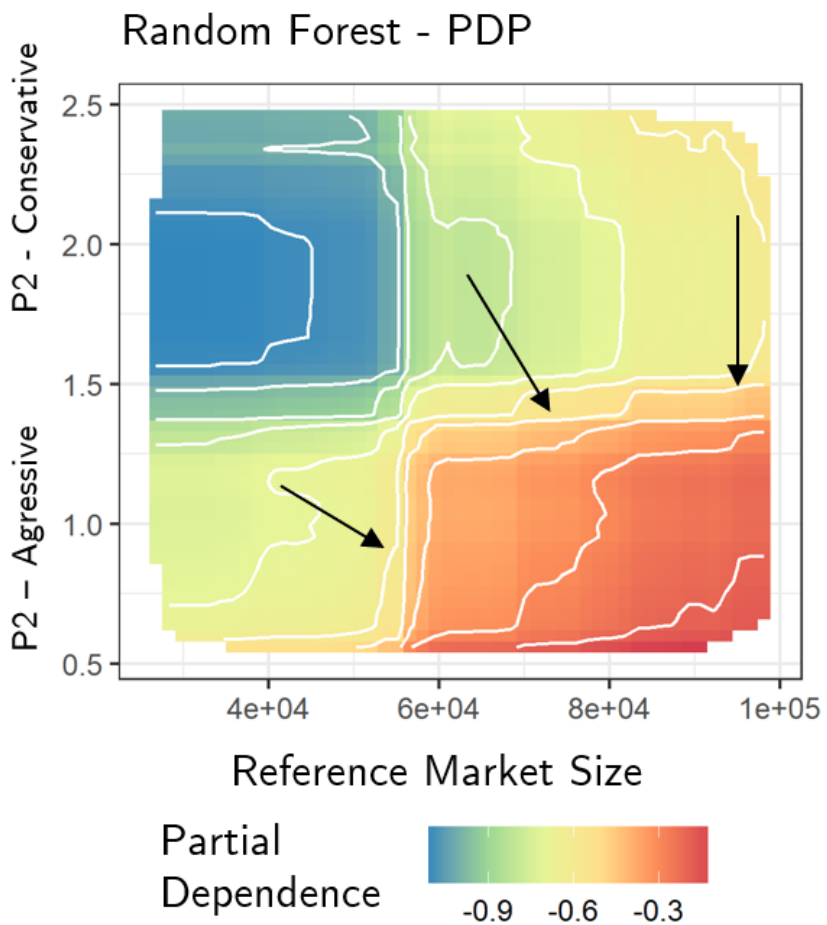
Selected Candidate Strategy

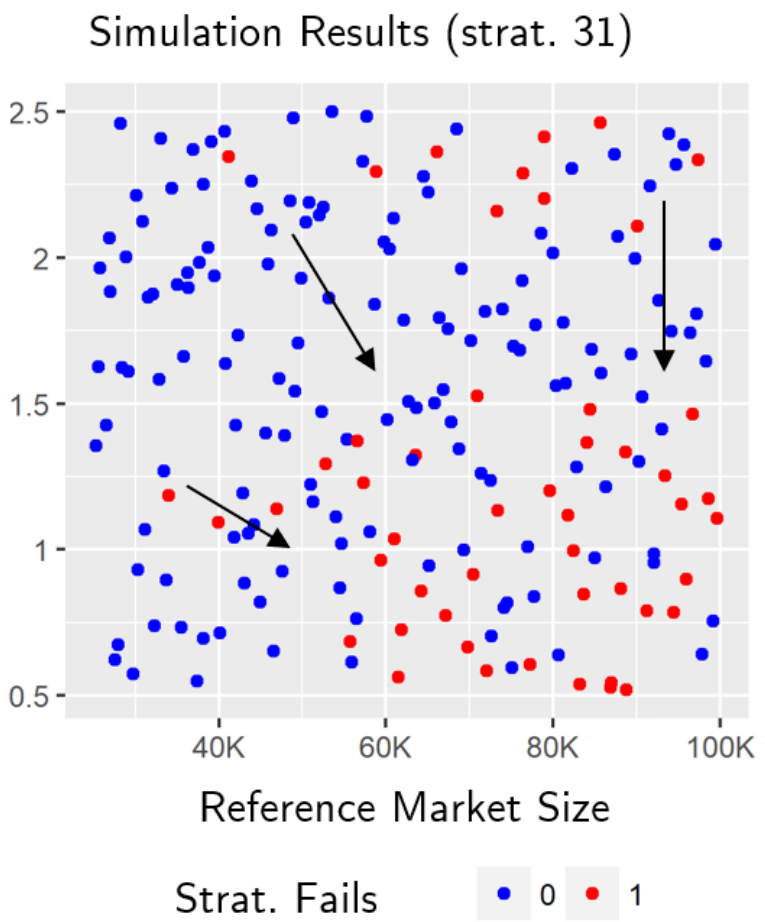
- **Aggressive, Closed Source** Strategies dominated their counterparts;
- The strategy with the **least 75 percentile Regret** was selected for vulnerability analysis.
- Under this strategy (31), the player chooses to **price aggressively** with a **high target market share** (40 %), **invest less in R & D** (5%) with a **closed source** strategy.

