ANALYSIS OF LAUNCH FAMILY COMPOSITION UNDER CONSIDERATION OF UNCERTAIN LAUNCH MARKET SCENARIOS

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DLR

Overview

- Launch vehicle families
  - Definition
  - Composition
- Parametric cost model
- Uncertain future launch markets
- Payload assignment
- Results
  - Composition trade-offs

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Launch vehicle families

- Simultaneously operating launch vehicles with shared components, for example:
  - Ariane 6/Vega C
  - Falcon 9/Falcon Heavy
    - F9 can also be considered a family of its own if its operating modes (ELV,DRL or RTLS) are considered separately
- Currently, launch vehicle families based on Prometheus engines are being discussed as options for future European launch vehicles
  - Investigated in ESA study NESTS

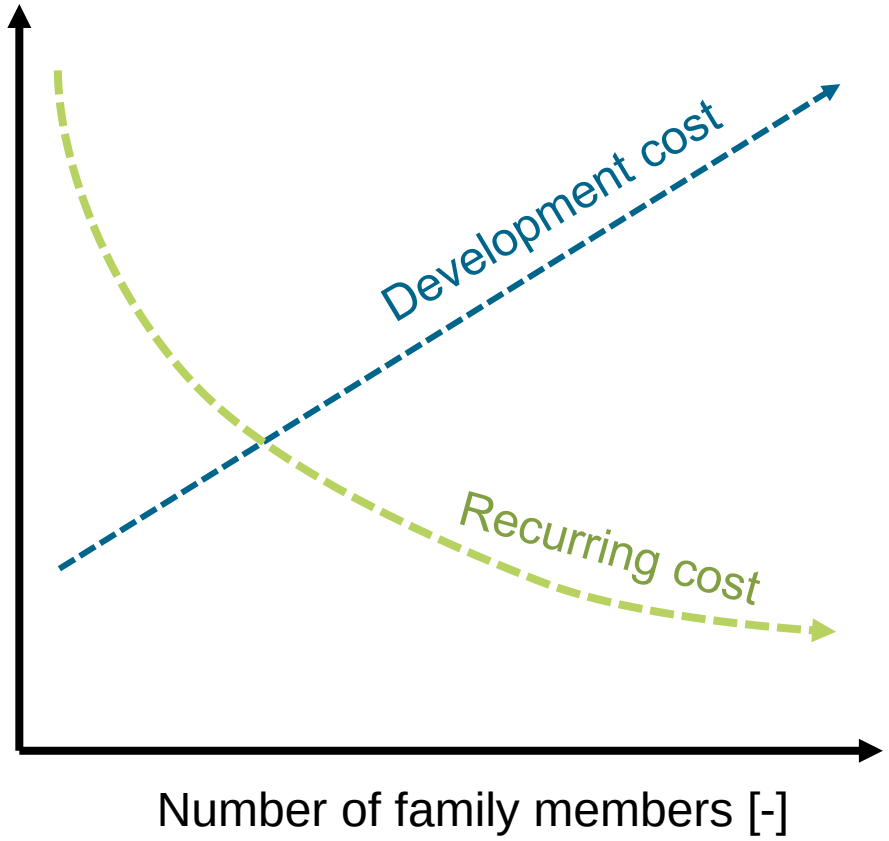
Source: ESA

Source: ArianeGroup

Launch vehicle family composition

- How large should a future European launch vehicle family be?

- Additional family members lead to
  - Possibly lower recurring costs by enabling tailored payload assignment
  - Additional system development costs
- Recurring cost depends heavily on launch scenario and payload assignment



