Conditional Demand Forecast Accuracy in a Bigger PODS Network

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Traditional vs. Conditional Demand Forecast Error Metrics

- **Traditional Demand Forecast Error:**

Unconstrained FCST – (Actual Bookings + Rejected Demand)

  » Not suitable for dependent demand, and does not provide enough information to assess forecast quality.

- **Conditional Demand Forecast Error:**

(Forecast | Policy) – (Bookings | Policy)

  » Forecast error is computed conditional on the policy offered.
    - Does not require explicit estimates of rejected demand.
    - Exhibits expected relationship between demand forecast error and revenue in tests in simple and complex networks.

When Does the Minimum Demand Forecast Error <-> Maximum Revenue Relationship Hold?

- **<u>Hypothesis</u>: The minimum error <-> maximum revenue relationship holds so long as several conditions are met:**

Customer choice is modeled correctly

The assumptions of the forecast error metric must reflect patterns of actual customer choice

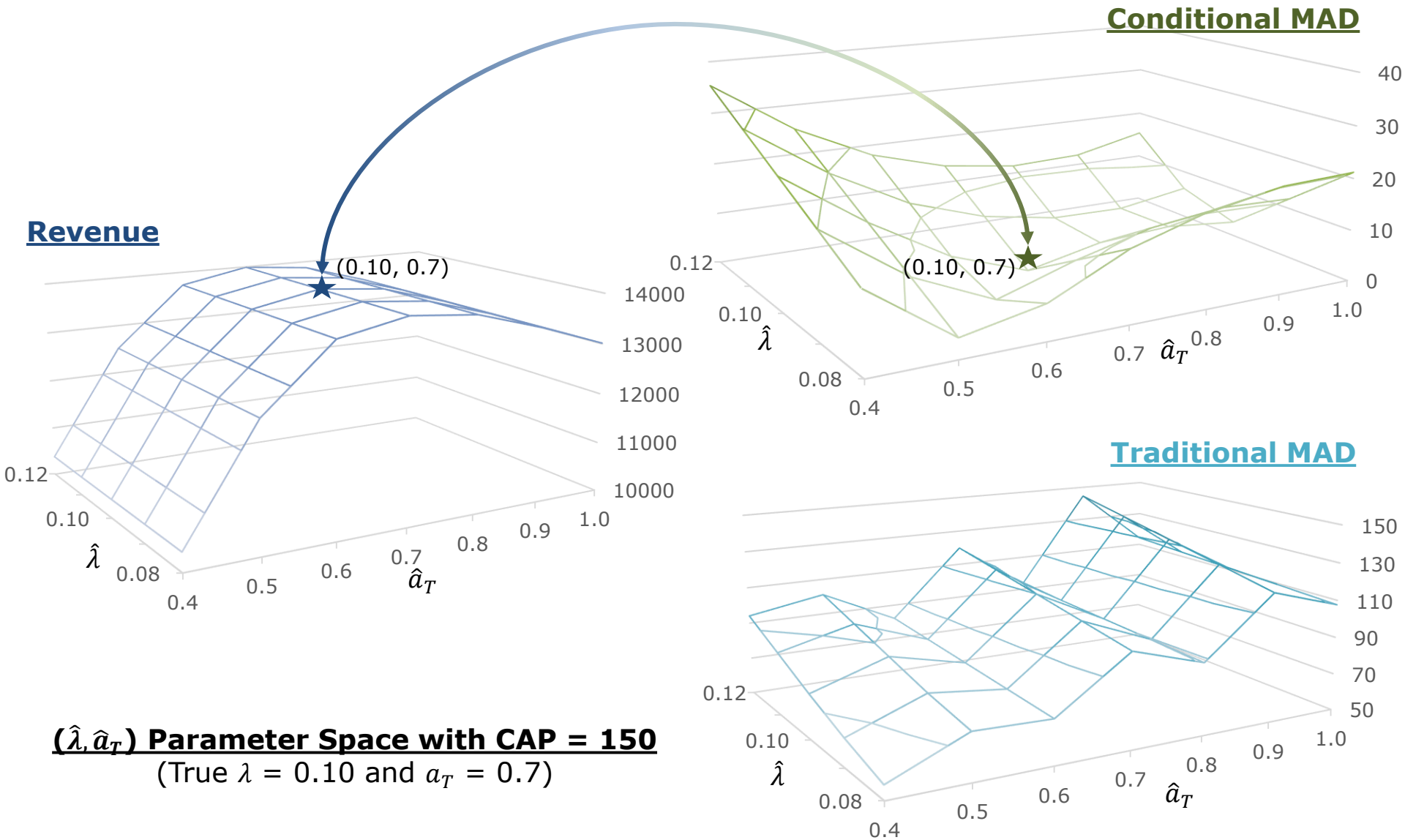
The entire parameter space is evaluated

Varying only a single forecast parameter can miss the true global minimum forecast error

A representative sample of policies is offered

The global optimum can only be revealed if a representative sample of policies is considered

Changing Only One Forecast Parameter at a Time May Not Find Global Min. Forecast Error or Max. Revenue

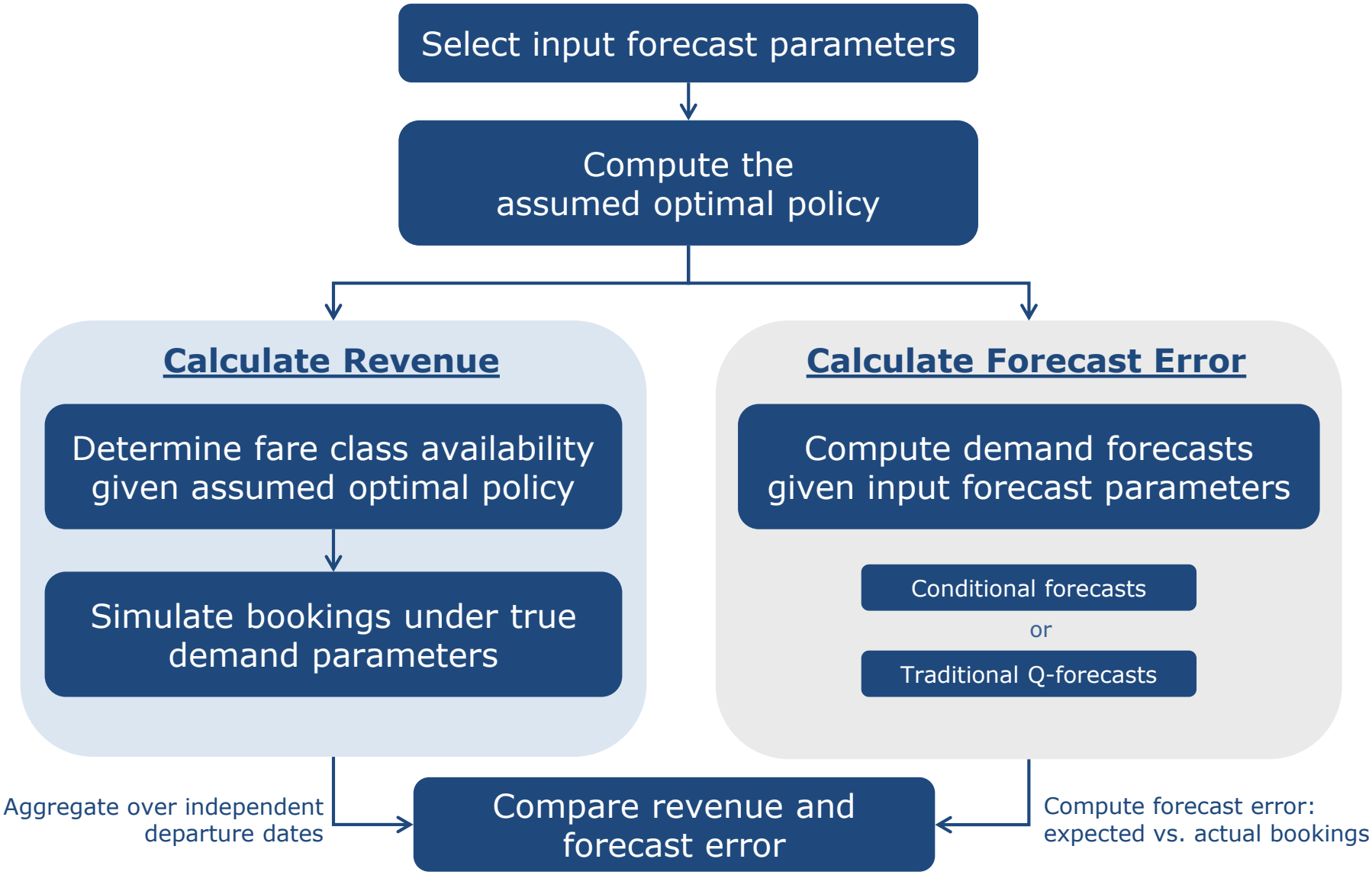


$(\hat{\lambda}, \hat{a}_T)$ Parameter Space with CAP = 150

(True λ = 0.10 and a_T = 0.7)

Note: Single-leg simulation outside of PODS

Overview of Experimental Design in PODS



Measuring Conditional Demand Forecast Error in PODS

CONDITIONAL FORECASTING STATS, AIRLINE 1

TF	DAY	LOFO	CLS	#OBS	FCST	BKG
1	1	6	1	1.000000	0.000106	0.000000
1	1	6	2	1.000000	0.002158	0.000000
1	1	6	3	1.000000	0.029448	0.000000
1	1	6	4	1.000000	0.403480	0.000000
1	1	6	5	1.000000	0.897587	0.000000
1	1	6	6	1.000000	2.148263	3.296500

- » **LOFO**: Lowest open fare class
- » **Number of Observations**: Percent of samples (x100) in which LOFO policy is offered for a given TF, DAY
- » **Forecast**: Average forecast by class conditional on lowest open class
- » **Bookings**: Average bookings by class in that TF, DAY

- **This report allows us to compute conditional demand forecast MAD across all policies and days:**

$$MAD = \sum_{LOFO} \frac{\left|\Sigma_{DAY}\Sigma_{FC}\left[\left(FCST_{FC,DAY} \mid LOFO\right) - \left(BKG_{FC,DAY} \mid LOFO\right)\right]\right|}{\#\ of\ Observations}$$

Review from Last Agifors Meeting (HKG): Fully Unrestricted A1ONE

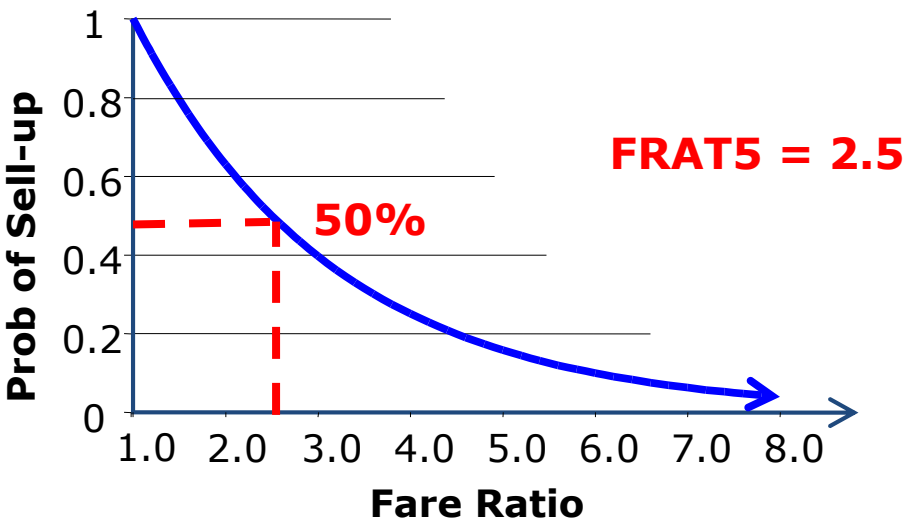
Network Structure for Network A1ONE

Methodology

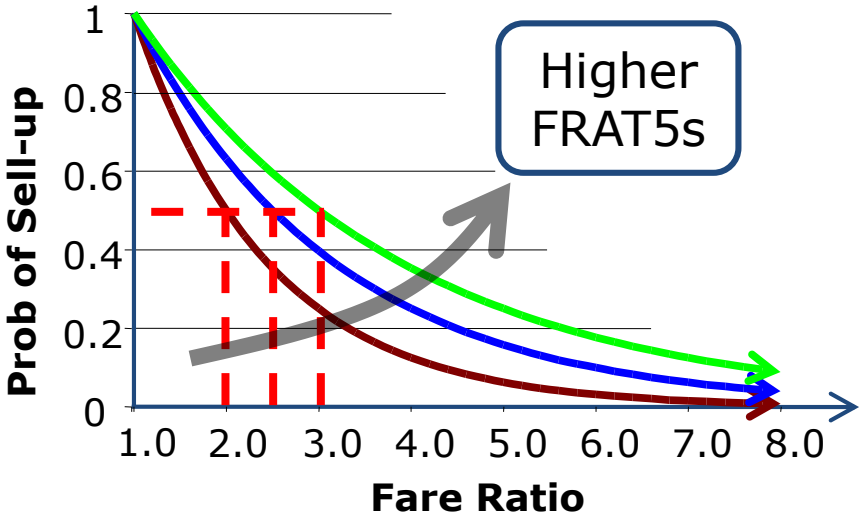
- 1 market (single-carrier)
- Fare structure: fully-unrestricted, No advance purchase (see next slide)
- Test at 3 Different Demand Levels (LF=84%, 88%, 91%)
- Error measures: RMSE, MAD, BIAS
- Adjusted the quality of the forecaster by applying controlled bias to:
  - » Volume (forecast multiplier FM=0.5,…,2.0).
  - » Frat5 estimates (scaled versus true underlying).

