Timing is Important: Risk-aware Fund Allocation based on Time-Series Forecasting

Fuyuan Lyu, Linfeng Du, Yunpeng Weng, Qiufang Ying, Zhiyan Xu, Wen Zou, Haolun Wu, Xiuqiang He and Xing Tang

When shall I buy CAD

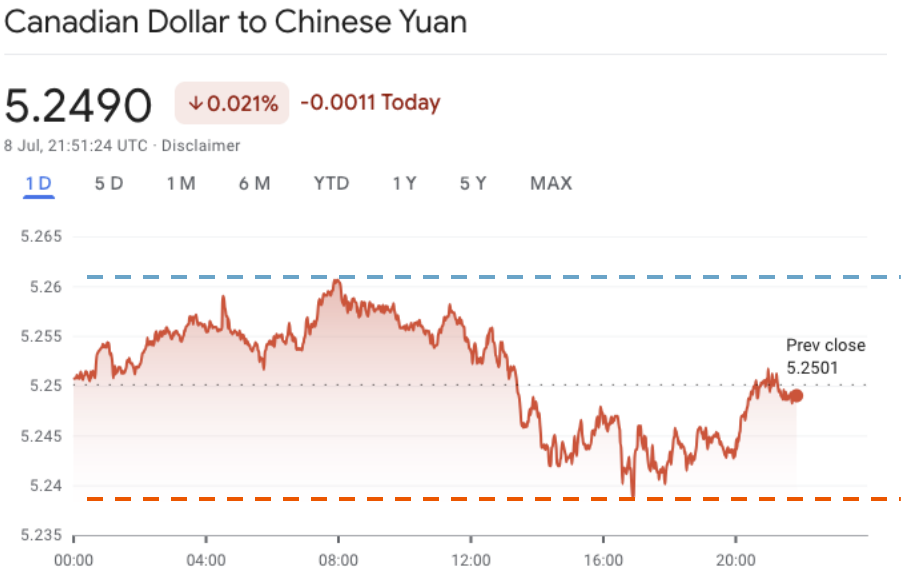


Image Captured from Google Finance

- Fuyuan plans to attend the KDD
- He needs to buy 100 CAD cash
- When is the optimal timing?