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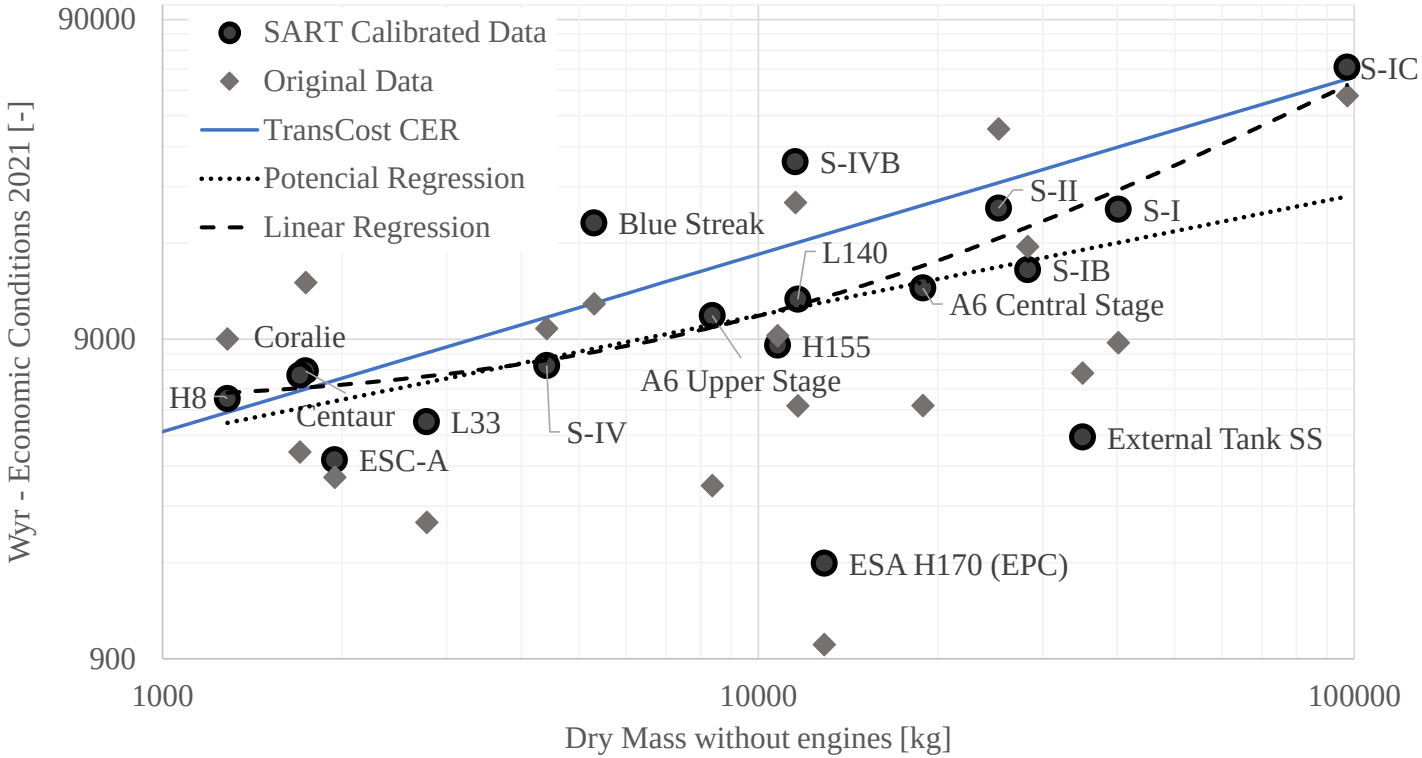
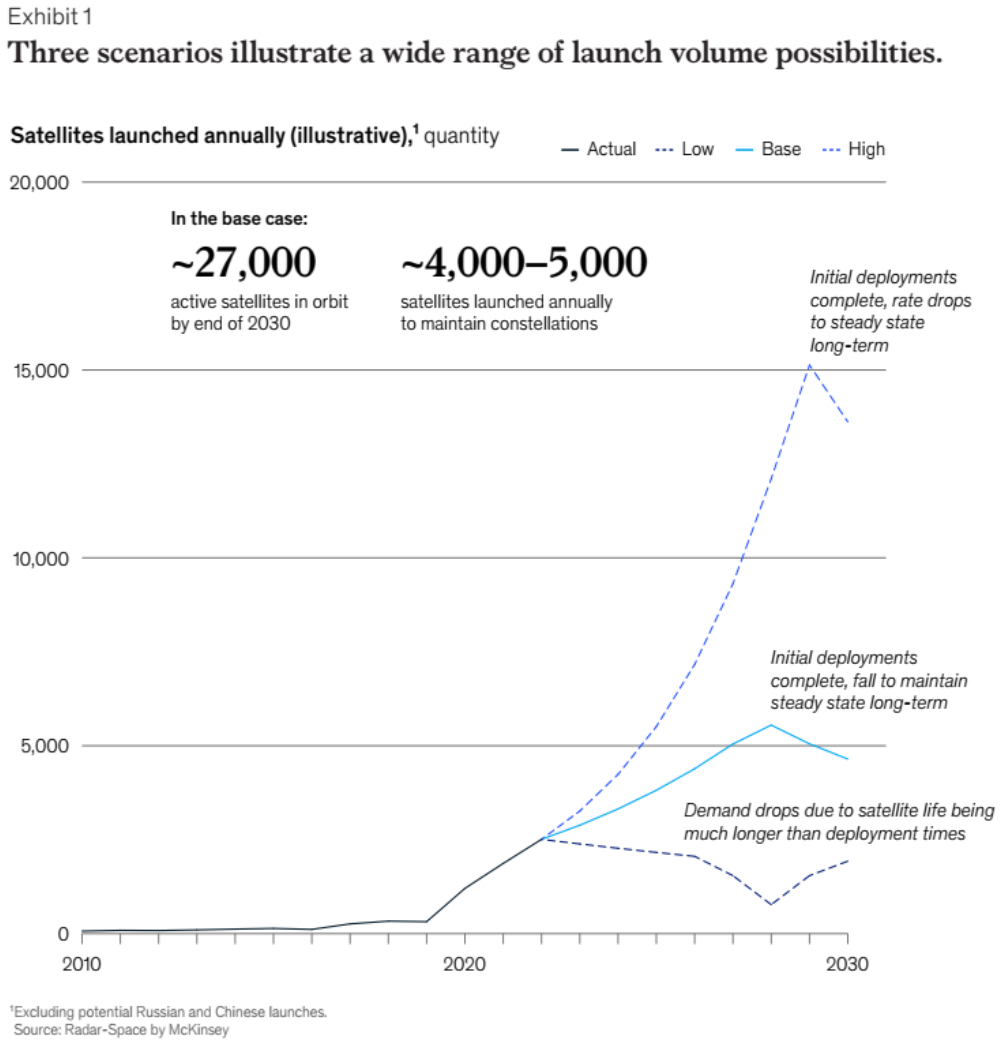
Cost estimation

- Parametric cost model TRANSCOST is used for assessment of recurring and non-recurring cost.
  - Generation of new CERs for reusable components and update of existing CERs
- Development and production efforts are estimated with
  - Effort $= a * M^x$
- Range of factors are applied to account for technical quality, technical readiness, learning effects etc.
- Parametric cost modelling only suited for early design phases where detailed subsystem data is not available
  - Comparison of different architectures depends heavily relative CER quality
  - Has highest confidence if similar configuration/stages are compared



Future launch market

- Prediction of future launch market is **unavoidably** connected to large **uncertainties**
- Especially considering the **long** development and exploitation phase **duration**
- Launch market used herein loosely based on ESA forecasts, with uncertainties wrt:
  - Market share
  - No. of launch epochs
  - Dedicated launch probability



Source: McKinsey

Properties of launch market scenario

Parameter	Range of possible values
Number of GTO payloads per year	[7,13]
Number of SSO Payloads per year	[11,20]
Total number of constellation payloads	[2000,4000]
Number of launch epochs	[10,80]
Dedicated launch probabilty	[0,0.8]
Market share	[0.2,1.0]
Payload mass GTO	[2500, 8000]
Payload mass SSO	[300,6500]
Payload mass for constellations	[400,600]

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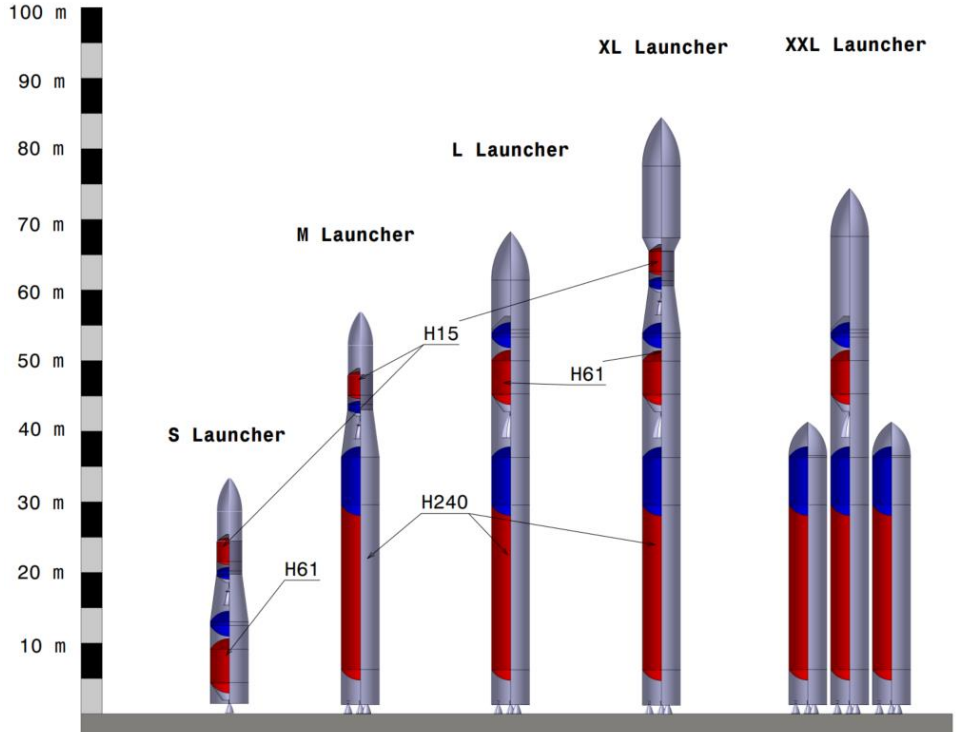
Payload assignment for rocket families – Problem