Review: WTP Values Based on "FRAT5" Estimates

- "FRAT5" is the Fare Ratio at which 50% of pax will sell-up
  - A proxy for WTP



- Higher FRAT5s indicate higher WTP (i.e. more sell-up from low to high fare classes)



Review: Experimental Design

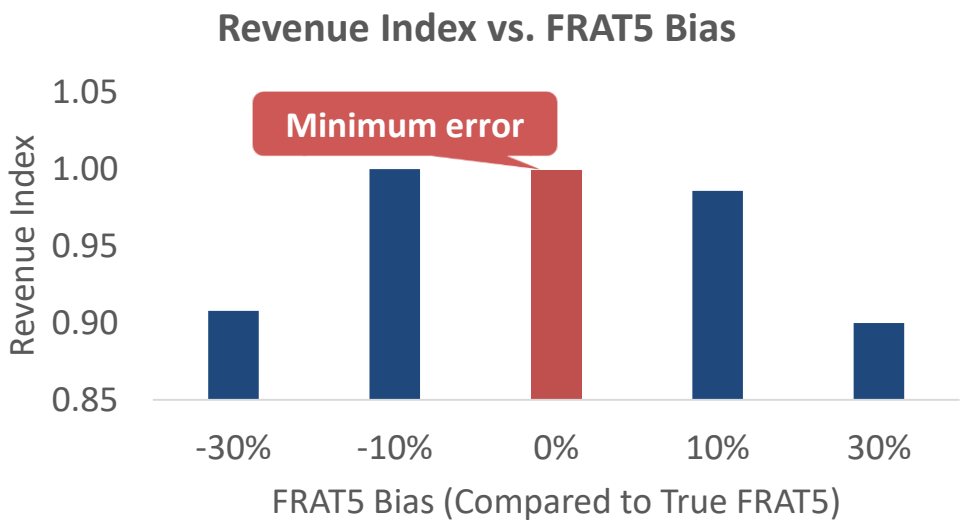
- Network A1ONE (demand calibrated to 84% LF in base case)

Fully Unrestricted Fare Structure for Network A1ONE

FC	Fare	AP	R1	R2	R3
1	$500	0	0	0	0
2	$390	0	0	0	0
3	$295	0	0	0	0
4	$200	0	0	0	0
5	$160	0	0	0	0
6	$125	0	0	0	0

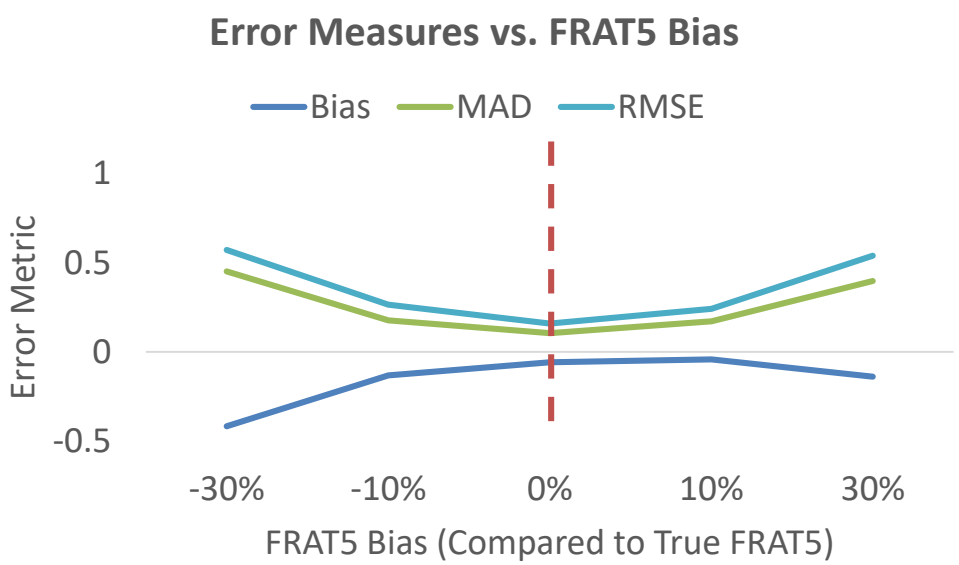
- Optimizer = Unbucketed Dynamic Program; Fare Adjustment = 1.0 (full)
- Forecaster = Q-forecasting
- Unconstrainer = Booking Curve

Review: Does Max Revenue = Min Error? Sensitivity to FRAT5 bias (84% LF)



Conclusion

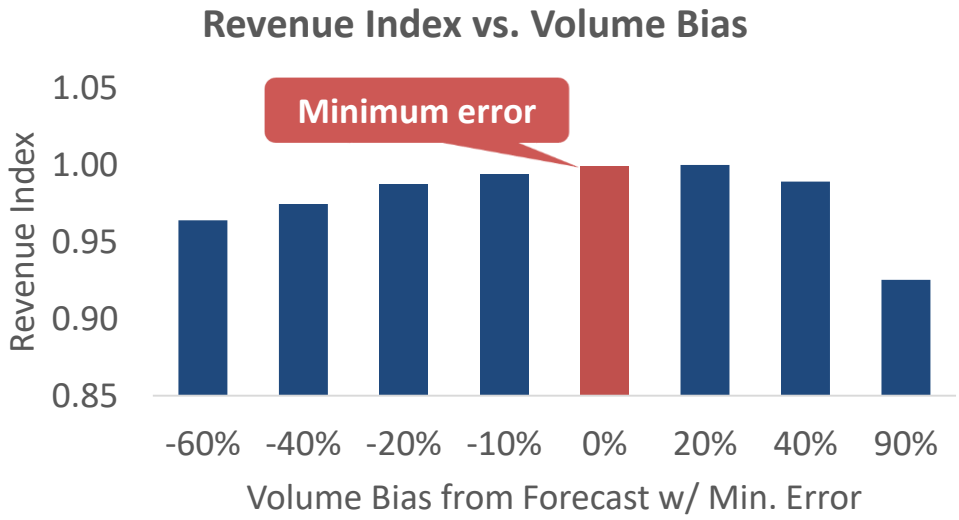
- True FRAT5 and (minimum error) and -10% FRAT5 Bias have statistically insignificant differences in revenue



Conclusions

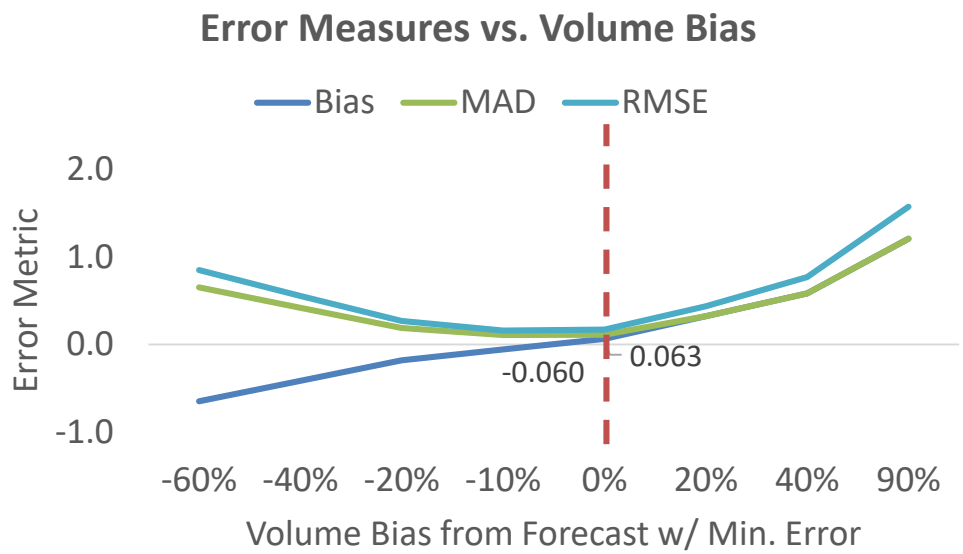
- Min Error in MAD and RMSE occur for Input FRAT5 = True Frat5
- BIAS is only slightly better for True FRAT5 +10%

Review: Does Max Revenue = Min Error? (set True FRAT5) Sensitivity to Volume Bias (84% LF)



Conclusions

- Max revenue occurs at +20% Volume Bias
- Volume Bias = 0% revenue is just 0.1% lower than 20% Volume Bias (statistically insignificant)

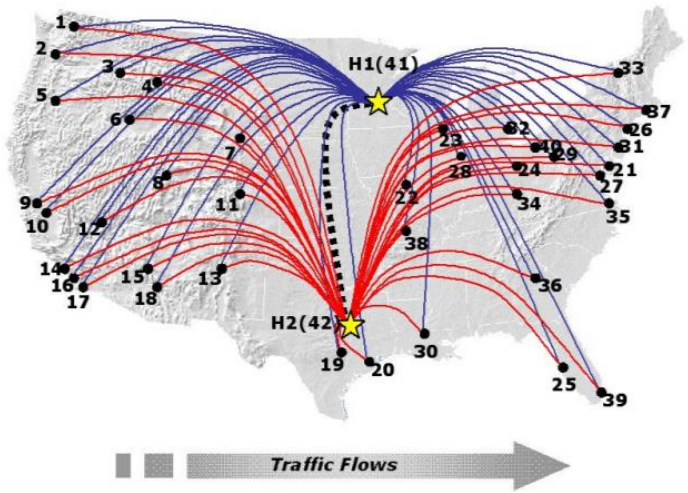


Conclusions

- Minimum bias occurs at -10% Volume Bias and +0% Volume Bias (statistically insignificant)

※ Volume Bias = Difference in Forecast Multiplier compared to the forecast that produced the minimum error (FM = 1.1).

New Experiments 1-3 Setup: Network D6



FC	AP	Unrestricted			Semi-Restricted		
		R1	R2	R3	R1	R2	R3
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1
3	0	0	0	0	0	1	1
4	0	0	0	0	1	0	1
5	0	0	0	0	1	1	0
6	0	0	0	0	1	1	1

- **Much bigger network than A1one, 2 fare environments**
- **Recall: We adjust two input forecast parameters:**
  - » **Forecast Multiplier** (Volume) and **FRAT5 curve for HF/FA** (WTP)
- **Each case calibrated to AL1 highest-revenue input forecast parameters.**
  - » Both airlines use HF/FA with rev. maximizing FA scalar in that scenario.

RM Systems and Input Forecast Parameters

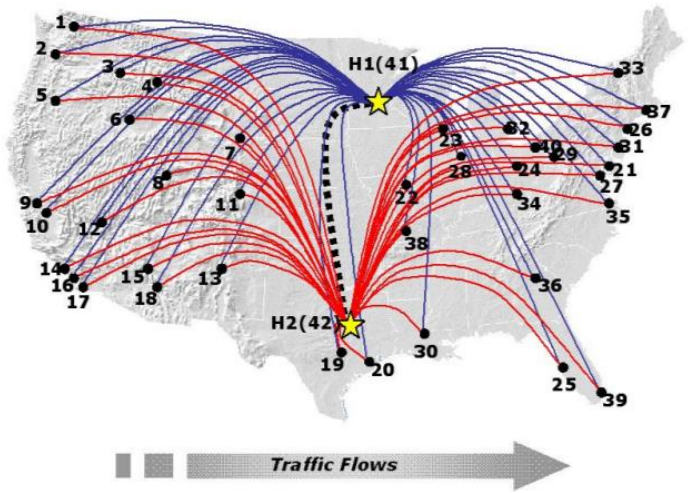
- **Initially (experiment #1), both airlines use the same RM systems and input forecast parameters.**

- **Then (#2-3), we add asymmetric behavior, making it more challenging to relate revenue and conditional demand forecast error.**
  - » Adds another dimension to the forecast parameter space that is not directly observed by the forecaster.