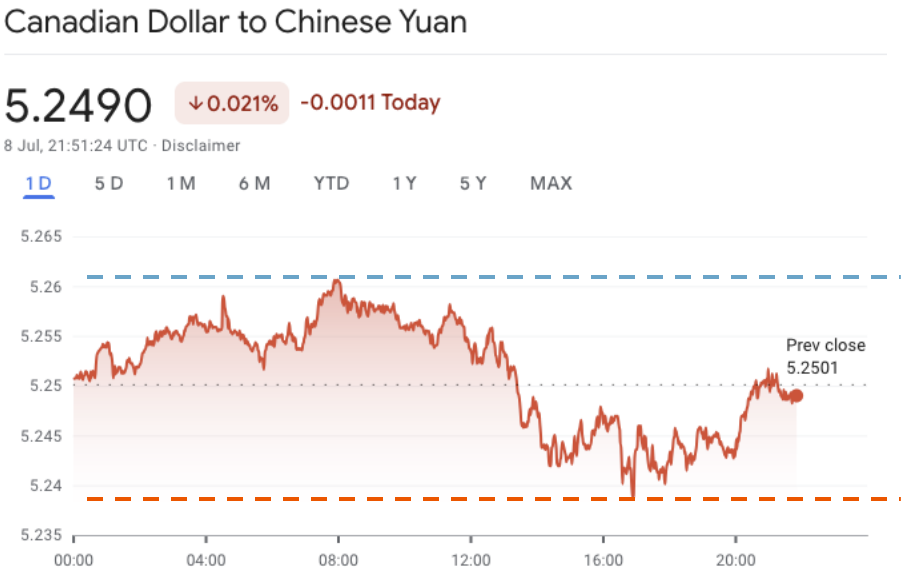
Max: 5.261

Diff = 100 * (5.261 – 5.239) = 2.2 CNY

≈ 0.5 * 

Min: 5.239

When shall Tencent buy CAD



As the volume increase, the gap becomes non-neglectable

Max: 5.261

Diff = 100M * (5.261 – 5.239) = 2.2 M CNY

≈ 0.5M *

Min: 5.239

Image Captured from Google Finance

Business Background

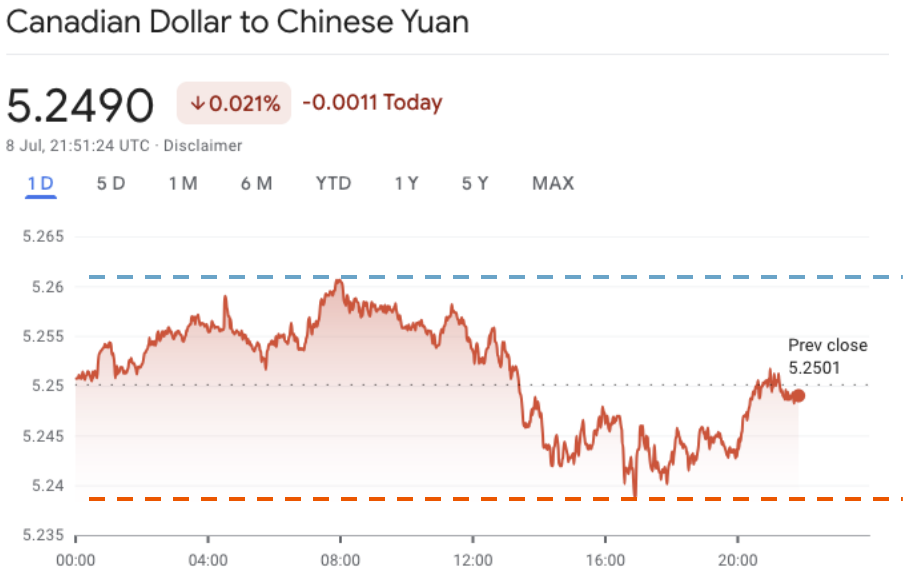
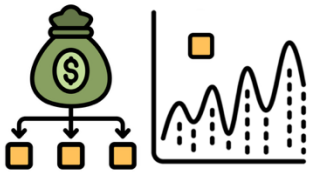


Image Captured from Google Finance

- WeChat Pay Oversea is 24/7 available.
- But Currency Market is not.
- This requires WeChat to serve as an exchanger sometime.
- The exchange volume on weekend is particularly high!
- Need to buy huge cash reserve before Friday.

Predict-then-Optimize

F. A. over Assets



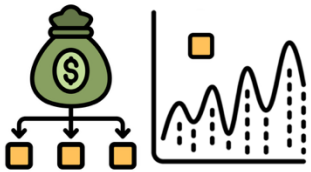
F. A. over Time

Definition: Buy certain amount of assets over a period of time, while its price varies.

E.g. Buy 1k USD over Friday

Predict-then-Optimize

F. A. over Assets



F. A. over Time

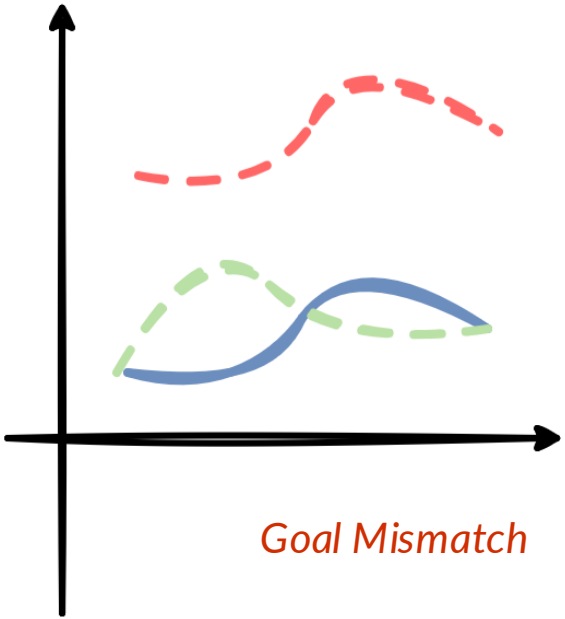
Definition: Buy certain amount of assets over a period of time, while its price varies.