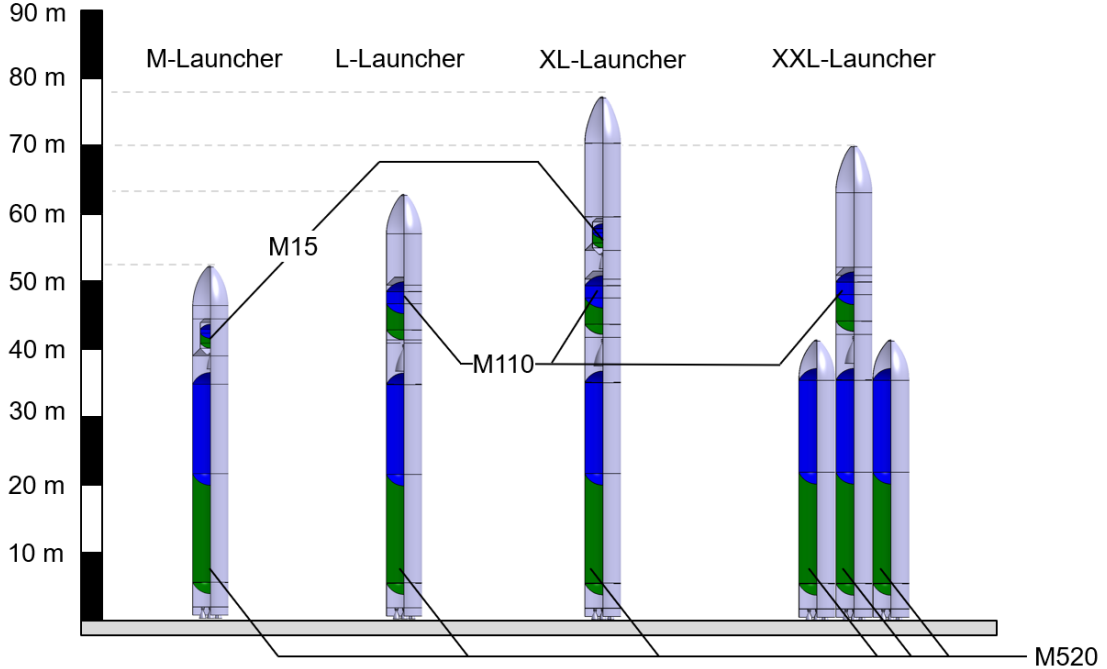
- For a single launcher payloads have to optimally packed
- In a launch vehicle family **multiple launch options** exist for every payload
- Large solution space
  - For 100 payloads and two launch options the total number of possible assignments is larger than 10^{30}, a “quintillion”
- Combinatorial optimization necessary
  - Case of **bin packing** with cost associated with each bin
  - Average cost of each bin/vehicle depends on the number of launchers
- Details of implementation in Ref 1)

Source: DALL-E

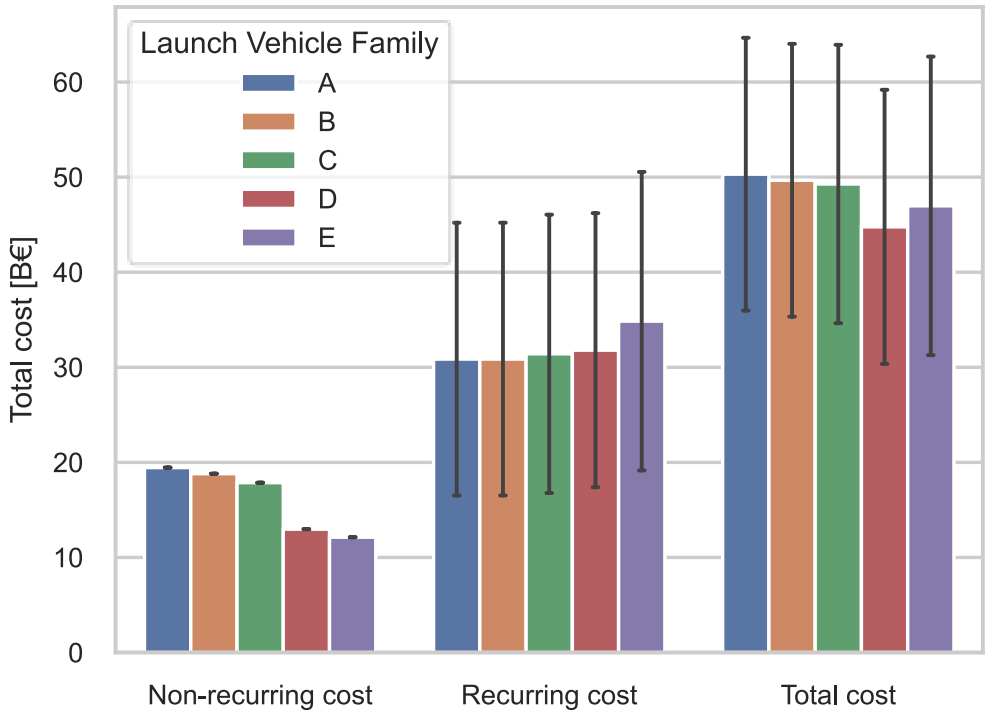
Case study

- Method is applied to two launch vehicle families:
  - **LH2** fueled **VTVL** family
    - **Prometheus-H and Vinci as engines**
  - **LCH4** fueled **VTVL** family
    - **Prometheus and Mira as engines**
- Investigation of up to five compositions:
  - **A: S, M, L, XL, XXL**
  - **B: M, L, XL, XXL**
  - **C: L, XL, XXL**
  - **D: L, XXL**
  - **E: XXL**
- As RLV and ELV families
- More information in Ref 2