- **Three new experimental conditions tested:**
  - » **Experiment 1:** Symmetric RM systems, symmetric input forecast parameters
  - » **Experiment 2:** Asymmetric RM systems, symmetric input forecast parameters
  - » **Experiment 3:** Asymmetric input forecast parameters, symmetric or asymmetric RM systems

Experiment 1: Symmetric RM Systems and Symmetric Input Forecast Parameters

Experiment 1 Setup: Symmetric RM Systems, Symmetric Forecast Parameters



FC	AP	Unrestricted			Semi-Restricted		
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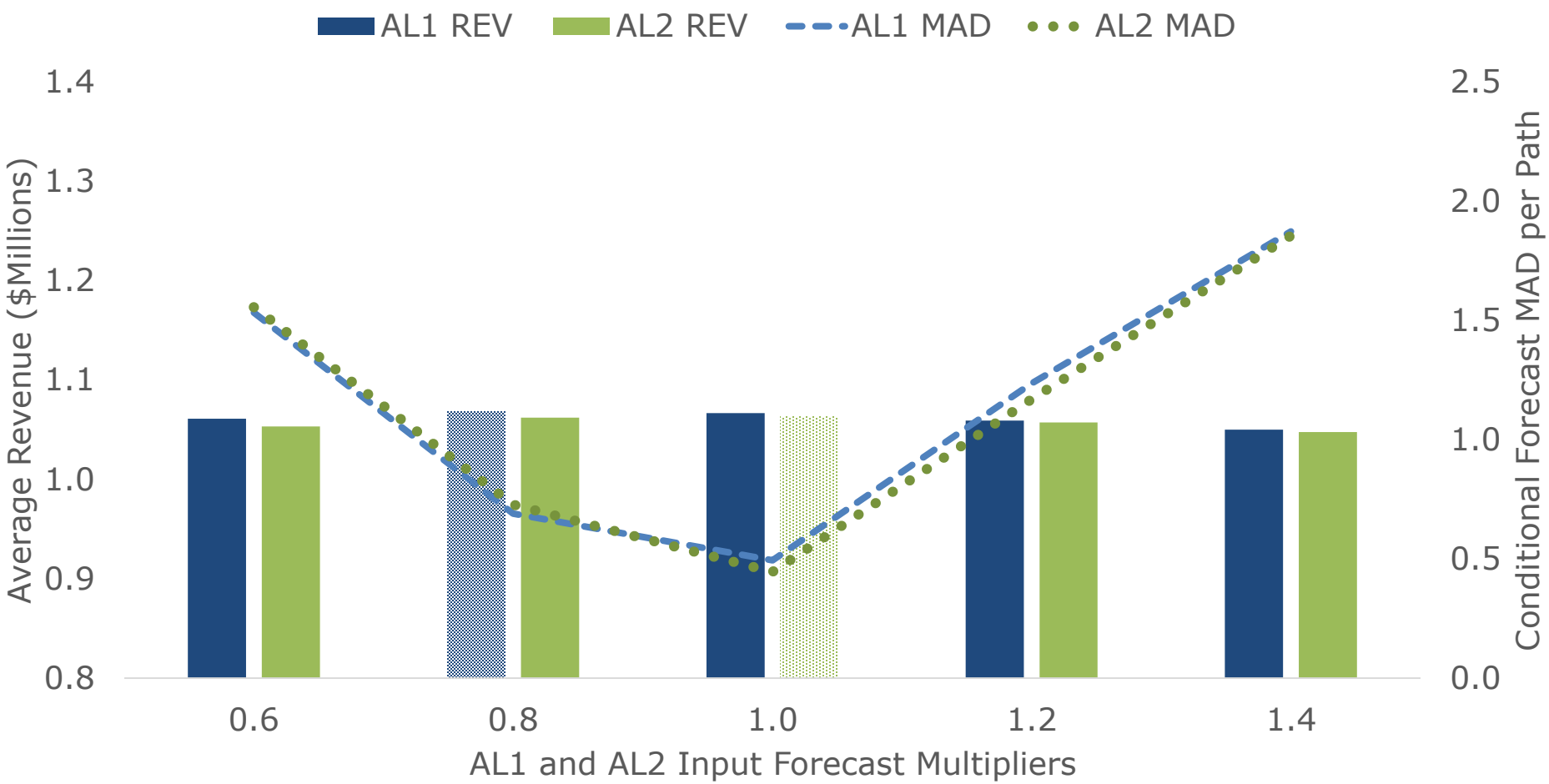
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1
3	0	0	0	0	0	1	1
4	0	0	0	0	1	0	1
5	0	0	0	0	1	1	0
6	0	0	0	0	1	1	1

- **In this series of simulations, airlines use both symmetric RM systems and symmetrically adjust input forecast parameters.**
  - » AL1/2 use same RM optimization (either **UDP or ProBP)**
  - » Both airlines adjust FRAT5 and/or forecast multipliers simultaneously.
  - » Airlines both use HF/FA, with fare adjustment scalar set to maximize AL1 revenue in base case.

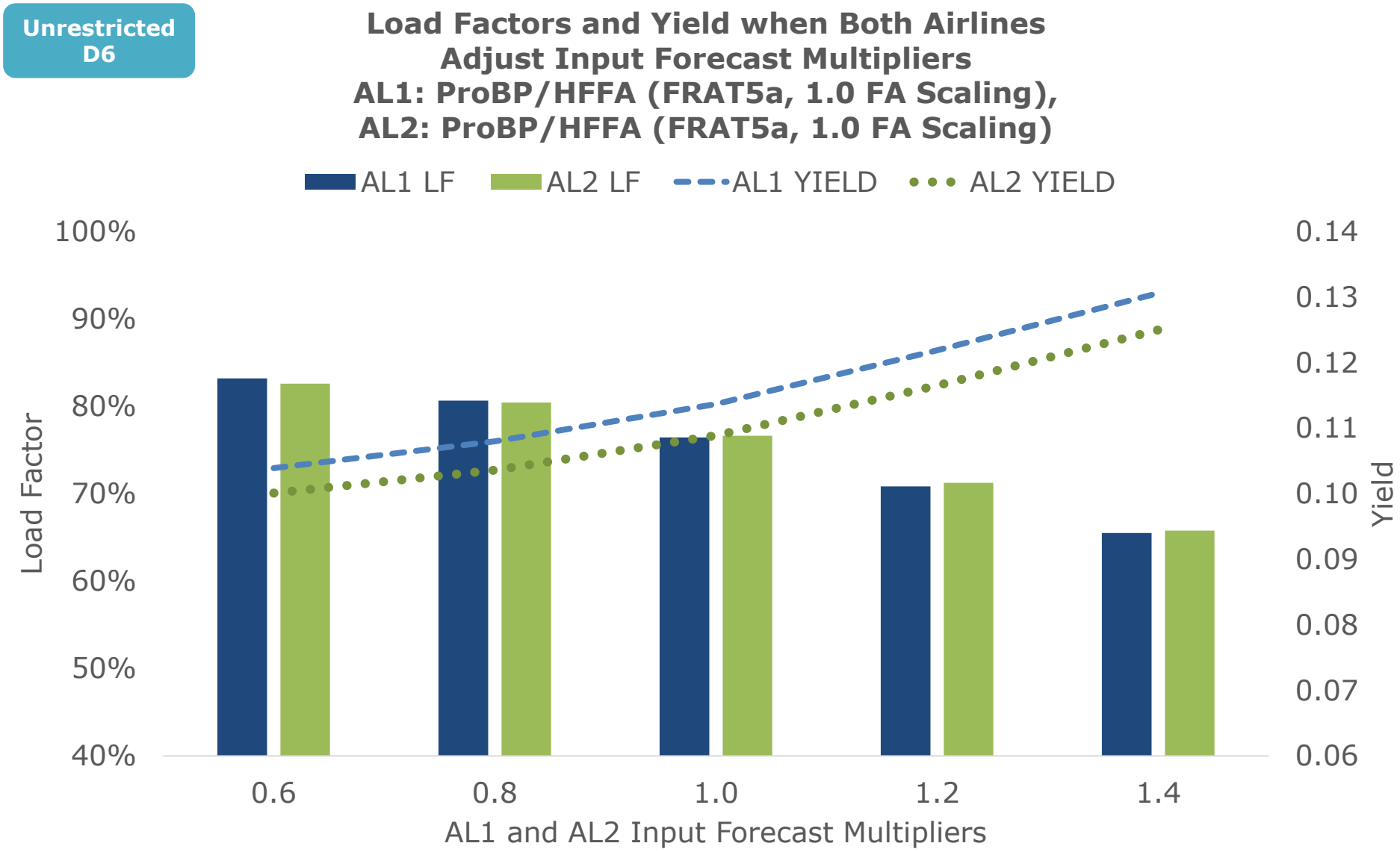
Min. Conditional Forecast Error ≈ Max. Revenue when Both Airlines Use ProBP and Vary Forecast Multipliers

Unrestricted
D6



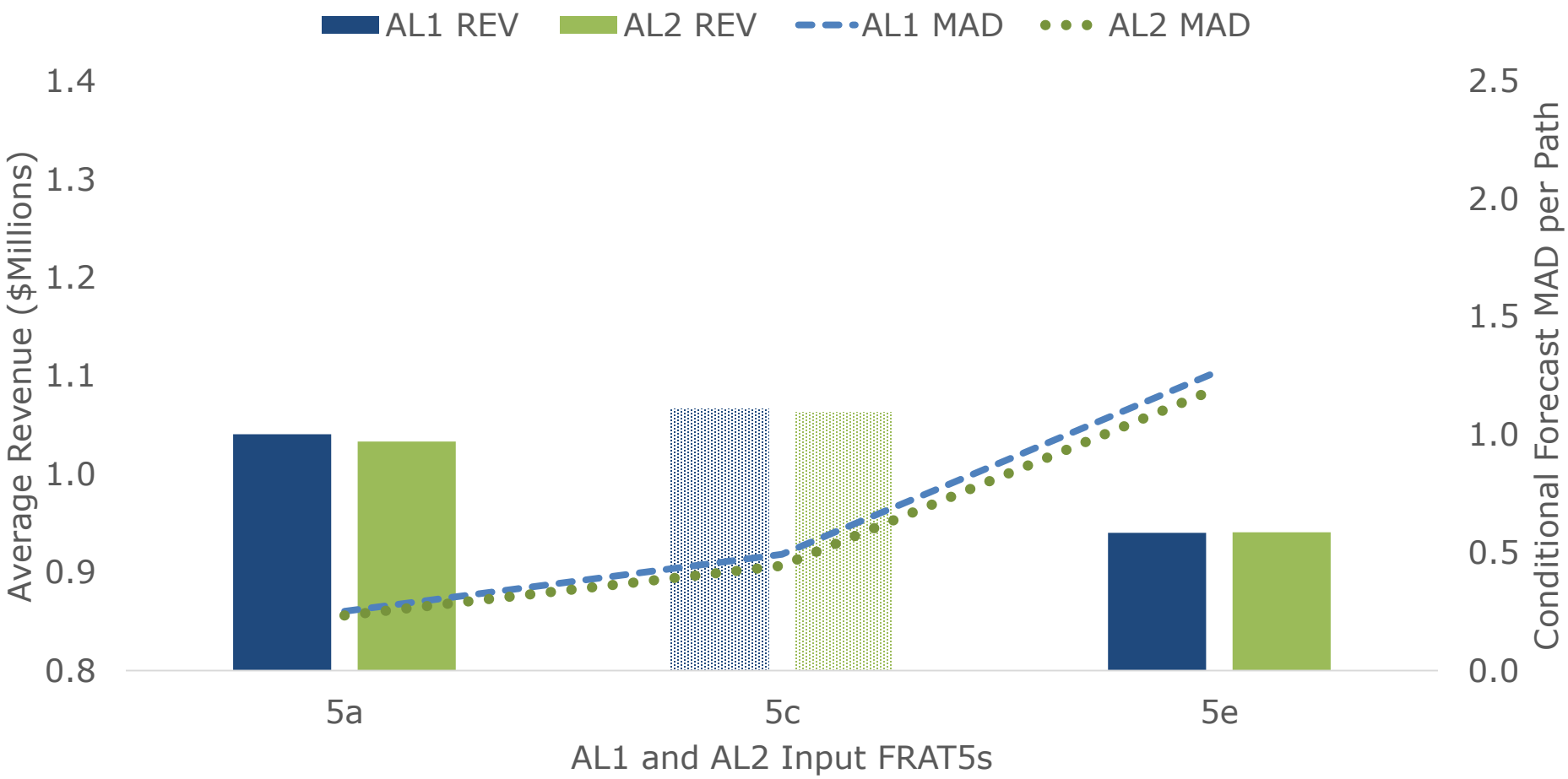
Using Higher Forecast Multipliers Decreases LFs and Increases Yields (Due to Less Availability of Lower FCs)

