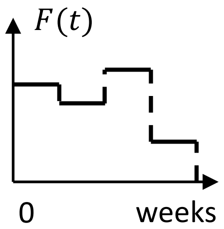
# Dynamic pricing of corporate deposits with deep reinforcement learning

## Deposits pricing as an analogy to a self-driving car

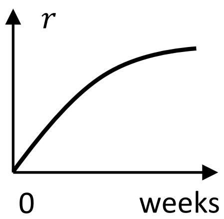
### Problem

- Deposits are a source of liquid financing for a commercial bank
- The volume of bank's deposits portfolio depends on the offered interest rate
- Thus, deposits should be priced to make total portfolio volume $V(t)$ equal to bank's liquidity requirements $F(t)$
- In addition, the total cost of deposits portfolio should be minimized
- An analogy could be drawn between dynamic pricing of deposits and a self-driving car

### Analogy to a self-driving car




Liquidity requirements → Road



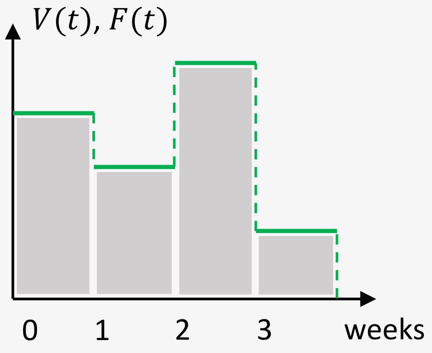

Interest rate curve → Steering wheel and pedals

Interest expense → Fuel consumption

# Trade-off between short-term and long-term deposits

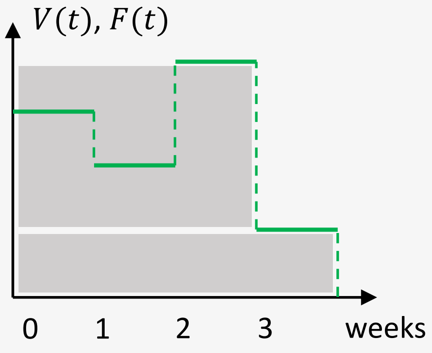
**Strategy 1 – short-term deposits**

- Amount of funds equal to $F(t)$ can be raised by taking a new portfolio of short-term deposits every period $t$
- Short-term deposits are cheaper, but mature quick and so have to be rolled over



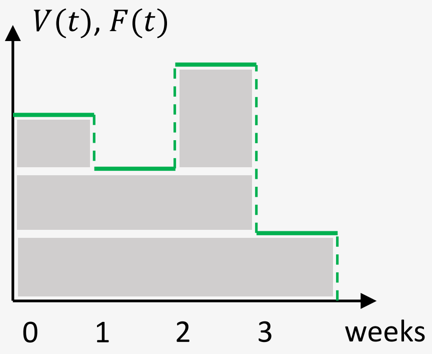

**Strategy 2 – long-term deposits**

- Another strategy is to initially take such long-term deposits that will certainly meet all expected liquidity needs $F(t)$
- Long-term deposits are more expensive
- Excessive funds can be reinvested through money market




**Optimal strategy**

- Optimal strategy that minimizes total cost of portfolio while fulfilling liquidity constraints is some superposition of strategy 1 and strategy 2
- Relative weights of two strategies depend on market conditions



# Pricing of deposits as an optimal control problem

Optimal control problem setup for managing portfolio of deposits with maturity terms $\theta \in \{\theta_i\}$ during a $T$–day period

Discounted financial result for day t

$$\sum_{t=1}^{T} \gamma^t \cdot U(t) \to max$$

Interest rate constraints based on the model applicability range

$$r_{t,\theta} \in [r_{lower\ bound}, r_{upper\ bound}], \qquad |r_{t,\theta} - r_{t-1,\theta}| \le r_{delta\ bound}$$

Interest expense

Reinvestment income due to excess liquidity

Borrowing cost due to liquidity shortage

Risk-norm constraints

$$U(t) = -\sum_{\theta=1}^{\Theta} V_{t,\theta} \cdot \widetilde{r_{t,\theta}} + R_r\left(max\left(\sum_{\theta=1}^{\Theta} V_{t,\theta} - F(t), 0\right)\right) - L_v\left(max\left(F(t) - \sum_{\theta=1}^{\Theta} V_{t,\theta}, 0\right)\right) - L_r(V_{t,\theta})$$

Deposits daily addition volume

$$v_{t,\theta}^{in} = f_{\theta}^{elasticity}(r_{t,\theta}, \dots)$$

Dynamics of portfolio volume

$$V_{t,\theta} = V_{t-1,\theta} - v_{t,\theta}^{out} + v_{t,\theta}^{in}$$

Dynamics of portfolio weighted-average interest rate

$$\widetilde{r_{t,\theta}} = \widetilde{r_{t-1,\theta}} \cdot \frac{(V_{t-1,\theta} - v_{t,\theta}^{out})}{V_{t,\theta}} + r_{t,\theta} \cdot \frac{v_{t,\theta}^{in}}{V_{t,\theta}}$$