E.g. Buy 1k USD over Friday

A Predict-then-Optimize (PtO) framework:

- A forecasting model: $y_T = M(x_T)$
- An allocation model: $\min_a a * y_T, \quad \text{s.t.} \sum a = 1$

Why not two-stage



Goal Mismatch

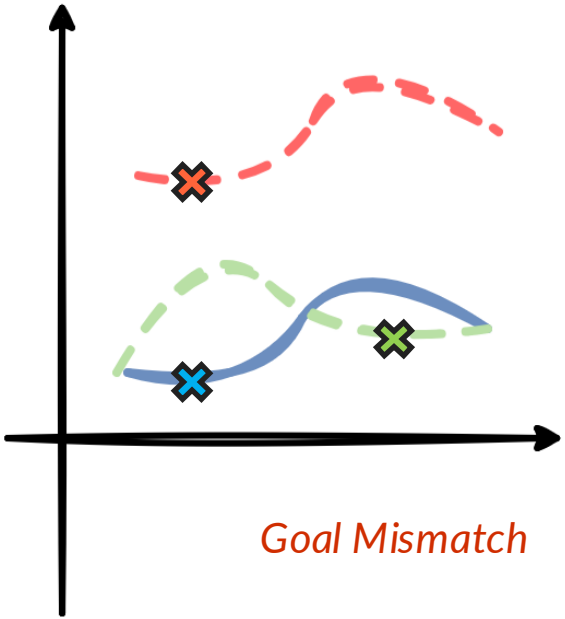
Prediction: Green > Red

Optimization: Red > Green

A Predict-then-Optimize (PtO) framework:

- A forecasting model: $y_T = M(x_T)$
- An allocation model: $\min_a a * y_T, \quad \text{s.t.} \sum a = 1$

Why not two-stage



Goal Mismatch

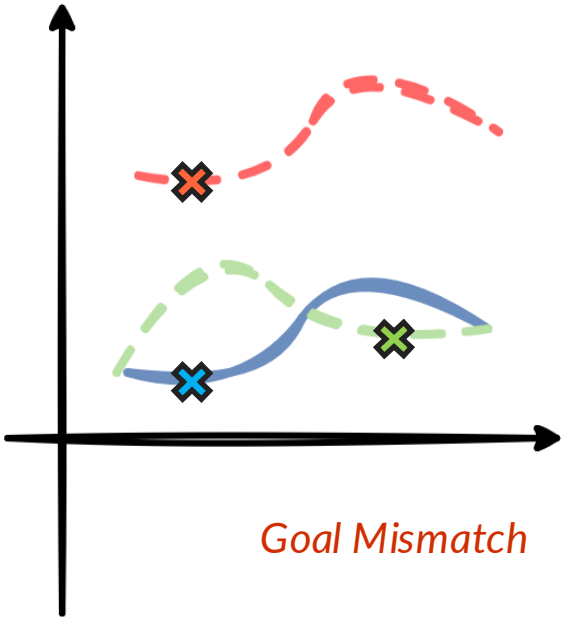
Prediction: Green > Red

Optimization: Red > Green

A Predict-then-Optimize (PtO) framework:

- A forecasting model: $\mathrm{y_T} = M(x_T)$
- An allocation model: $\min_{\mathrm{a}} \mathrm{a} * \mathrm{y_T}, \quad \mathrm{s.t.} \sum a = 1$

Why not two-stage



Goal Mismatch

Require a new training framework to "backprop" optimization feedback into training of prediction

Prediction: Green > Red

Optimization: Red > Green

A Predict-then-Optimize (PtO) framework:

- A forecasting model: $y_T = M(x_T)$
- An allocation model: $\min_a a * y_T, \quad \text{s.t.} \sum a = 1$

RTS-PnO

- Goal Mismatch between prediction and allocation stages

RTS-PnO

- Goal Mismatch between prediction and allocation stages
- Apply the SPO+[1] loss to time series for goal alignment

$$L_o = \frac{1}{|D|} \min_{M(\cdot)} \sum_{D} l_o(a^*(\hat{y}_T), a(y_T))$$

$$l_o\big(a^*(\hat{y}_T), a(y_T)\big) \triangleq 2a^*(y_T)\hat{y}_T - a^*(y_T)y_T + \max_{a \in A}\{ay_T - 2a\hat{y}_T\}$$

[1] Elmachtoub, Adam N., and Paul Grigas. "Smart "predict, then optimize"." Management Science 68.1 (2022): 9-26.