Unrestricted
D6



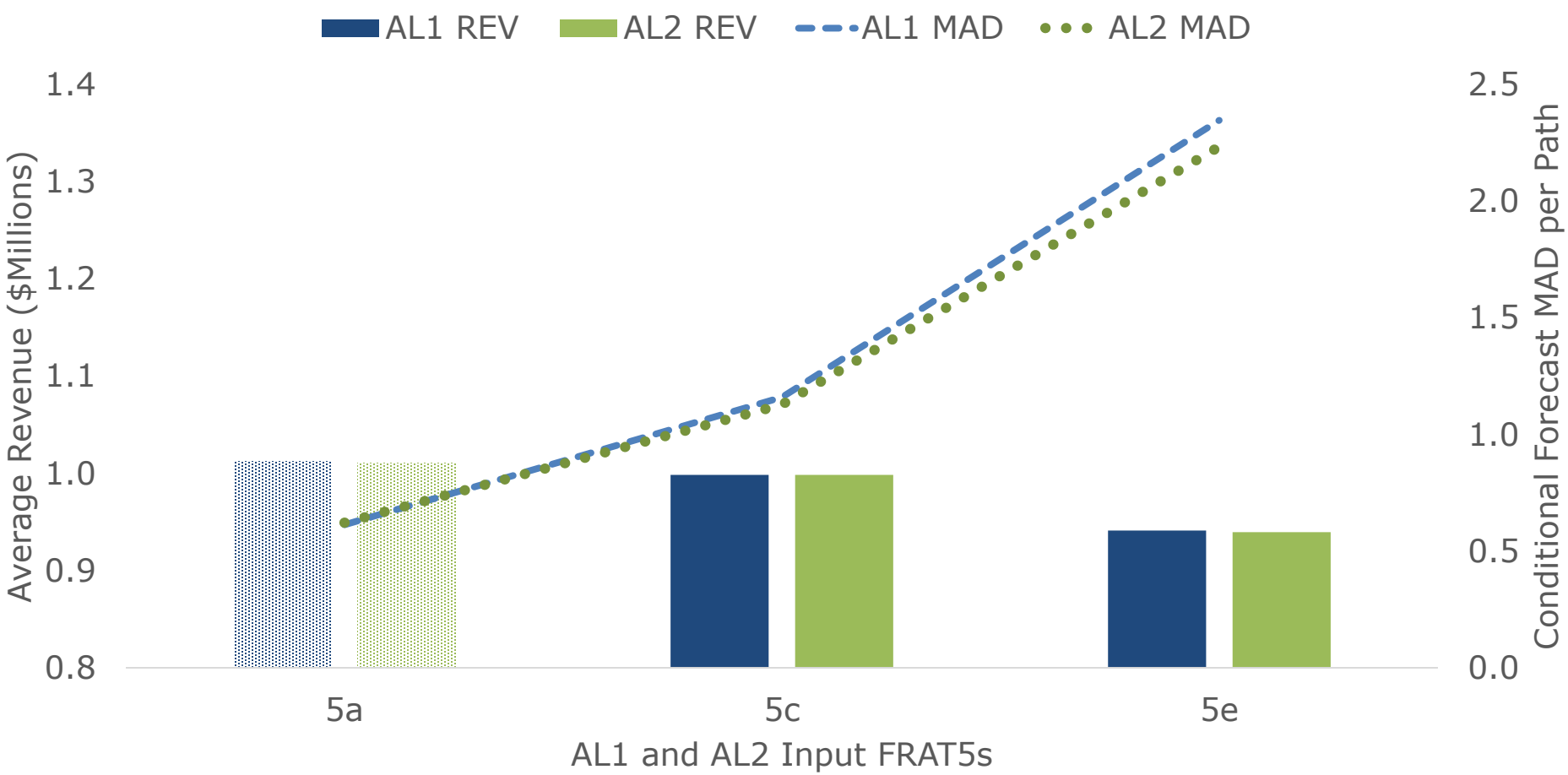
Conditional MAD is Not Precisely Related to the Highest Revenue when varying FRAT5 (ProBP)

Unrestricted
D6



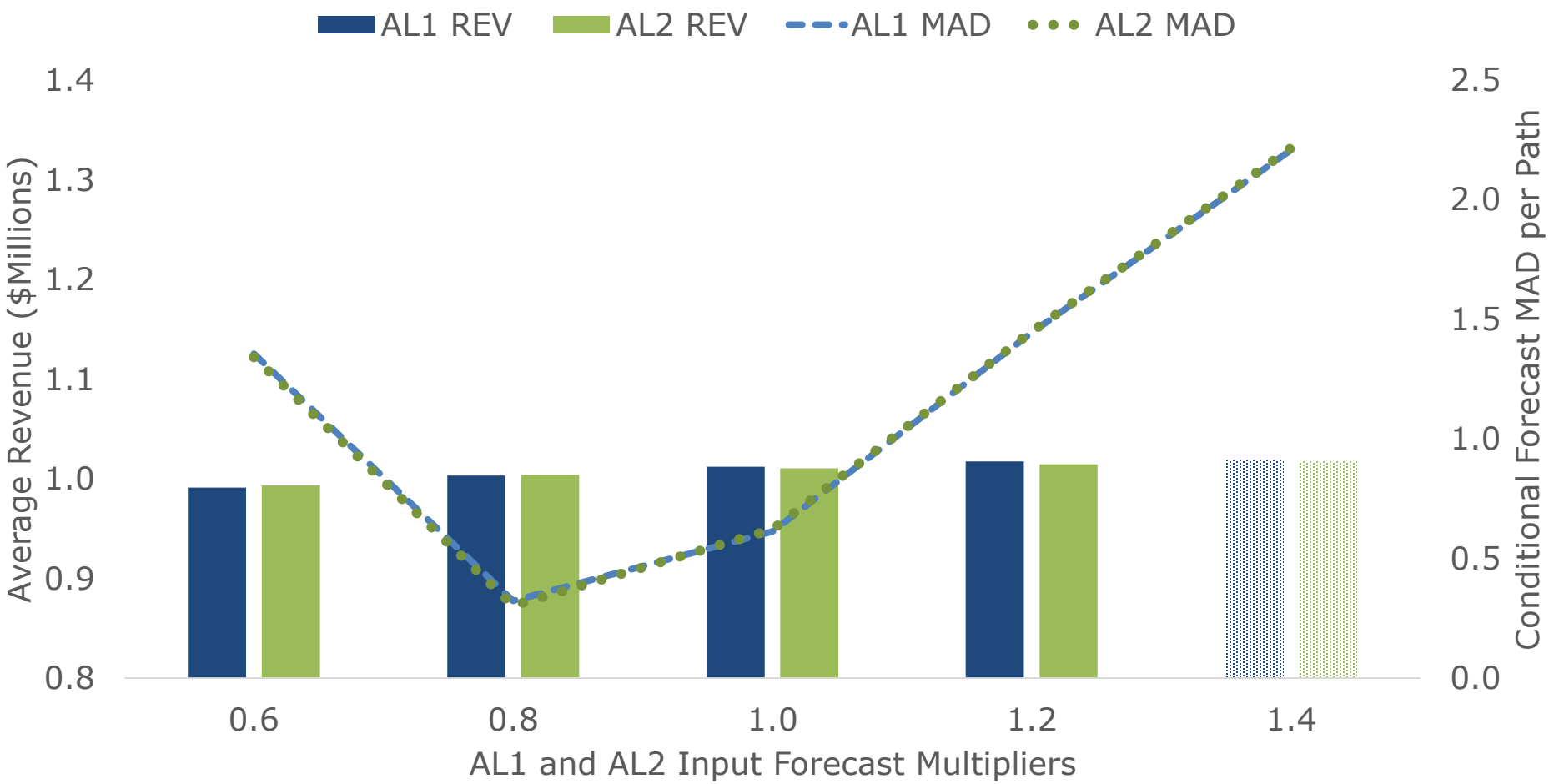
But With UDP, the Minimum Conditional Forecast MAD Does Occur at the Highest Revenue FRAT5

Unrestricted D6



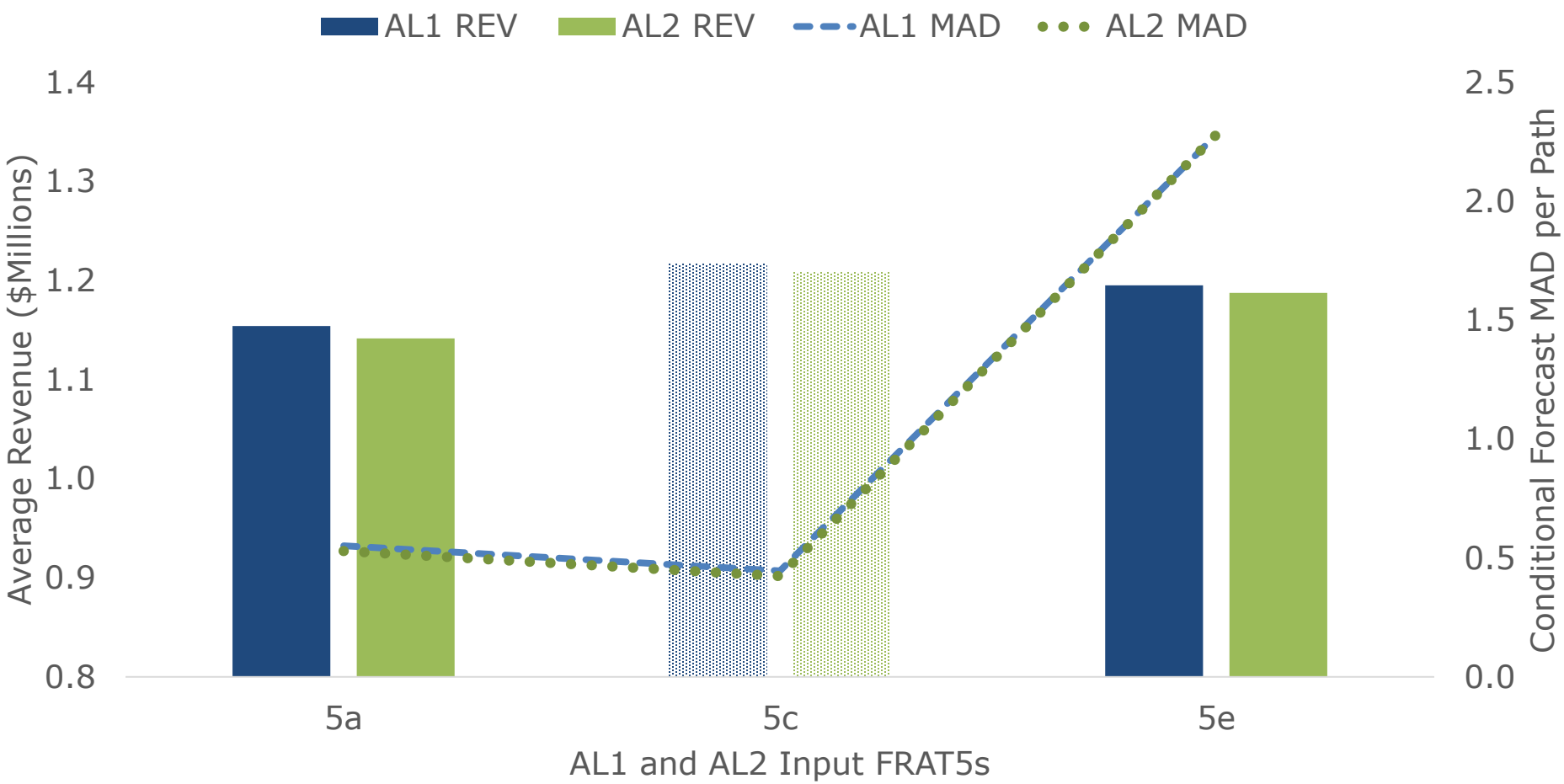
When Forecast Multipliers are Varied with UDP, Min. Conditional MAD Not at Max. Revenue Point