# Elasticity model of deposits daily addition volume

**Inputs**

- $r_\theta$ – interest rate for term $\theta$
- Current portfolio statistics
- Money market indicators
- Broader market indicators
- Seasonal effects

**Gaussian Process**

**Output**

Probabilistic distribution for daily addition volume of deposits with term $\theta$


**Current portfolio statistics**:

- Portfolio size
- Matured volume
- Amount of embedded options

**Money market indicators**:

- Central Bank auctions
- Tax calendar
- Federal Treasury balance
- Monetary base
- Finance Ministry interventions

**Broader market indicators**:

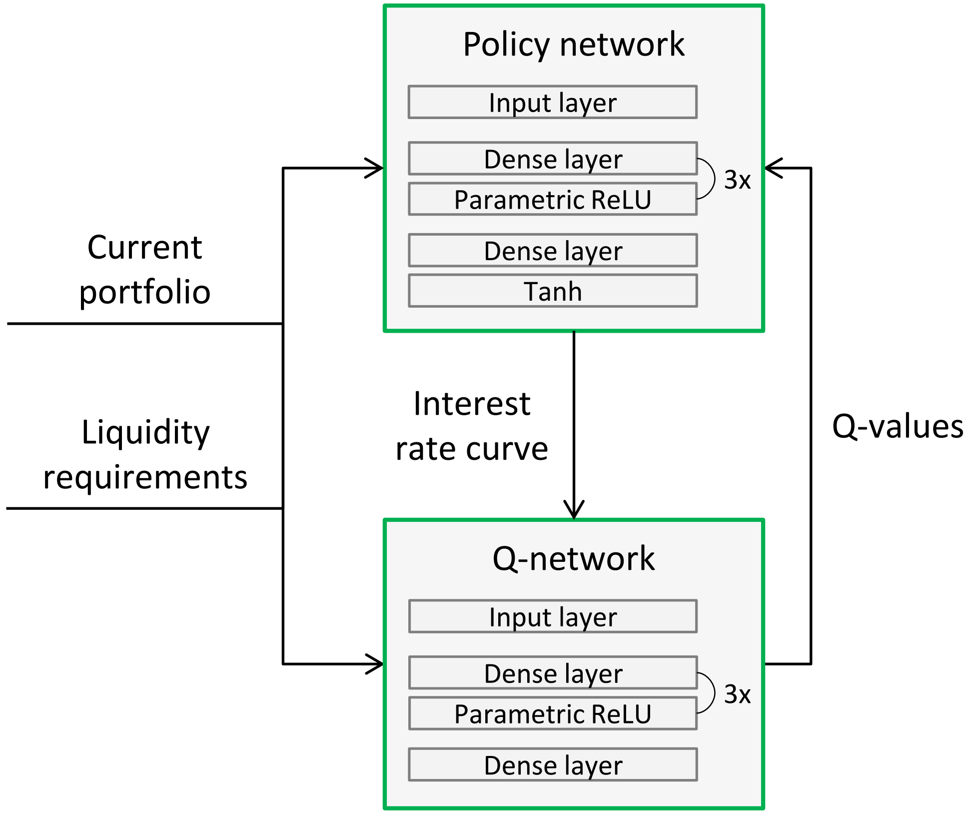
- FX rates
- Oil and natural gas prices
- Gold price
- Stock market indices
- Bond market indices
- Volatility indices

**Seasonal effects**:

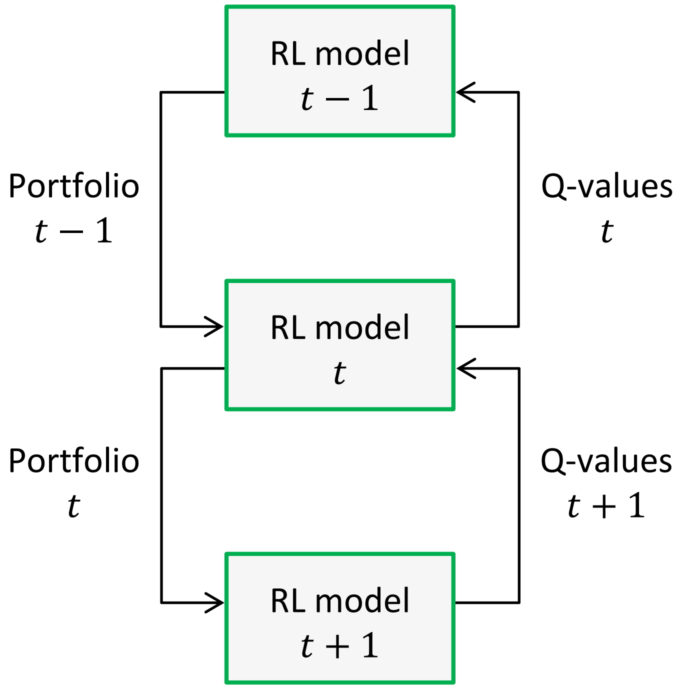
- Monthly
- Weekly (ends of quarters)
- Daily (near weekends and public holidays)