Uncertainty of Forecasting

- The uncertainty of forecasting varies across steps

Uncertainty of Forecasting

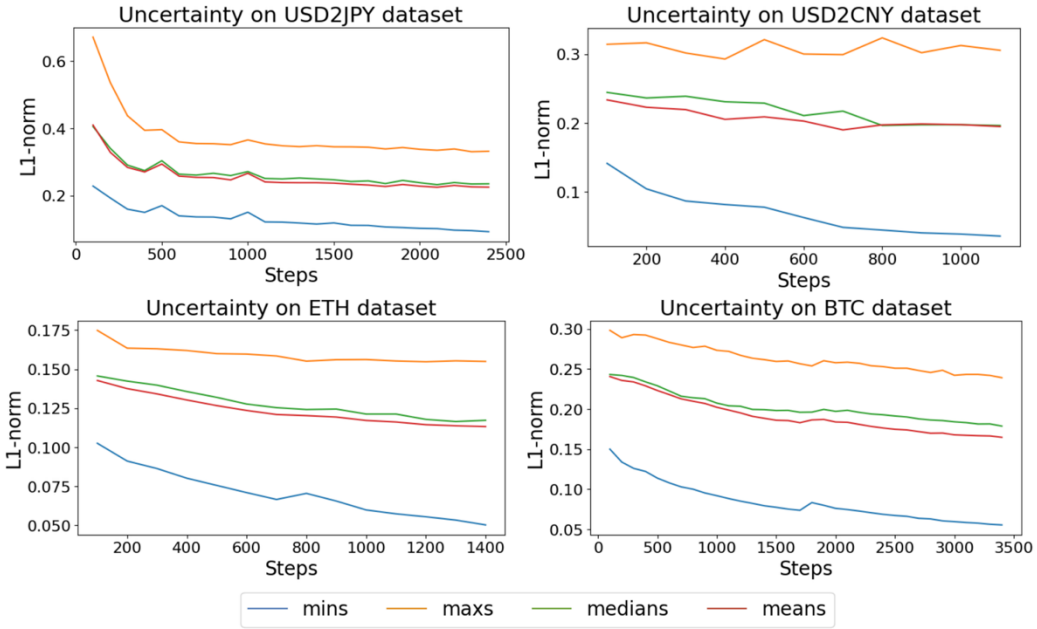
Algorithm 1 Calculating Positional Uncertainty for Forecasting Model

Require: Calibration Dataset $\mathcal{D}_c$, coverage rate γ
Ensure: Positional Uncertainty $\mathbf{r}$

1: Initialize Positional Uncertainty Sets $\epsilon_1 = \{\}, \cdots, \epsilon_H = \{\}$
2: **for** for data instance (x_T, y_T, c_T) in Calibration Set $\mathcal{D}_c$ **do**
3: Calculate $\hat{y}_T = [\hat{p}_{T+1}, \cdots \hat{p}_{T+H}]$ given Eq. 2
4: **for** h in $1, \cdots, H$ **do**
5: $\epsilon_h \leftarrow \epsilon_h \cup \{|\hat{p}_{T+h} - p_{T+h}|\}$
6: **for** h in $1, \cdots, H$ **do**
7: $r_h = \left(\frac{|\mathcal{D}_c|+1}{|\mathcal{D}_c|}\gamma\right)$ - quantile in ϵ_h
8: Return $\mathbf{r} = [r_1, r_2, \cdots, r_H]$

- The uncertainty of forecasting varies across steps
- Positional-aware risk on forecasting