Unrestricted D6



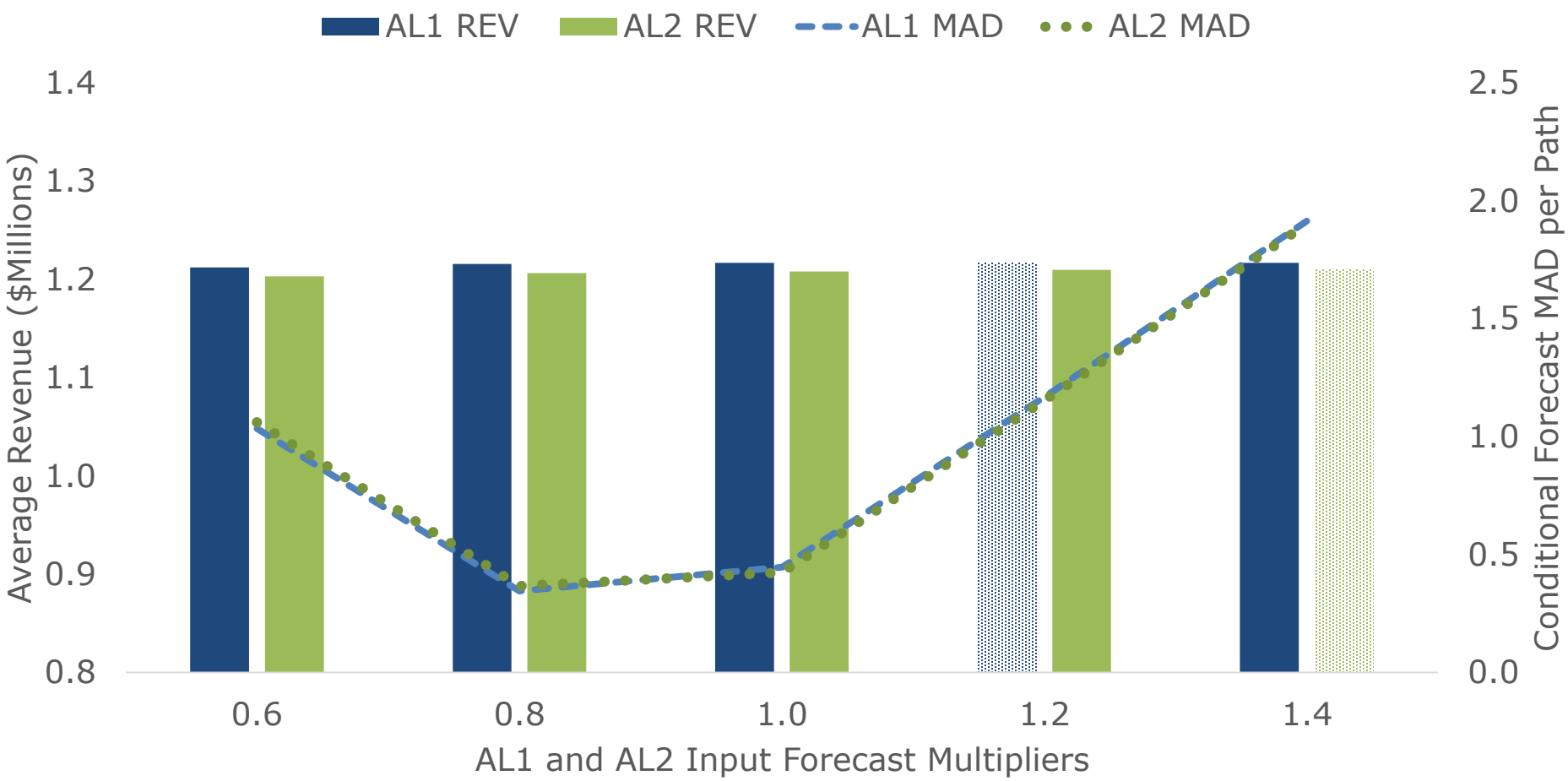
Semi-Restricted D6: Min. Conditional MAD Occurs at Max. Revenue when Varying FRAT5 (UDP)-same as Unrestricted D6

Semi-Restricted D6



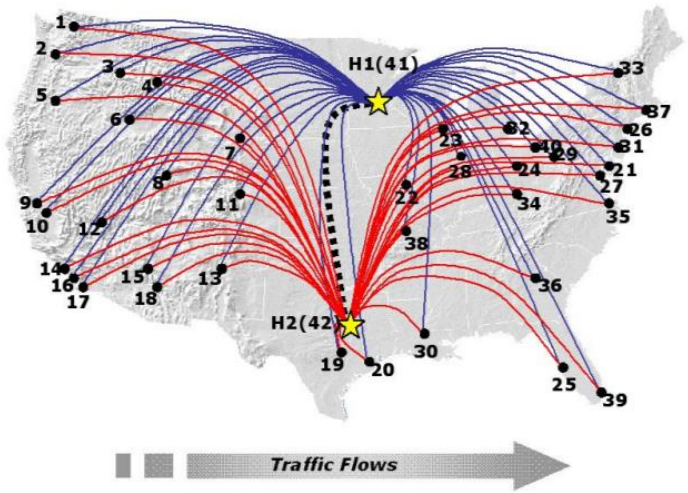
As In Unrestricted D6, Mismatch Between Conditional MAD and Revenue with Various Forecast Multipliers

Semi-Restricted D6



Experiment 2: Asymmetric RM Systems with Symmetric Input Forecast Parameters

Experiment 2 Setup: Asymmetric RM Systems, Symmetric Forecast Parameters

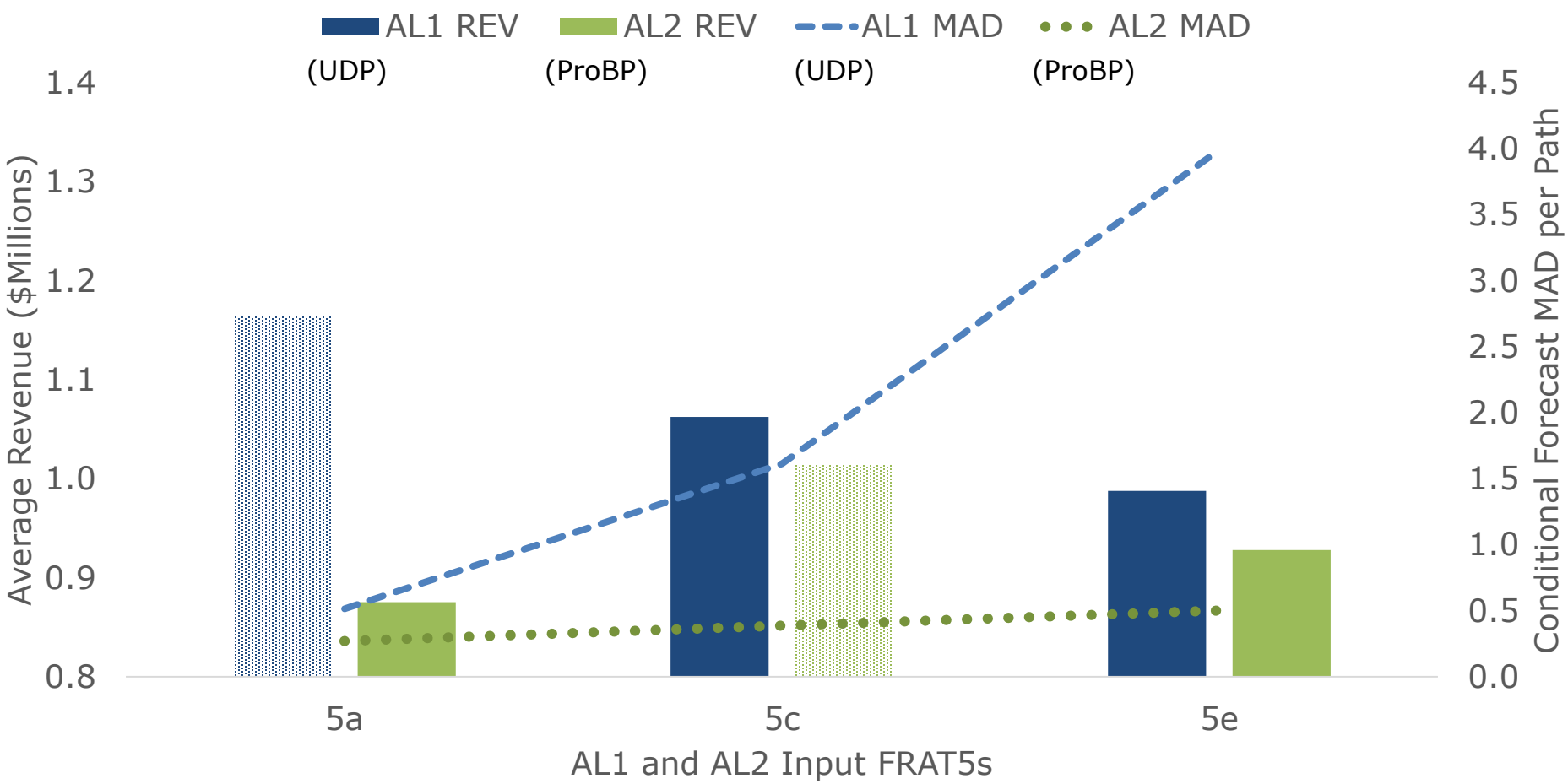


FC	AP	Unrestricted			Semi-Restricted		
		R1	R2	R3	R1	R2	R3
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1
3	0	0	0	0	0	1	1
4	0	0	0	0	1	0	1
5	0	0	0	0	1	1	0
6	0	0	0	0	1	1	1

- **In this next series of simulations, airlines use asymmetric RM systems, but symmetrically adjust input forecast parameters.**
  - » AL1 uses **UDP**, AL2 uses **ProBP**
  - » Both airlines adjust FRAT5 and/or forecast multipliers simultaneously.
  - » Airlines both use HF/FA, with fare adjustment scalar set to maximize AL1 revenue in base case.