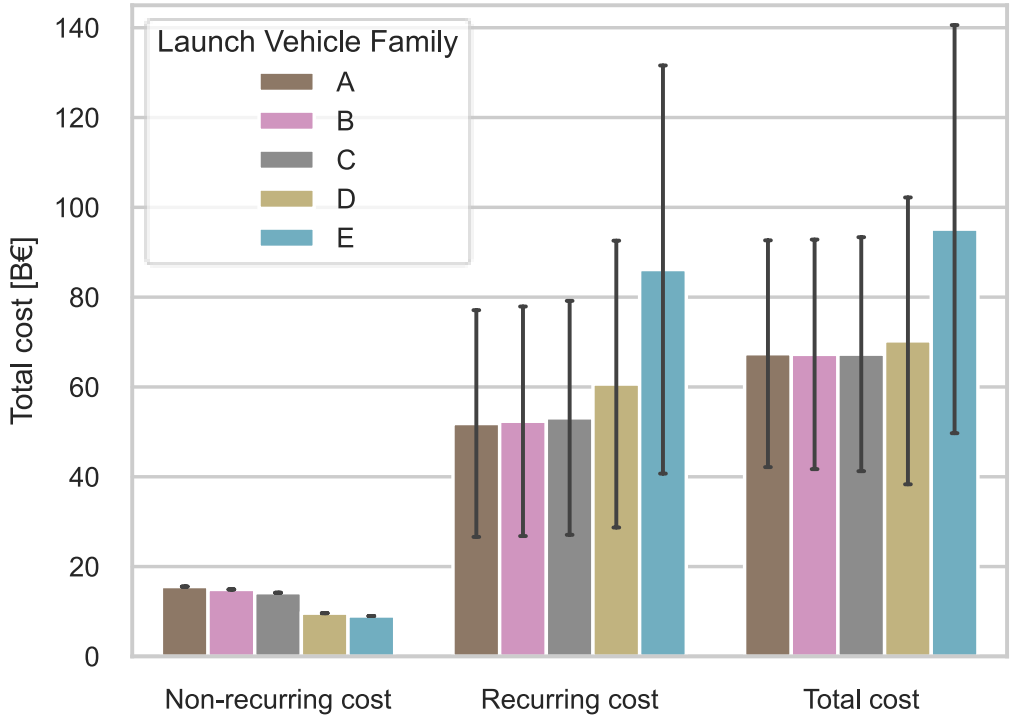




Results for LH2 fueled family compositions



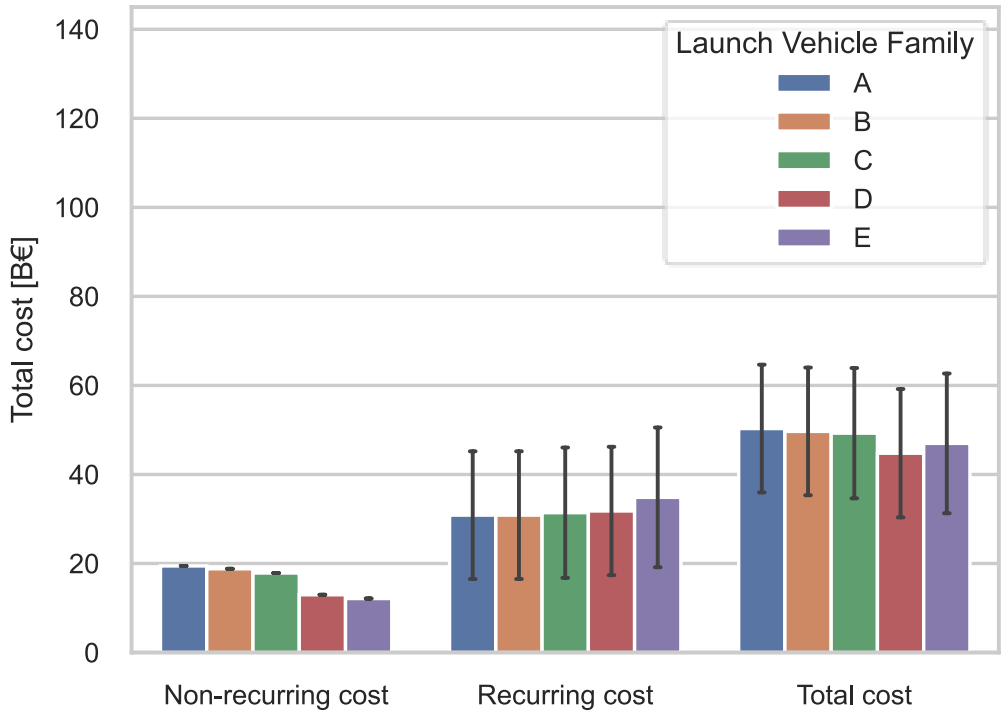
LH2 RLV family



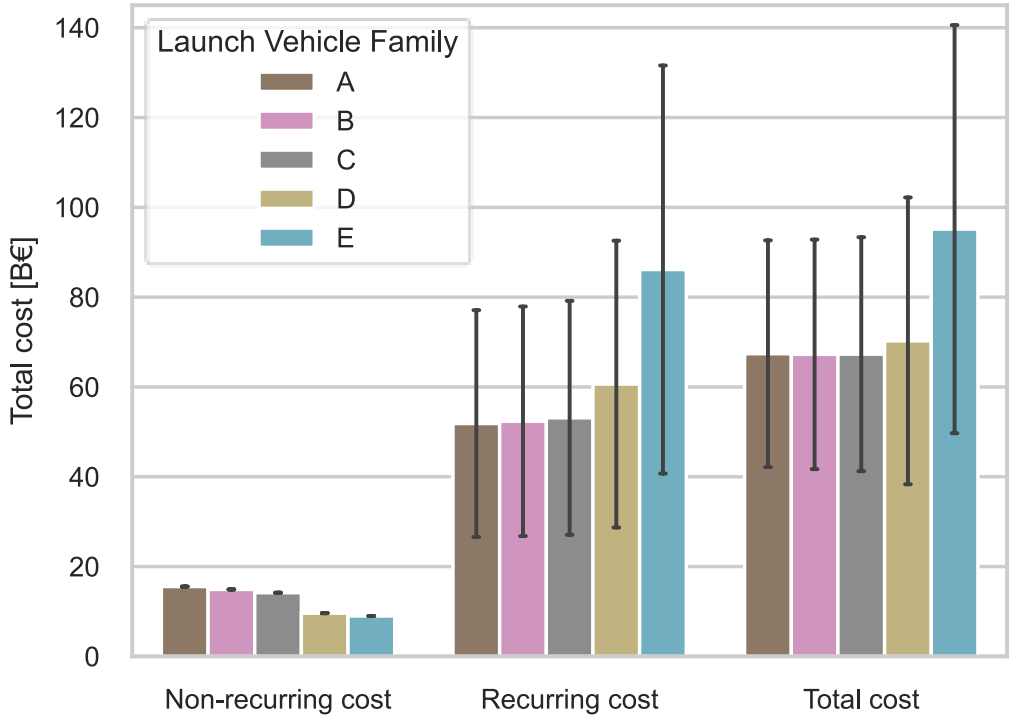
LH2 ELV family

- Results indicate that the large family approach works better for ELV than for RLV
- Variation in recurring cost is result of range of underlying market samples