Why not a fixed threshold



The threshold varies during training phase

Evaluation

Category	Dataset	Forecasting-Only				Risk-Avoid				RTS-PtO		RTS-PnO		Relative Improvement	
		Top-1		Top-5		Top-1		Top-5							
		regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret(%)	R.R.(%)
Currency	USD2CNY	36.88	5.10	37.00	5.12	35.80	4.95	35.83	4.96	35.74	4.94	**31.68**	**4.38**	12.82%	12.79%
	USD2JPY	54.50	34.92	54.21	34.73	49.66	31.90	50.01	32.12	52.11	32.66	**48.77**	**31.25**	1.82%	2.08%
	AUD2USD	19.56	29.60	19.92	30.15	19.38	29.36	19.49	29.52	19.48	29.51	**19.06**	**28.84**	1.68%	1.80%
	NZD2USD	17.43	28.75	17.66	29.14	16.54	27.29	16.64	27.44	16.82	27.75	**15.68**	**25.85**	5.48%	5.57%
Stock	S&P 500	134.99	4.25	135.47	4.24	**122.50**	**3.84**	124.24	3.90	126.06	3.94	124.05	3.90	-1.27%	-1.56%
	Dow Jones	1090.88	4.16	1075.79	4.09	1022.73	3.91	1032.21	3.93	1022.90	3.92	**997.52**	**3.82**	2.53%	2.36%
Cryptos	BTC	2159.78	4.46	2167.96	4.47	1856.21	3.90	1858.57	3.91	1924.65	3.96	**1843.26**	**3.70**	0.70%	5.41%
	ETH	151.14	5.56	149.61	5.48	131.41	**4.68**	131.42	**4.68**	138.60	4.96	**131.40**	4.73	0.00%	-1.07%
Avg. Rank		5.38	5.5	5.63	5.5	2	1.88	3.38	3.13	3.5	3.5	1.13	1.25		

Setup:

- Datasets: 4 * Currency + 2 * Stock + 2 * Cryptos
- Backbone: PatchTST

$$\text{regret} \triangleq |a^*(y_T) \cdot y_T - a^*(\hat{y}_T) \cdot y_T|$$

$$\text{R. R.} \triangleq \frac{\text{regret}}{|a^*(y_T) \cdot y_T|}$$

Evaluation

Category	Dataset	Forecasting-Only				Risk-Avoid				RTS-PtO		RTS-PnO		Relative Improvement	
		Top-1		Top-5		Top-1		Top-5							
		regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret(%)	R.R.(%)
Currency	USD2CNY	36.88	5.10	37.00	5.12	35.80	4.95	35.83	4.96	35.74	4.94	**31.68**	**4.38**	12.82%	12.79%
	USD2JPY	54.50	34.92	54.21	34.73	49.66	31.90	50.01	32.12	52.11	32.66	**48.77**	**31.25**	1.82%	2.08%
	AUD2USD	19.56	29.60	19.92	30.15	19.38	29.36	19.49	29.52	19.48	29.51	**19.06**	**28.84**	1.68%	1.80%
	NZD2USD	17.43	28.75	17.66	29.14	16.54	27.29	16.64	27.44	16.82	27.75	**15.68**	**25.85**	5.48%	5.57%
Stock	S&P 500	134.99	4.25	135.47	4.24	**122.50**	**3.84**	124.24	3.90	126.06	3.94	124.05	3.90	-1.27%	-1.56%
	Dow Jones	1090.88	4.16	1075.79	4.09	1022.73	3.91	1032.21	3.93	1022.90	3.92	**997.52**	**3.82**	2.53%	2.36%
Cryptos	BTC	2159.78	4.46	2167.96	4.47	1856.21	3.90	1858.57	3.91	1924.65	3.96	**1843.26**	**3.70**	0.70%	5.41%
	ETH	151.14	5.56	149.61	5.48	131.41	**4.68**	131.42	**4.68**	138.60	4.96	**131.40**	4.73	0.00%	-1.07%
Avg. Rank		5.38	5.5	5.63	5.5	2	1.88	3.38	3.13	3.5	3.5	1.13	1.25		