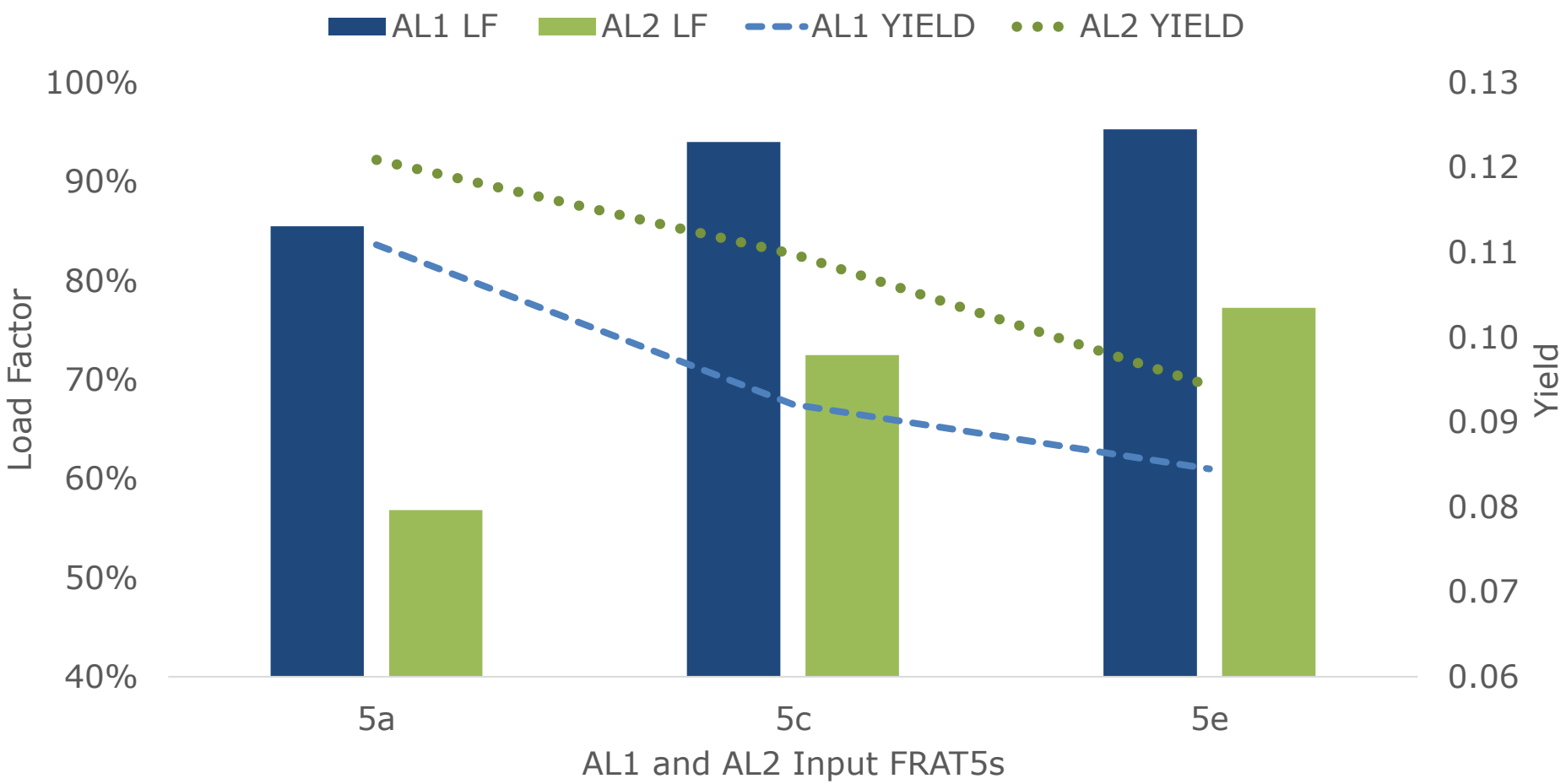
Min. Conditional Error <-> Max. Revenue Relationship True With UDP (AL1) when Varying FRAT5 (Not With ProBP/AL2)

Unrestricted D6



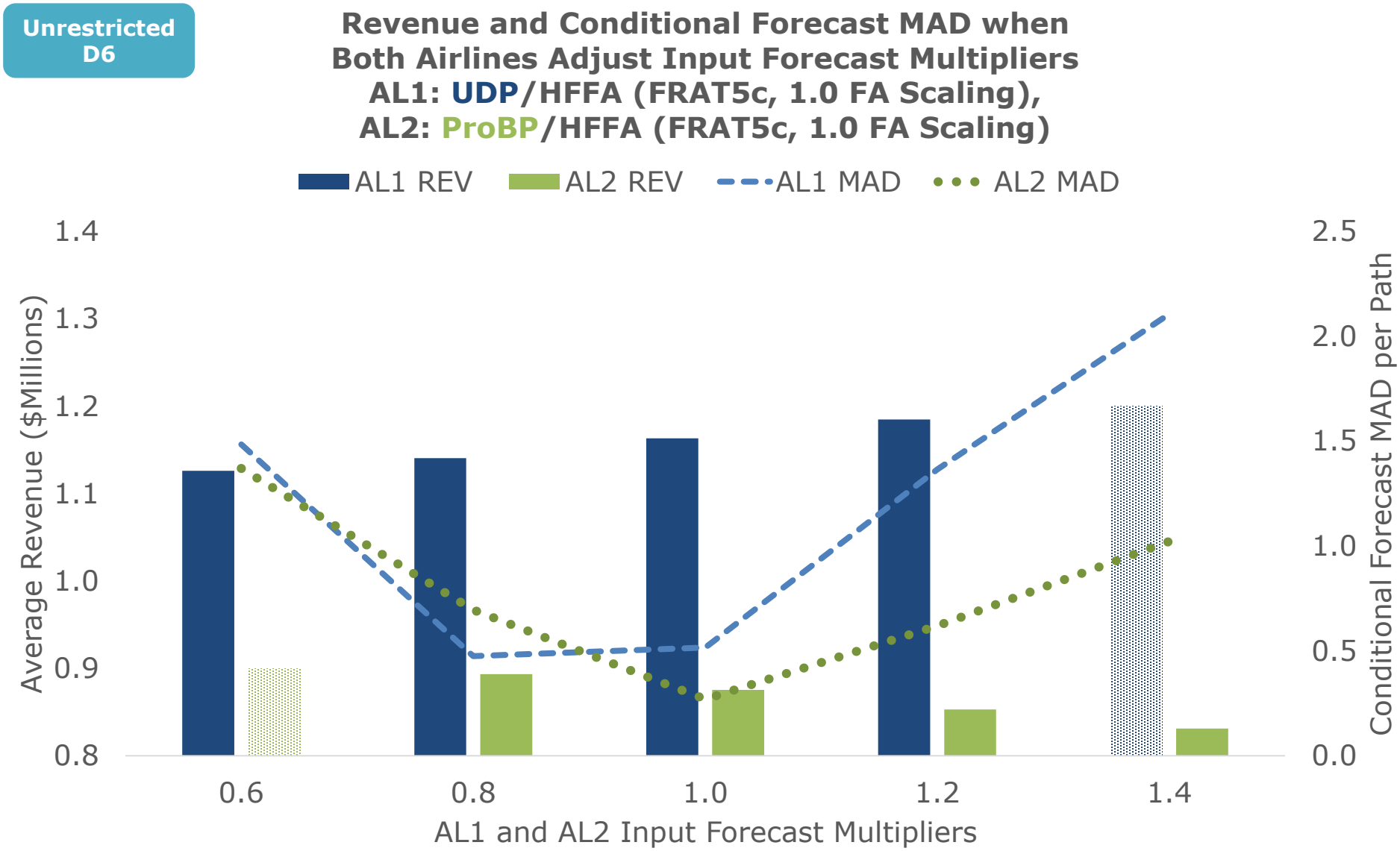
However, This Environment is Highly Asymmetric in Terms of Load Factor

Unrestricted D6



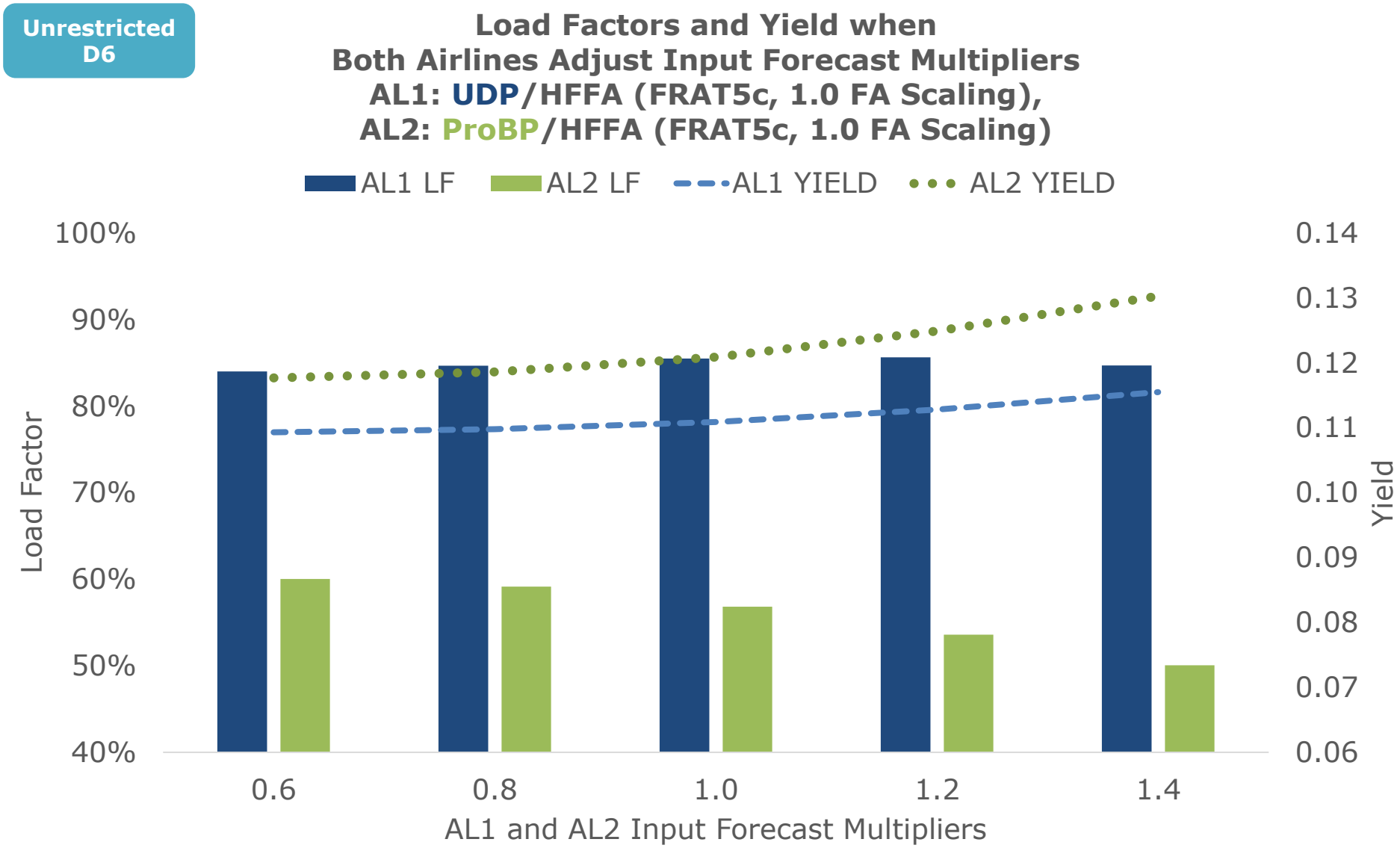
Unbalanced Environment Also Distorts Conditional MAD & Revenue Relationship when Varying Forecast Multipliers

Unrestricted
D6



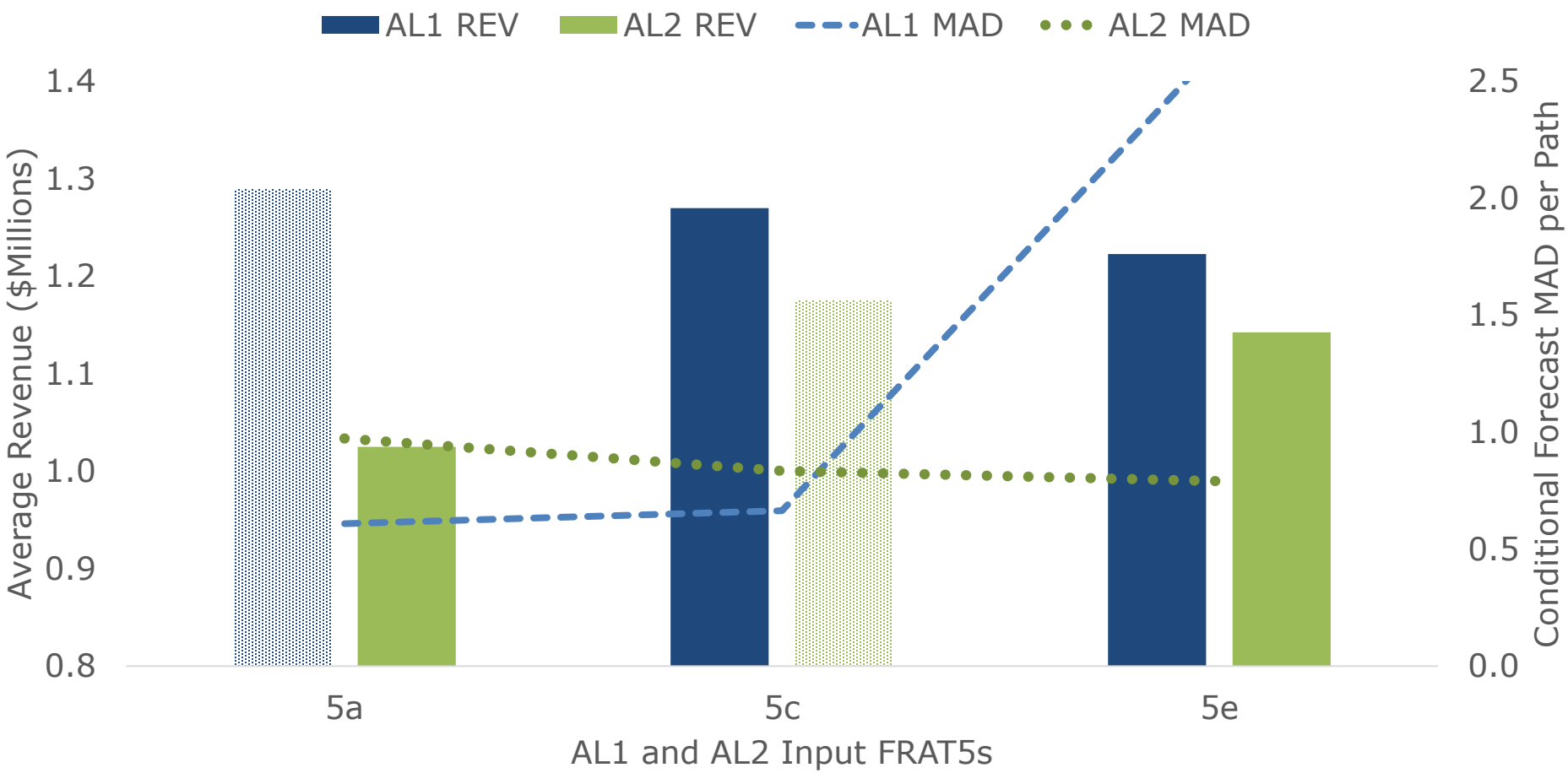
Forecast Multiplication Affects the ProBP Airline More than the UDP Airline In This Asymmetric Environment