Results for LH2 fueled family compositions



VTVL RLV family



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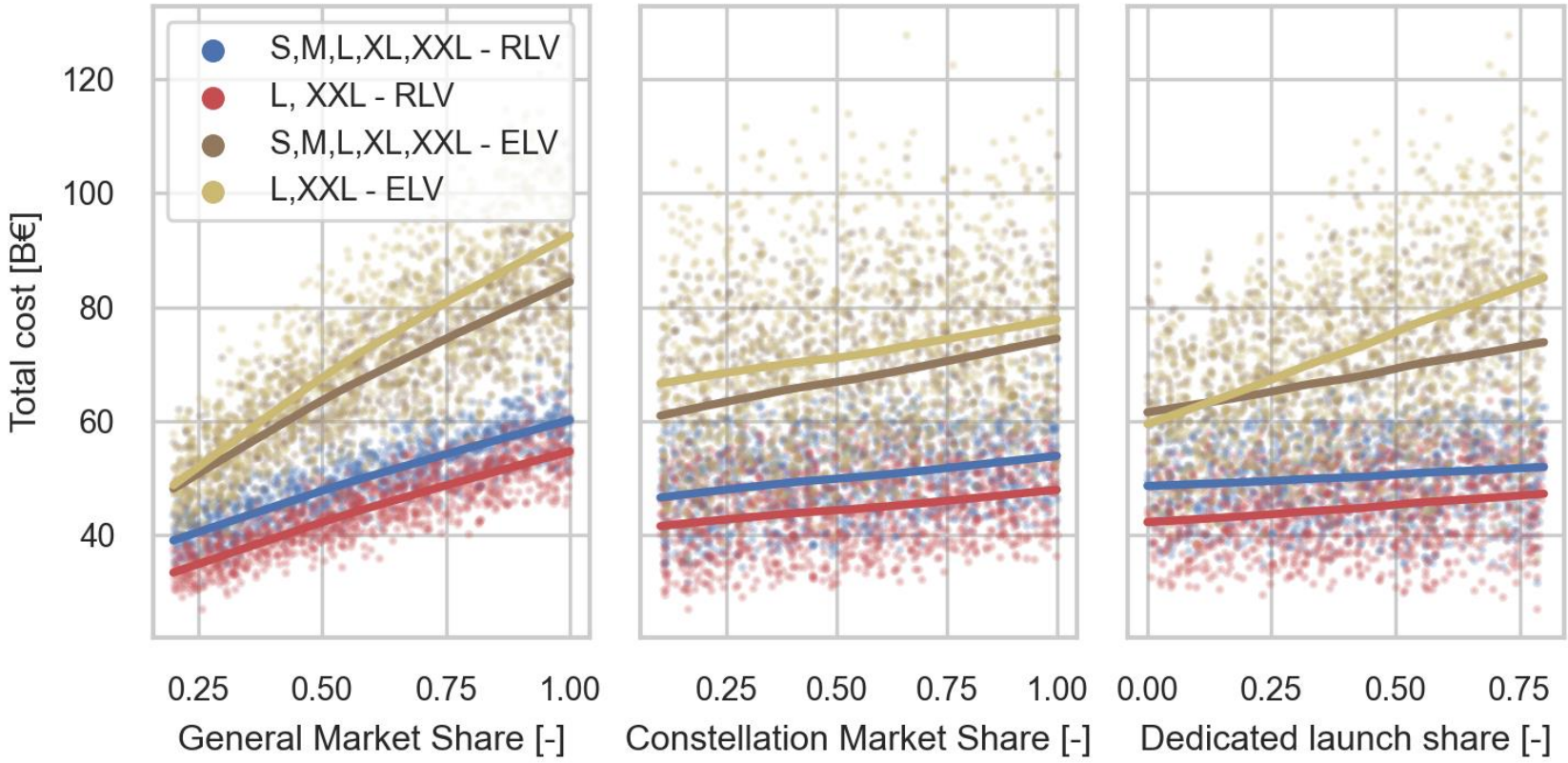
Effect of launch market uncertainties (LH2 VTVL family)



- Results consistent over large range of scenarios (4 to 31 launches per year over 20 years)
- Slope for ELV is much steeper

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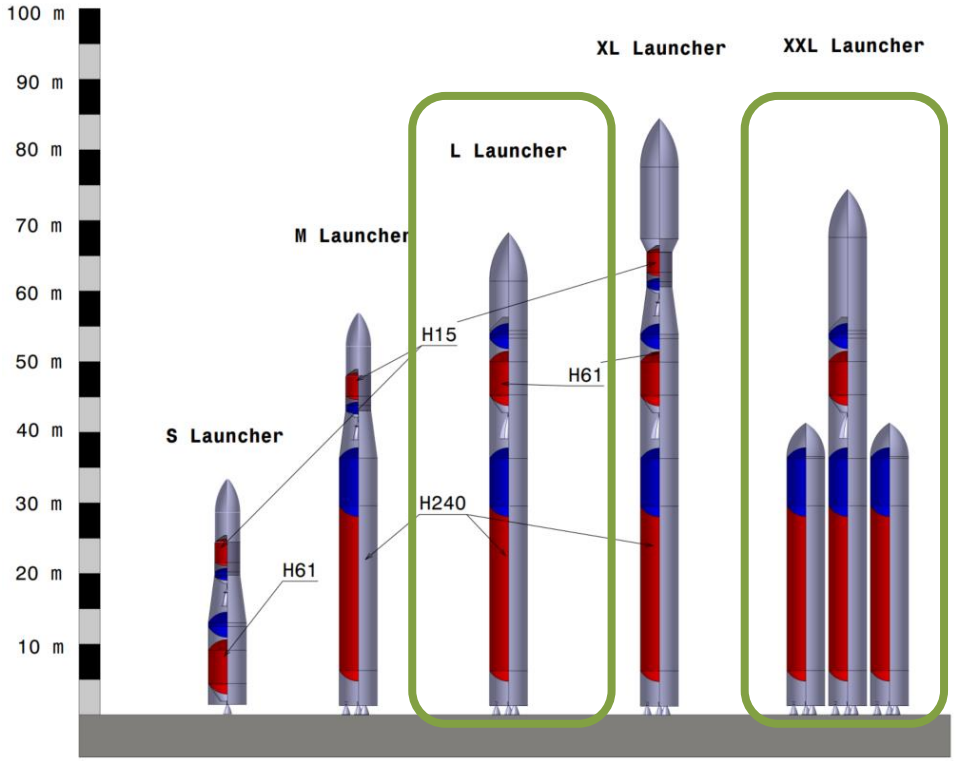
Conclusion & Outlook

- Larger launch vehicle family works well for ELV-based cases
- For launch vehicle families with reusable first stages, compositions with only two family members and three different components work well
  - Thanks to reusability the cost of using oversized launchers is reduced
- Results are similar for LH2 and LCH4 fueled families and across wide range of uncertainties with regard to launch market.