Vulnerability Analysis with Random Forests

- We trained a **Random Forest**, and employed the **Boruta Algorithm** to identify the most influential uncertainties that define the circumstances under which strategy 32 might fail (Regret $>$ 211.9 K USD);
- We use the **feature importance ranking** from the random forest to determine which uncertain parameters are more important to define the strategy's failure...

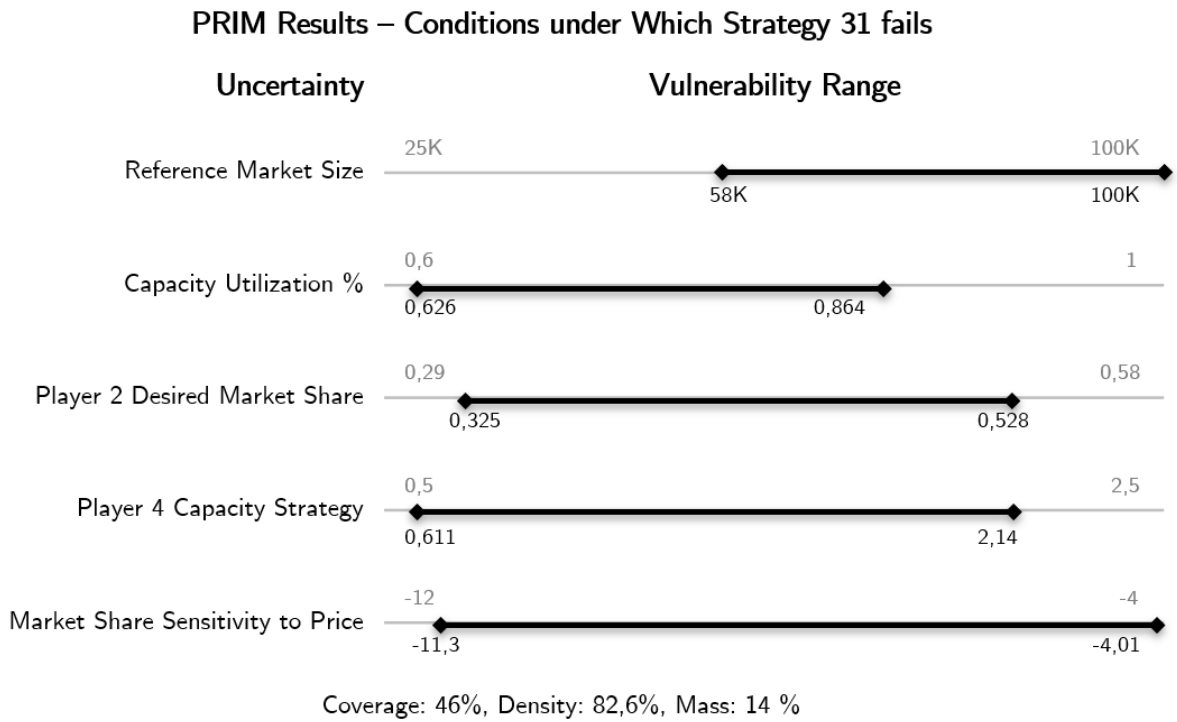
Visualizing Vulnerabilities with PDPs





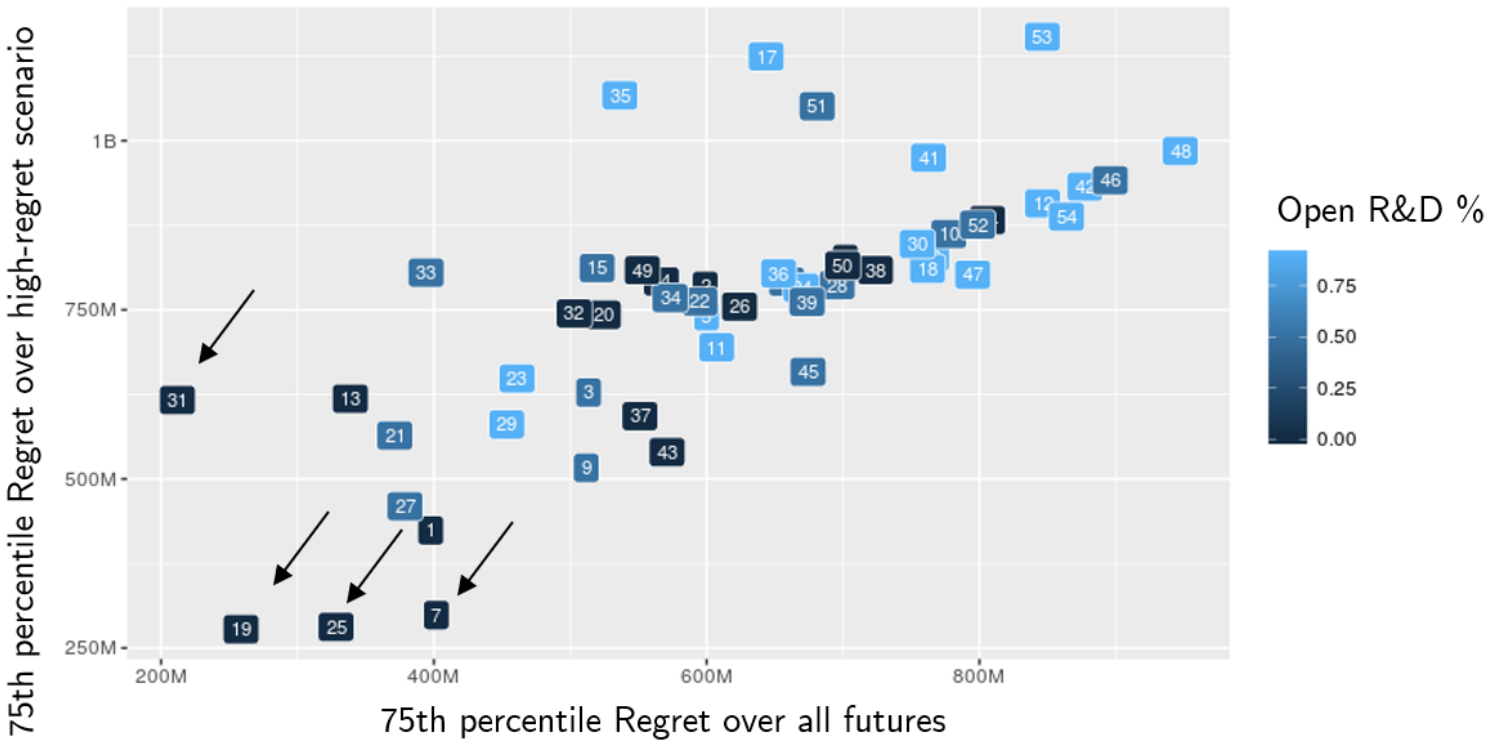
PRIM

PRIM also found a **high-regret region** where the **strategy failed on 82,1 %** of the futures simulated.