Unrestricted D6



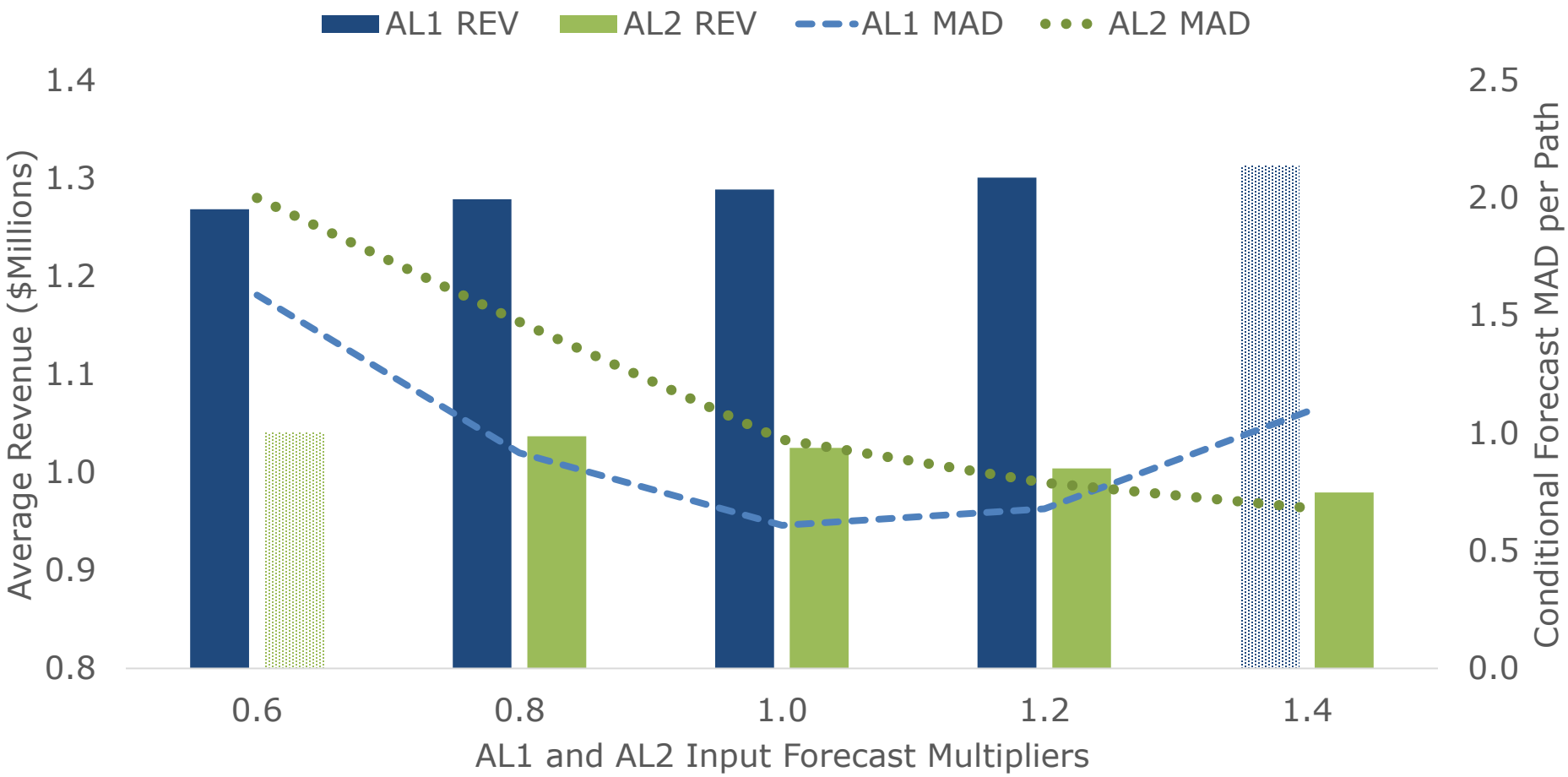
Semi-Restricted D6: Min. Conditional MAD <-> Max. Revenue with UDP when Varying FRAT5 (Not With ProBP)

Semi-Restricted D6



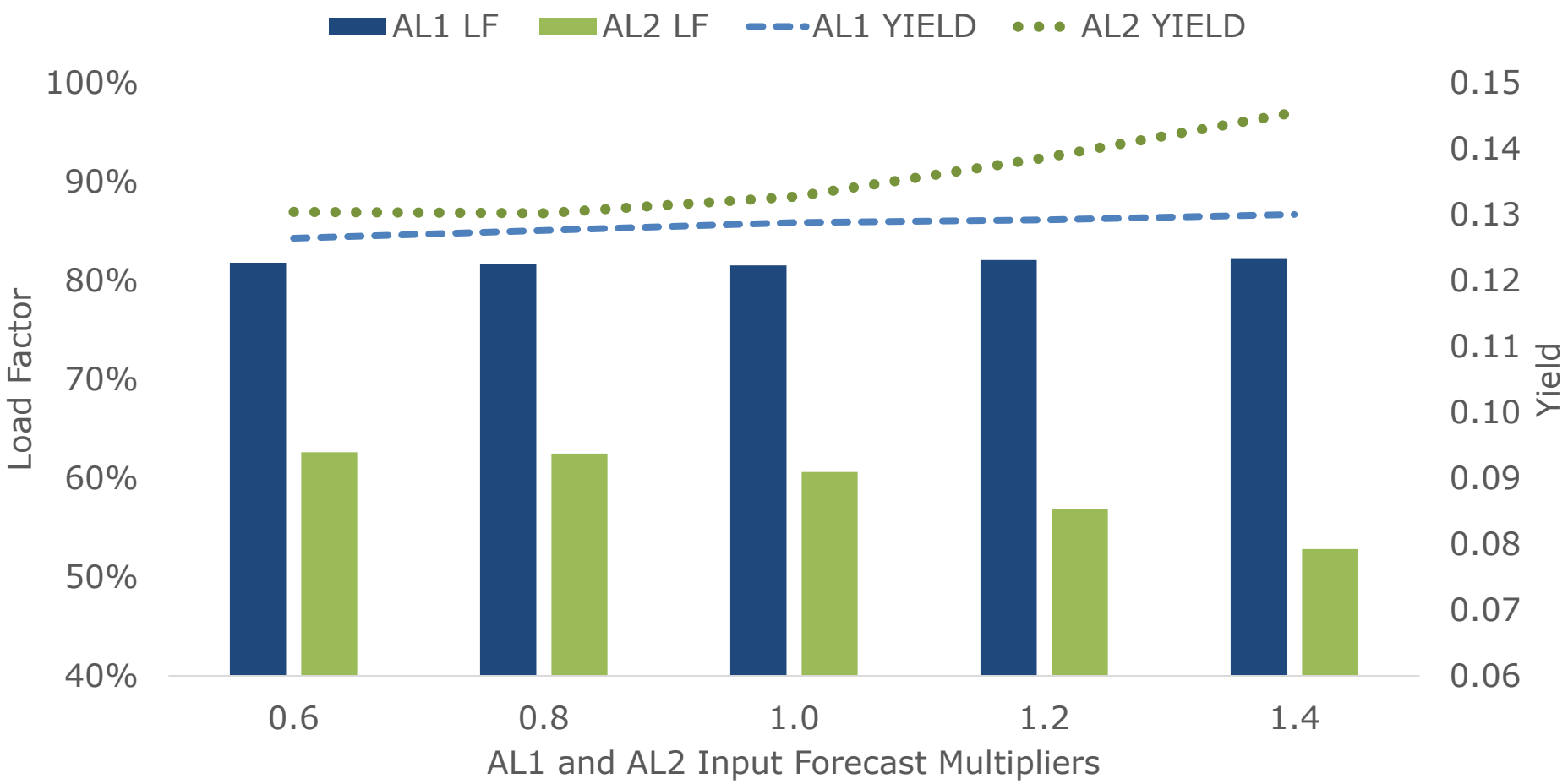
Poor Match Between Conditional MAD and Revenue When Forecast Multipliers are Varied

Semi-Restricted D6



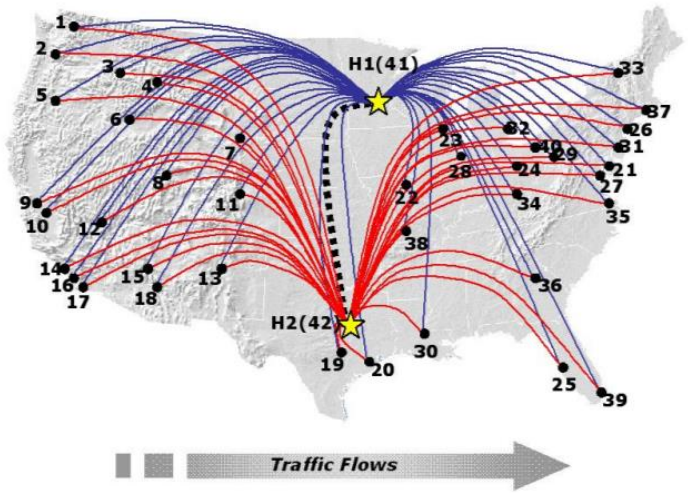
This is Likely Due to Highly Asymmetric Load Factors Between Airlines

Semi-Restricted D6



Experiment 3: Asymmetric Input Forecast Parameters with Symmetric or Asymmetric RM Systems

Experiment 3 Setup: Asymmetric Input Forecast Parameters, Symmetric or Asymmetric RM Systems



FC	AP	Semi-Restricted		
		R1	R2	R3
1	0	0	0	0
2	0	0	0	1
3	0	0	1	1
4	0	1	0	1
5	0	1	1	0
6	0	1	1	1

- **In this series of simulations, AL1 adjusts its forecast multiplier while AL2 keeps its forecast multiplier fixed at 1.0:**