Outlook:

- Extension to sizing optimization
- Improvement of underlying models



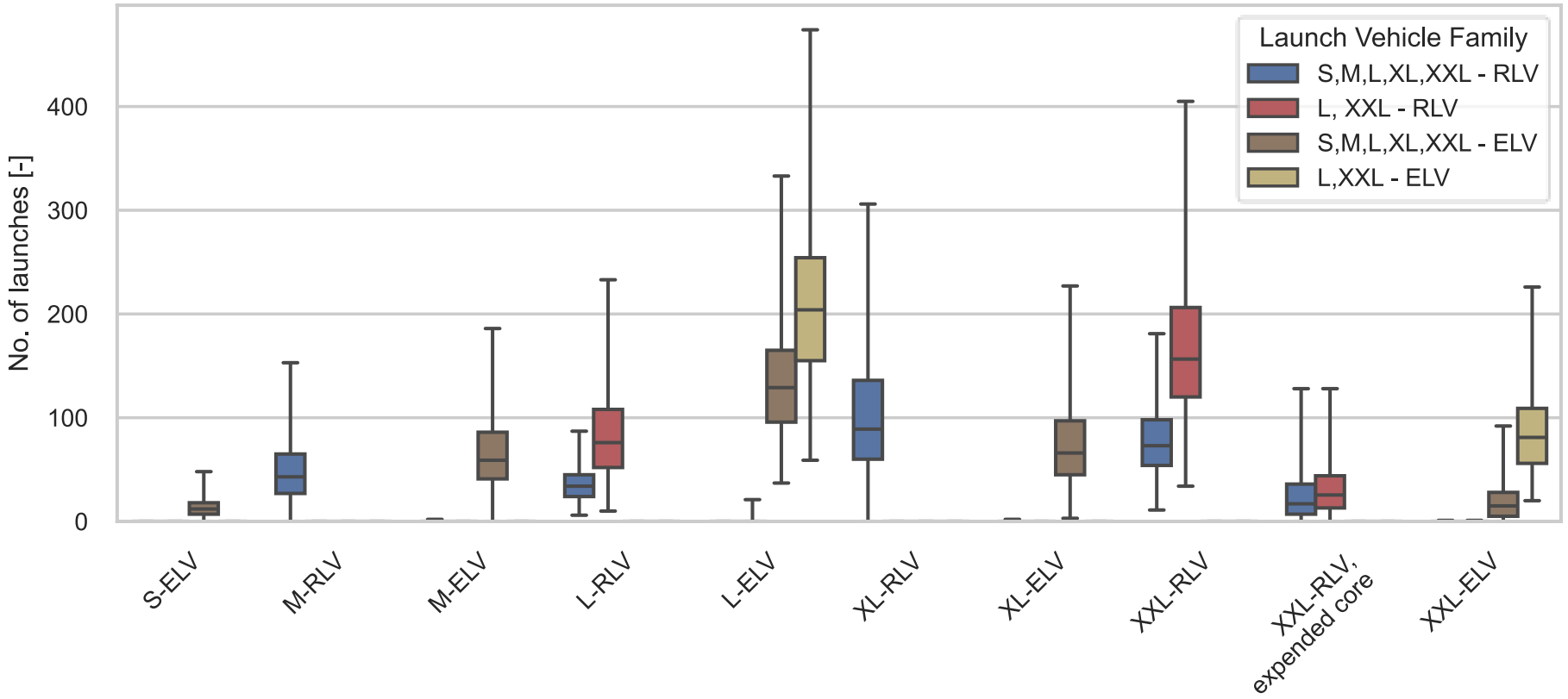
References

1) Wilken, Jascha (2024) *Cost estimation for launch vehicle families considering uncertain market scenarios.* Acta Astronautica (216), Seiten 15-26. Elsevier. doi: 10.1016/j.actaastro.2023.12.035. ISSN 0094-5765.

2) Sippel, Martin und Stappert, Sven und Callsen, Steffen und Bergmann, Kevin und Dietlein, Ingrid Monika und Bussler, Leonid (2022) *Family of Launchers Approach vs. "Big-Size-Fits-All".* International Astronautical Congress (IAC 2022), 2022-09-18 - 2022-09-22, Paris, France. https://elib.dlr.de/195201/

BACKUP

Distribution of launch numbers



- RLV families rely on larger launch vehicles

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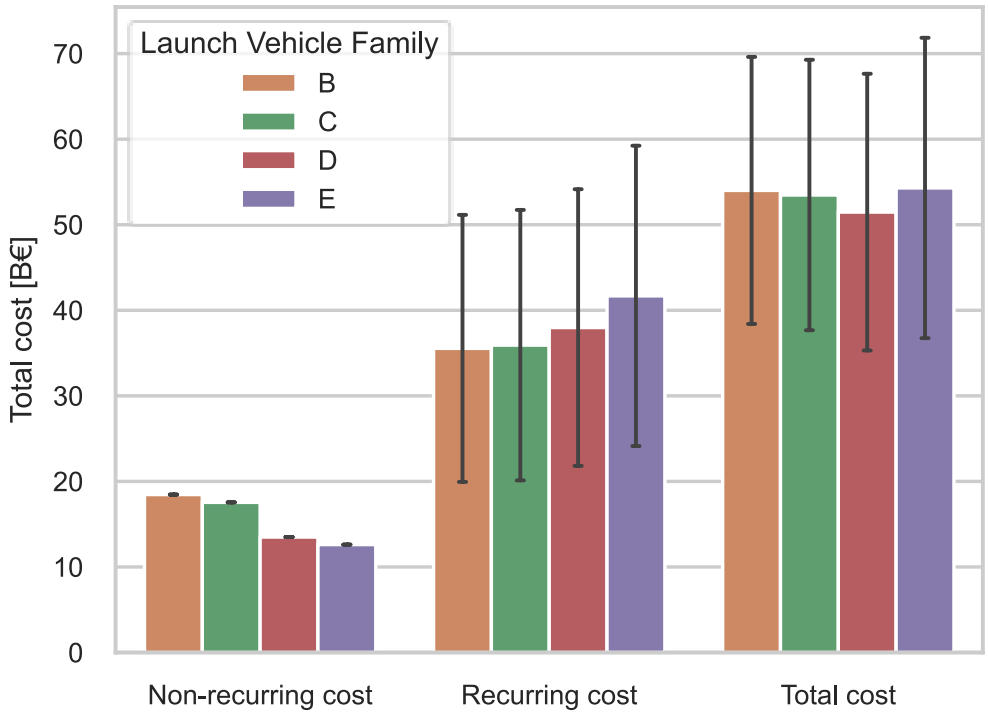
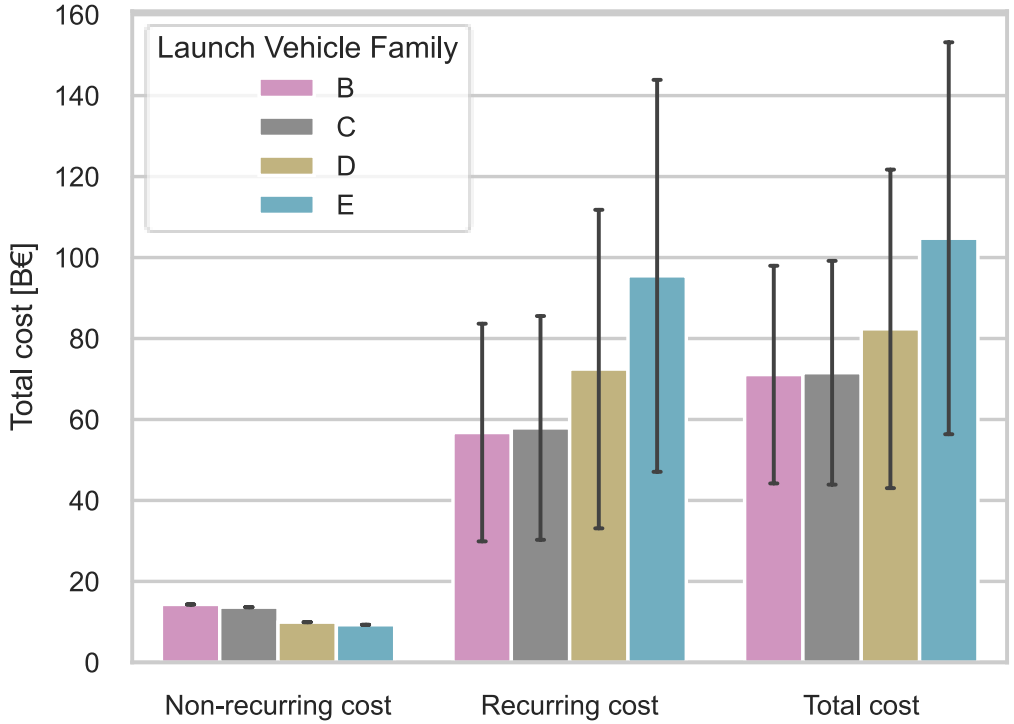
Results for LCH4 fueled family compositions