# Looking for right pricing with deep deterministic policy gradient

Base reinforcement learning model architecture




Stacking of base models through time




- Exploration process is done according to a truncated normal distribution with shrinking variance

# An example of corporate deposits pricing

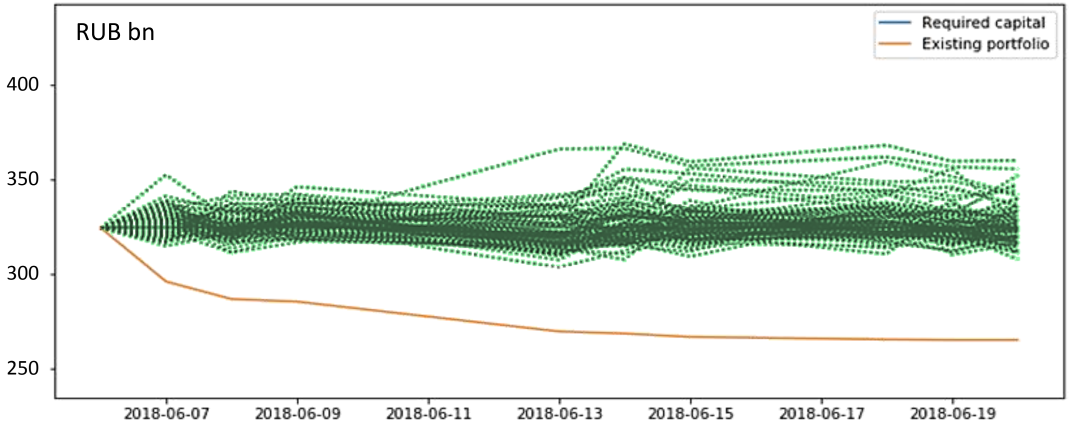
- Lets consider the problem of pricing short-term ruble-denominated large corporate client deposits on a daily basis
- Terms of new deposits are split into 6 buckets of roughly same size for simplification
- What should be interest rate curve as of the pricing date (7th June 2018) given the expected liquidity requirements of the bank?
- What is expected portfolio volume and structure given this pricing?

Term buckets of deposits

| | |
|---|---|
| 1D | 1 day |
| 1W | 2 days – 1 week |
| 2W | 1 week – 2 weeks |
| 1M | 2 weeks – 1 month |
| 2M | 1 month – 2 months |
| 3M | 2 months – 3 months |

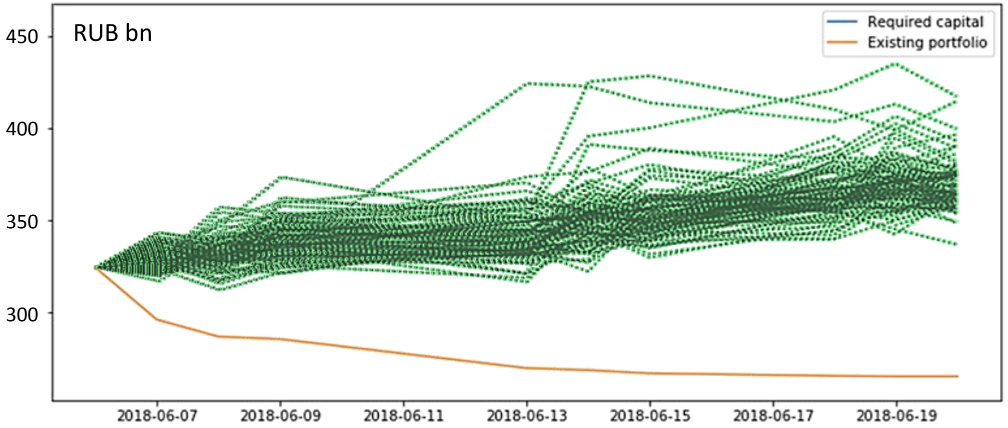
Goal → maintain the same portfolio volume during 2 weeks

Simulated portfolio volumes under optimal pricing policy




Goal → raise new funding of 50 RUB bn during 2 weeks

Simulated portfolio volumes under optimal pricing policy



## Conclusion

Key takeaways from the presented method:

- Approaching pricing of deposits as an optimal control problem lets simultaneously answer two questions: «what is the right pricing policy?» and «what is expected portfolio dynamics under this pricing policy?»

- Even though daily deposits addition volumes may have significant component of unpredictability, optimal control can absorb unexpected fluctuations by adjusting next day’s interest rate curve

    - This fact makes an impact on today’s pricing as optimal control can reduce portfolio variance

- Calculation of new pricing trajectories happens instantaneously, as the reinforcement learning model has already learnt optimal policies for various liquidity requirements

- The implemented model can also calculate expected financial result based on the actually observed portfolio trajectory so far