AL1 **FM =** **1.4 ⇕ 0.6** **AL2** **FM = 1.0**

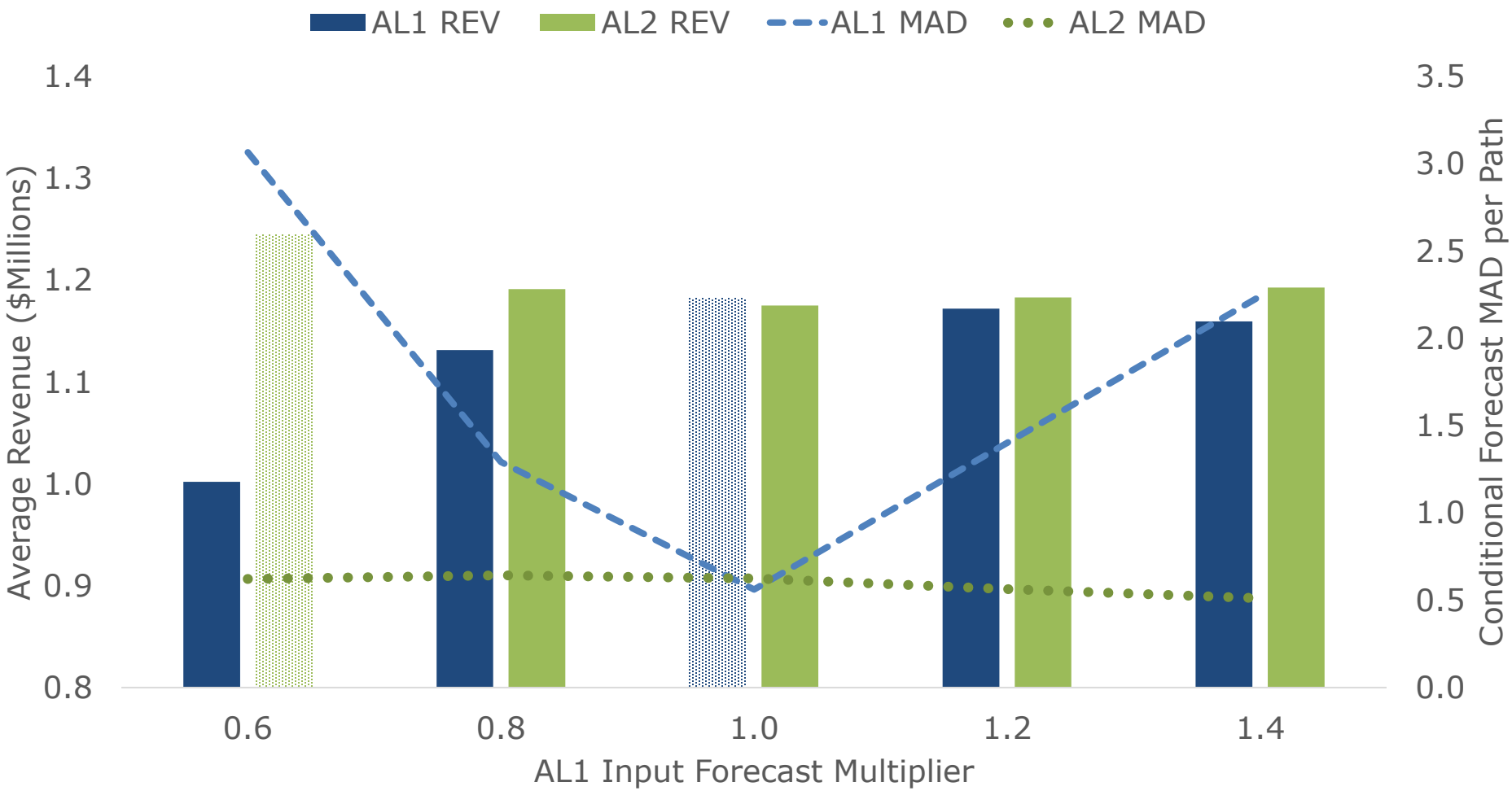
- **Semi-Restricted D6 only: both airlines use Standard Forecasting**
  - » Airlines use either EMSRb or ProBP.

Sym. RM (EMSR): Nice Match for AL1 when Varying FMs (Cause Little Change in AL2's Conditional MAD)

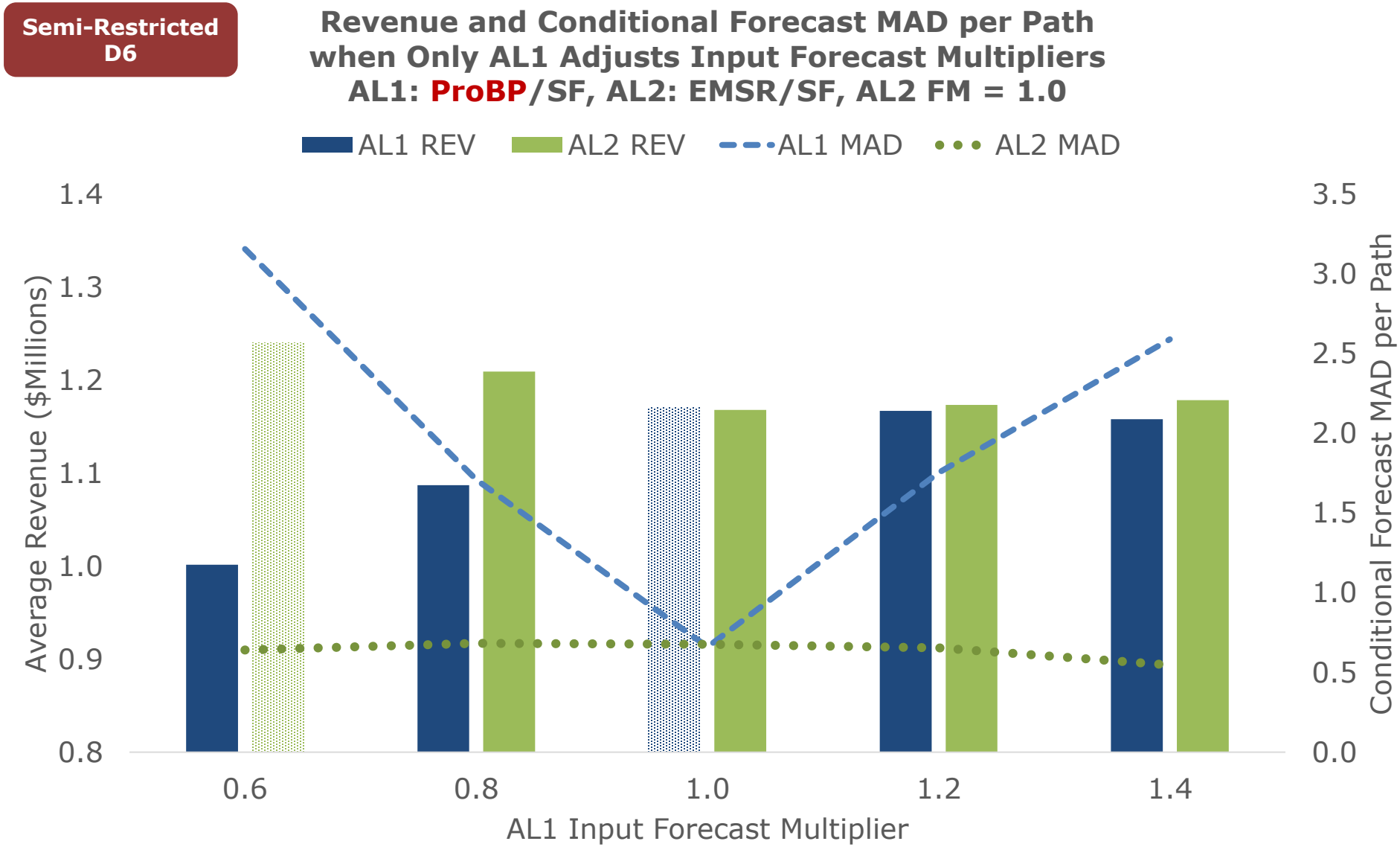
Semi-Restricted D6

Revenue and Conditional Forecast MAD per Path when Only AL1 Adjusts Input Forecast Multipliers

AL1: EMSR/SF, AL2: EMSR/SF, AL2 FM = 1.0

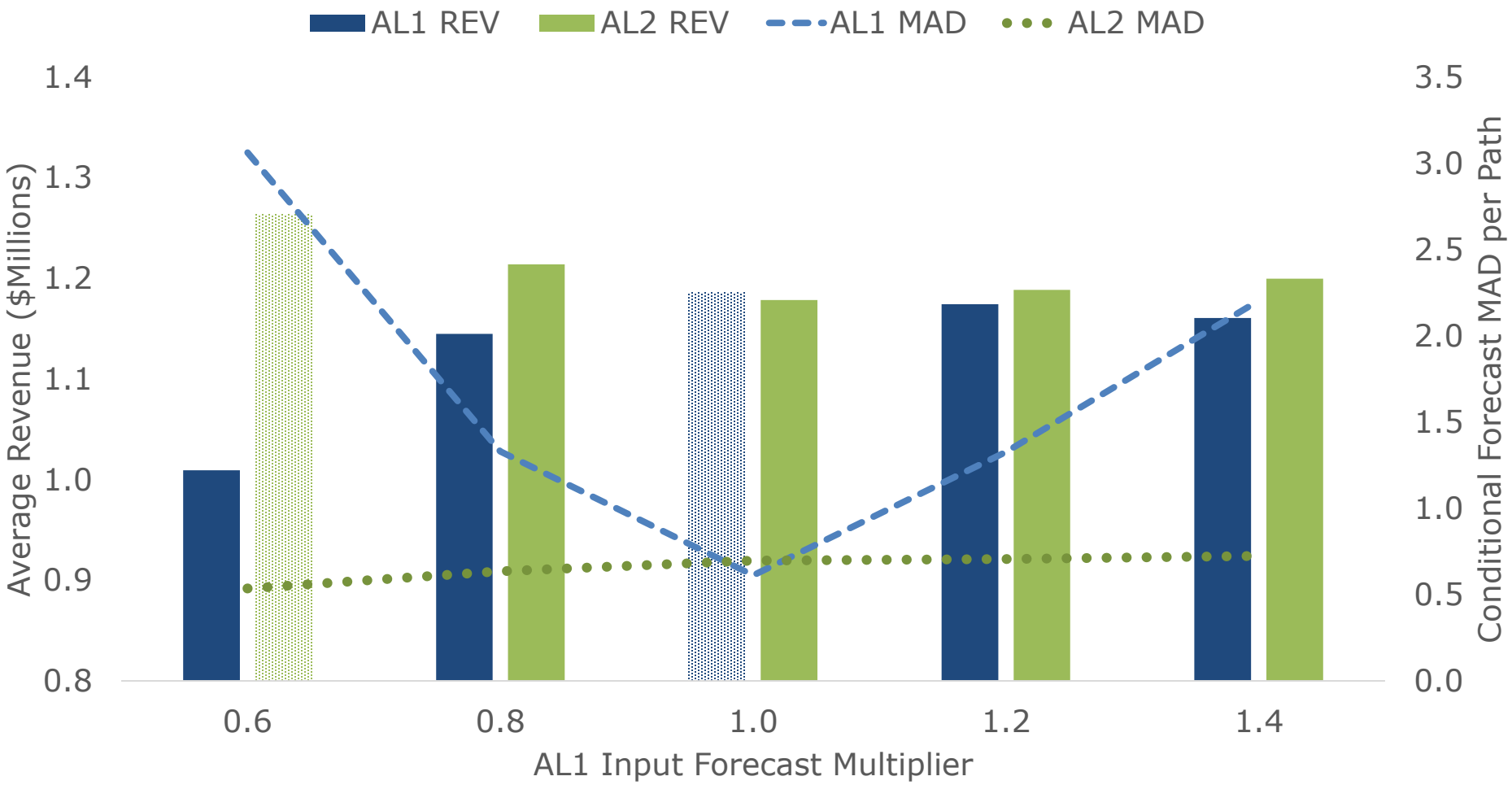


Same Pattern Holds Even if Asymmetric RM (AL1=ProBP, AL2=EMSR)



Sym. RM (ProBP): Min. Error <-> Max. Revenue Relationship Can Be Seen for Both Airlines when Varying FMs

Semi-Restricted D6



Conclusions

- **Minimum conditional demand forecast MAD <-> maximum revenue relationship can still be visible with asymmetric RM systems or input forecast parameters.**
  - As long as competitive RM situation is not too unbalanced.

- **One airline's changes in input demand forecast parameters had little impact other's conditional demand forecast MAD.**
  - But min. conditional MAD <-> max. revenue was only universally true for the airline that made the adjustment.

- **Min. error <-> max. revenue relationship was more visible when FRAT5 (WTP) was adjusted than when forecast multiplier (volume) was adjusted.**

- **No clear relationship between RM optimization method used (EMSR, ProBP, or UDP) and the minimum error <-> maximum revenue relationship.**

Passenger Origin Destination Simulator (PODS)

- The MIT PODS Research Consortium thanks the Boeing Company and PODS Research LLC for providing and supporting the PODS simulation.

- PODS was first developed at Boeing in the 1990s by Hopperstad et al, and has been enhanced in cooperation with the MIT PODS Consortium.

- The PODS simulation software is owned by

PODS
RESEARCH LLC