VTVL RLV family



VTVL ELV family

- Similar trends, but some differences due to differing payload performances
- Difference in total cost between different compositions is smaller than for LH2

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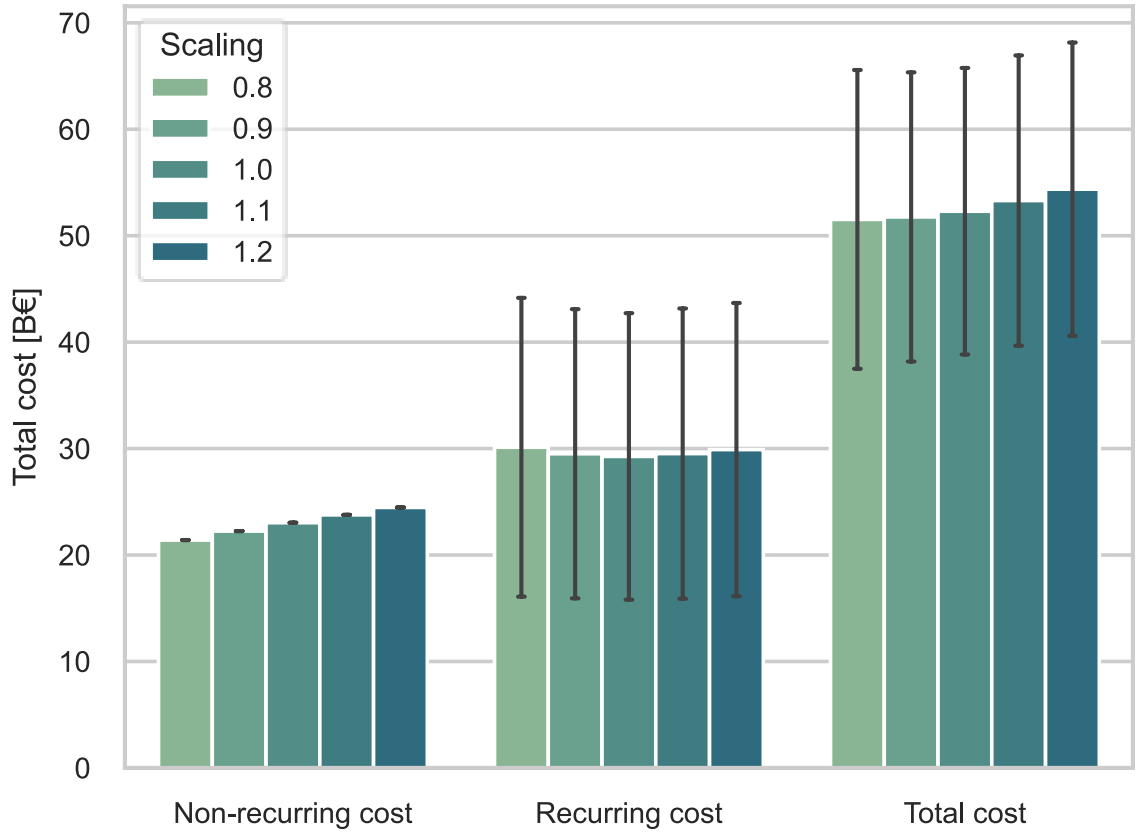
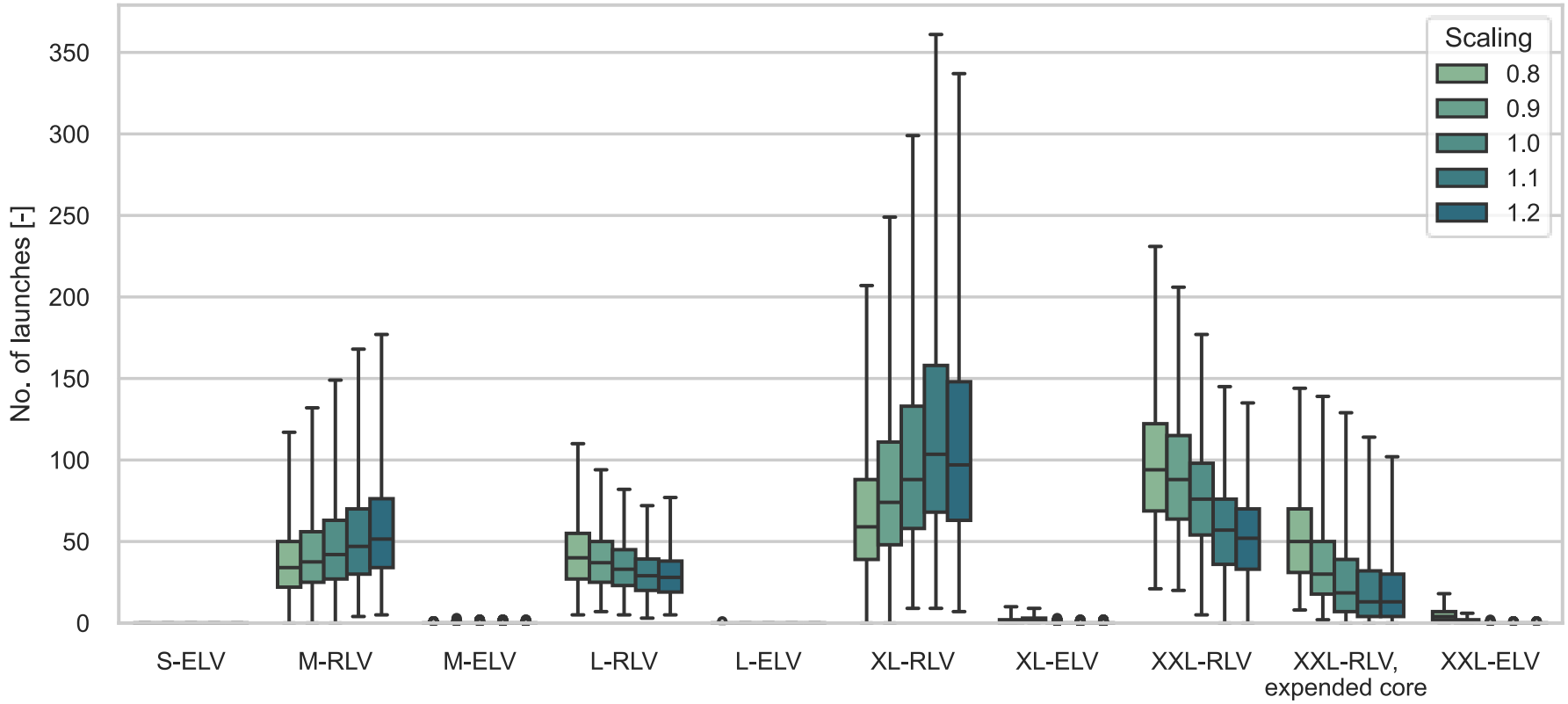
Optimal building block sizing