- RTS-PnO proves to be effective: *RTS-PnO > others*
- Forecasting-Only not reliable: *others > Forecasting-Only*
- Risk-Avoid is effective: *Good on Stock & Crypto*

Evaluation

Forecasting Model	Dataset	Forecasting-Only				Risk-Avoiding				RTS-PtO		RTS-PnO		Relative Improvement	
		Top-1		Top-5		Top-1		Top-5							
		regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓	regret(%)	R.R.(%)
DLinear	USD2CNY	36.99	5.12	36.73	5.08	35.50	4.91	38.11	5.27	35.31	4.98	**34.88**	**4.81**	1.23%	3.50%
	Dow Jones	1103.11	4.21	1128.71	4.24	**1036.65**	**3.96**	1075.97	4.08	1073.30	4.10	1042.35	3.98	-0.55%	-0.51%
TimesNet	USD2CNY	39.77	5.50	39.46	5.46	36.83	5.09	37.47	5.18	35.99	4.98	**33.73**	**4.66**	6.70%	6.87%
	Dow Jones	1157.76	4.40	1143.82	4.32	1037.71	3.98	1082.45	4.11	1042.67	3.95	**972.51**	**3.74**	6.70%	5.61%
FEDFormer	USD2CNY	36.44	5.04	36.89	5.10	36.28	5.02	36.53	5.05	35.94	4.97	**32.32**	**4.47**	11.23%	11.19%
	Dow Jones	1087.49	4.15	1100.99	4.19	1065.08	4.05	1078.61	4.09	1043.41	3.98	**1010.96**	**3.82**	3.21%	4.19%

- RTS-PnO is model-agnostic:

Good on other TS models

Ablation

Dataset	PtO		Fixed-PnO		Adaptive-PnO	
	regret↓	R.R.↓	regret↓	R.R.↓	regret↓	R.R.↓
USD2CNY	35.74	4.94	34.66	4.71	**31.68**	**4.38**
USD2JPY	52.11	32.66	49.21	31.83	**48.77**	**31.25**
S&P 500	126.06	3.94	129.13	4.02	**124.05**	**3.90**
Dow Jones	1022.90	3.92	1026.45	3.92	**997.52**	**3.82**
BTC	1924.65	3.96	1939.81	4.02	**1843.26**	**3.70**
ETH	138.60	4.96	136.66	4.90	**131.40**	**4.73**

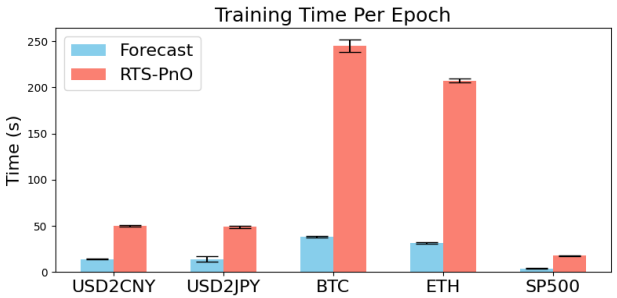
Category	Dataset	Prediction		RTS-PnO	
		MSE	MAE	MSE	MAE
Currency	USD2CNY	**0.0049**	**0.0397**	0.0053	0.0430
	USD2JPY	**0.0383**	**0.1263**	0.1201	0.2796
	AUD2USD	**0.0277**	**0.1220**	0.0350	0.1439
	NZD2USD	**0.0233**	**0.1072**	0.0327	0.1334
Stock	S&P 500	**0.1533**	**0.2744**	0.5567	0.6194
	Dow Jones	**0.1184**	**0.2354**	0.3552	0.4815
Criptos	BTC	**0.0197**	**0.0962**	0.0953	0.2321
	ETH	**0.0213**	**0.1003**	0.1297	0.2608