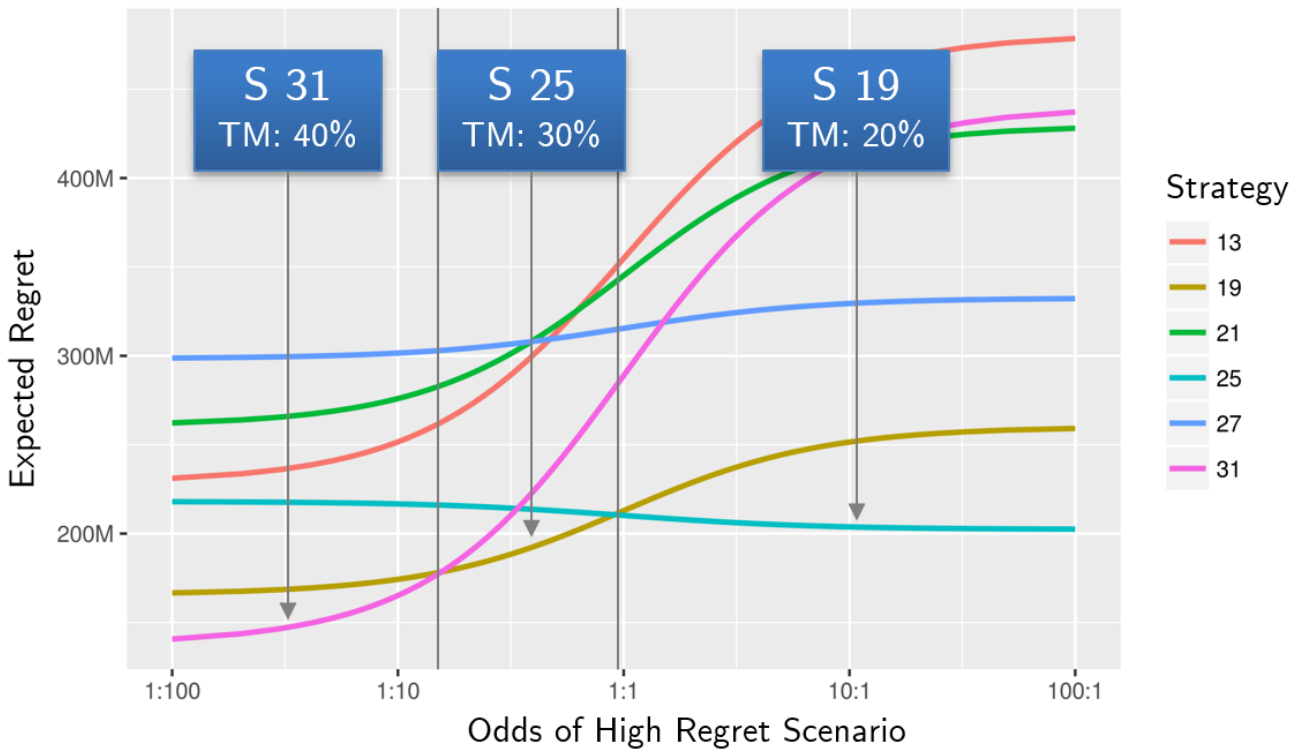
Trade-off Frontier

Trade-off analysis lends **no support for Open R & D or Conservative Strategies**, as the trade-off frontier is dominated by closed-source, less-aggressive strategies:



Trade-off Curves

Strategies 25 and 19 still use an aggressive heuristic but **have less ambitious target market share**:



Final Remarks

This analysis provides an exploration of model-based Business Strategic Decision aiding under the DMDU framework.

Future work might either relax some of the structural assumptions of the model employed on this analysis or turn to new deeply uncertain business problems.

Questions?

Questions?

Further Documentation

References and further documentation available at full master's dissertation (in portuguese) at:

www.pedronl.com/post

References I

Bass, Frank M. 1969. "A New Product Growth for Model Consumer Durables." *Management Science* 15 (5): 215–27. https://doi.org/10.1287/mnsc.15.5.215.

Cui, Anna Shaojie, Meng Zhao, and T Ravichandran. 2011. "Market Uncertainty and Dynamic New Product Launch Strategies : A System Dynamics Model." *IEEE Transactions on Engineering Management* 58 (3): 530–50.

Dattée, Brice, and Henry Birdseye Weil. 2007. "Dynamics of social factors in technological substitutions." *Technological Forecasting and Social Change* 74 (5): 579–607. https://doi.org/10.1016/j.techfore.2007.03.003.

References II

Mahajan, Vijay, and Eitan Muller. 1996. "Timing, diffusion, and substitution of successive generations of technological innovations: The IBM mainframe case." *Technological Forecasting and Social Change* 51 (2): 109–32. https://doi.org/10.1016/0040-1625(95)00225-1.

Maier, Frank H. 1998. "New product diffusion models in innovation management—a system dynamics perspective." *System Dynamics Review (Wiley)* 14 (4): 285–308. https://search.ebscohost.com/login.aspx?direct=true{\&}db=bth{\&}live.

References III

Sterman, John D., Rebecca Henderson, Eric D. Beinhocker, and Lee I. Newman. 2007. "Getting Big Too Fast: Strategic Dynamics with Increasing Returns and Bounded Rationality." *Management Science* 53 (4): 683–96. https://doi.org/10.1287/mnsc.1060.0673.