- Exploration of sizing of launch vehicle family
- Mass of components and payload performance are scaled linearly
  - Assumptions benefits downsizing as usually payload ratio decreases with smaller sizes
- Initial insights into good design points

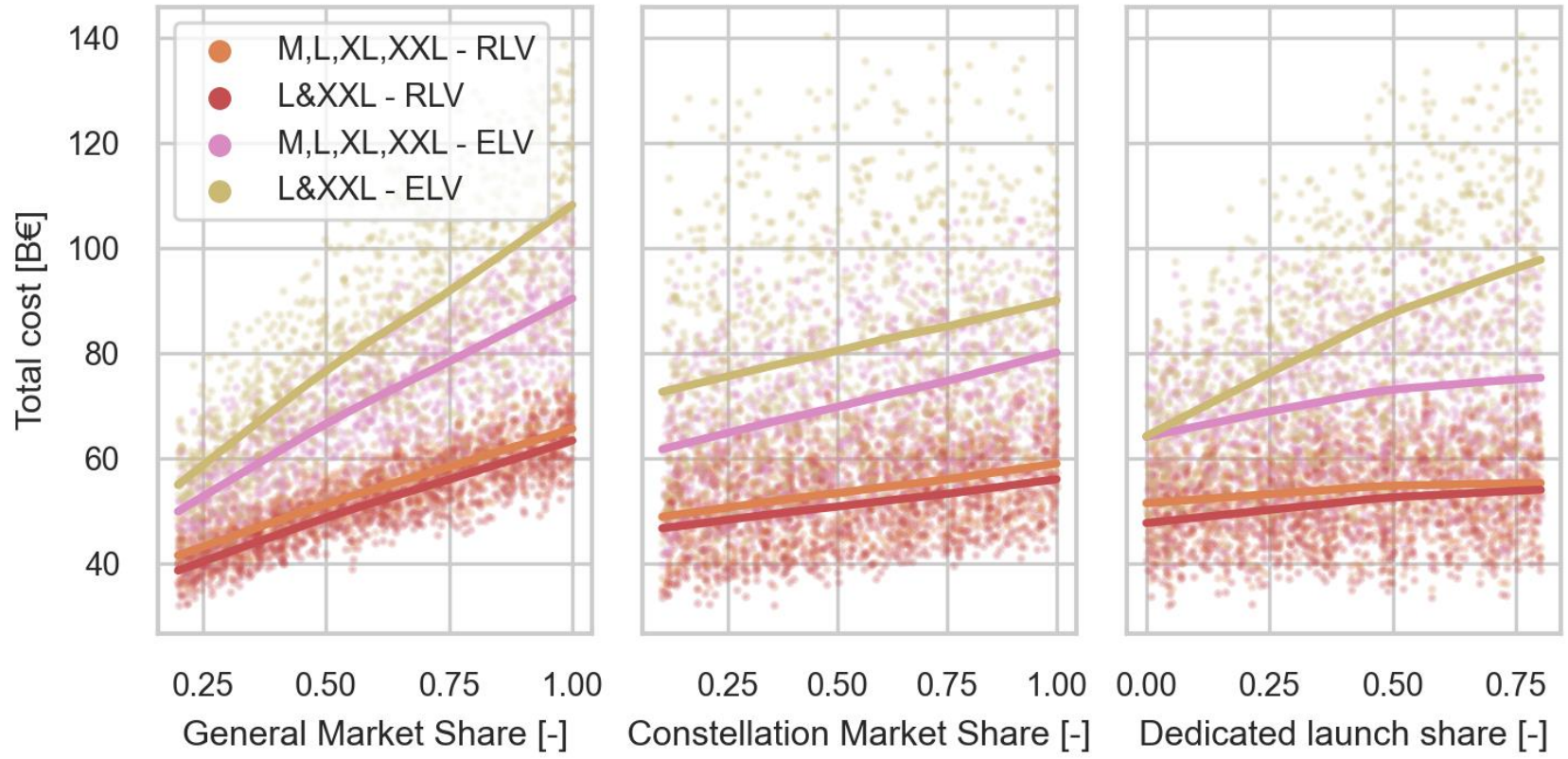


Shift of payload assignment with scaled families (LH2)



- Trend change in recurring cost occurs when XXL-ELV has to be used to fulfill launch market scenario

Effect of launch market uncertainties (LCH4 VTVL family)



- For RLV full family is only competitive for high number of dedicated launches
- Slope for ELV is much steeper

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