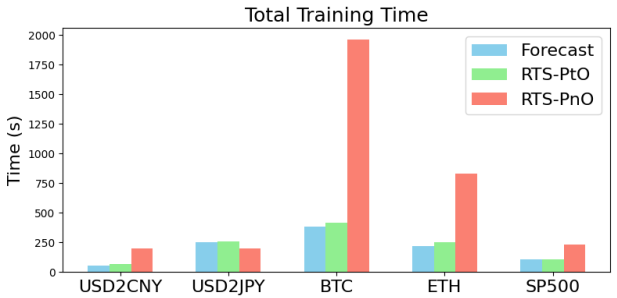
- Ablation on Risk Threshold:
- Ablation on Prediction Performance:

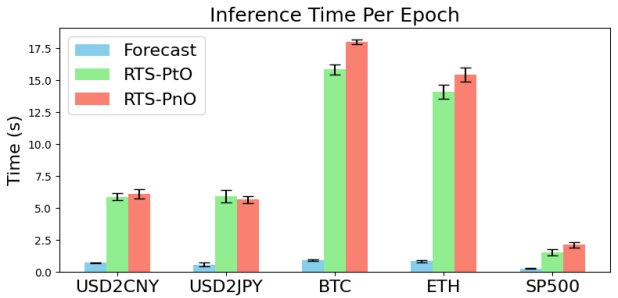
Adaptive > Fixed

Sacrifice the prediction accuracy

Efficiency Analysis

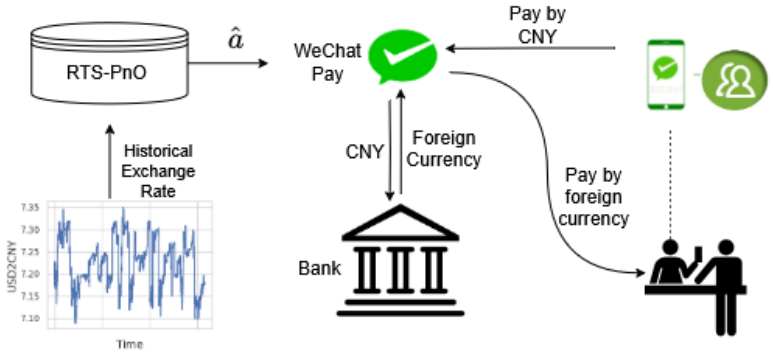


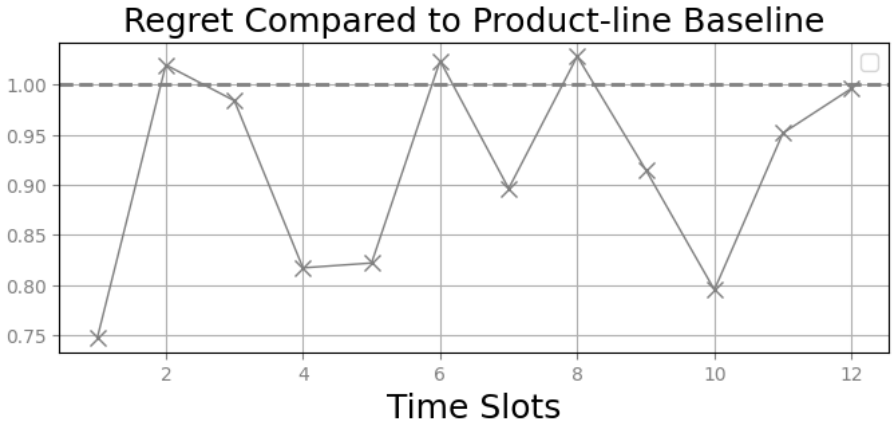




- Increase on both training and inference time
- Inference increase due to the additional allocation stage
- Training increase due to the additional proxy loss

Online Experiment





- Tencent requires to provide oversea services to customers during weekend
- A 8.4% decrease in terms of relative regret

Summary

1. Asset Allocation over Time

2. RTS-PnO:

   - Predict-and-Optimize framework

   - Adaptive risk-aware allocation

3. Evaluation on offline Financial AI datasets and online experiment

Thanks for listening!

1. Asset Allocation over Time

2. RTS-PnO:

   - Predict-and-Optimize framework

   - Adaptive risk-aware allocation

3. Evaluation on offline Financial AI datasets and online experiment

Code available at https://github.com/fuyuanlyu/RTS-PnO