



Les truites saumonées

Complex Social Systems: Final Project
06. December, 2021, Zürich

Learning to Trade: Examining Agent Behaviour in Markets

TABLE OF CONTENTS

01

BACKGROUND & RESEARCH QUESTION

Idea & main goal of the model

02

RL & Q-LEARNING

How to train the agents in the market environment

03

MARKET SYSTEM

How the market is structured

04

TESTING PARAMETERS & FINDINGS

The effect of parameters on the agent's behaviour

05

CONCLUSIONS & NEXT STEPS

Les truites saumonées



Our Team Name

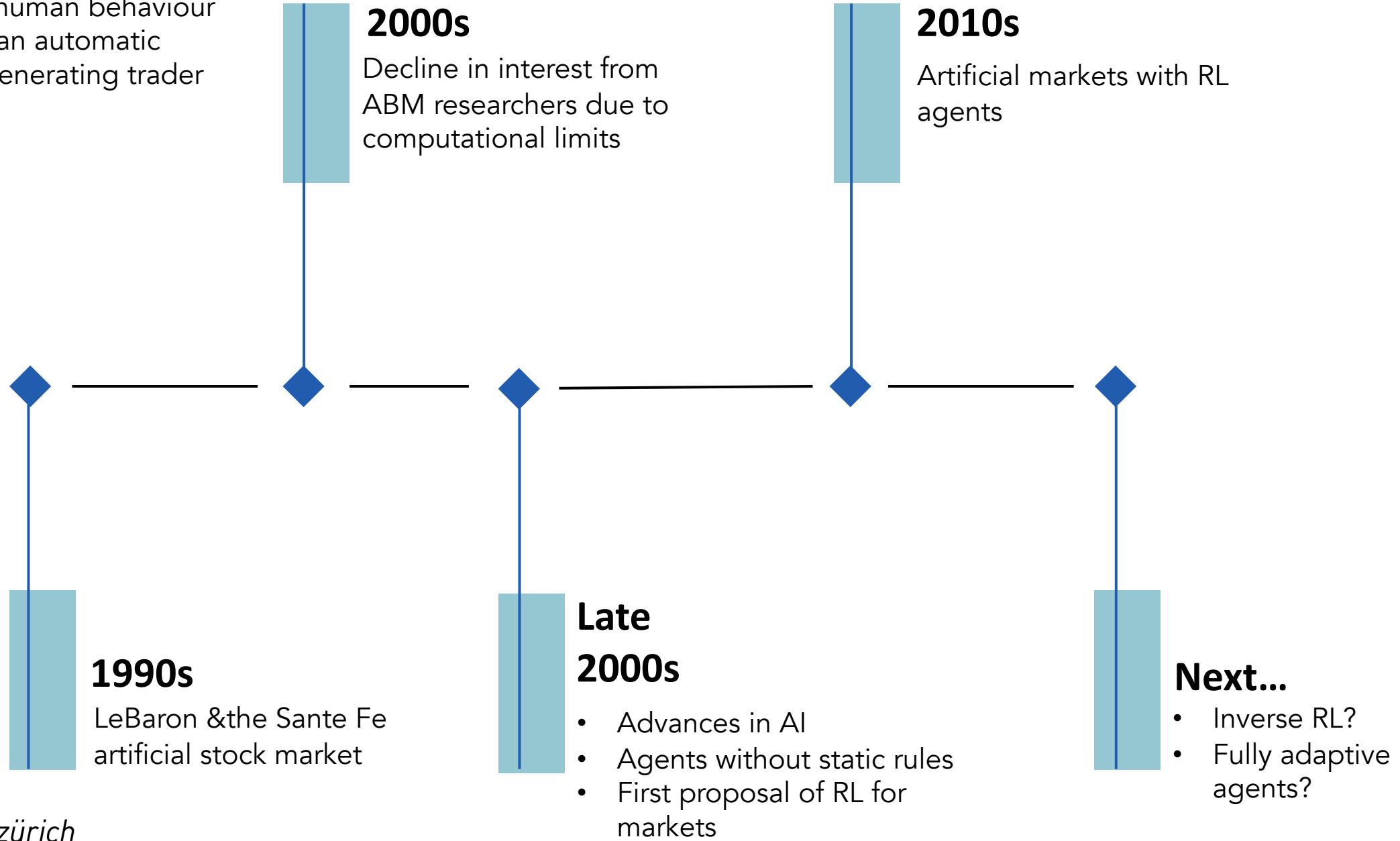
- A tribute to a Schubert lied – *Die Forelle*
- Trouts are strong – swim against the current



General Interest to:

- Model human behaviour
- Create an automatic profit-generating trader

Timeline of Artificial Markets



Our Research Goal

Create an agent-based representation of a market

AND

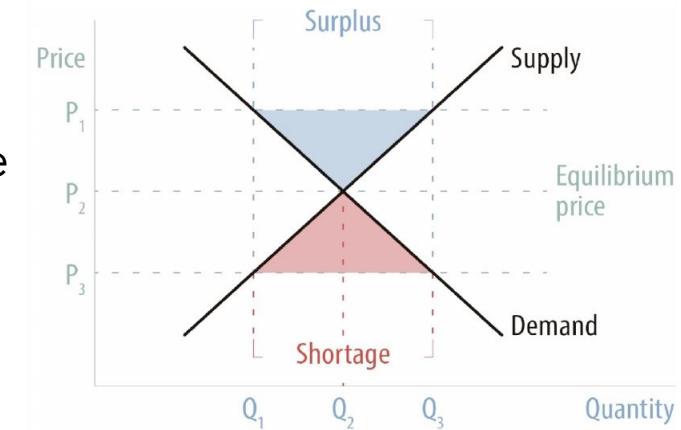
Determine the most important parameters that affect it



How should we approach this?

Approach 1

- Need 2 agents: seller & buyer
- Give each agent a supply (for sellers) or demand (for buyers) curve
- Seller tried to sell as many as possible at a set price
- Buyers try to buy as many goods at that price



Problem with Approach 1

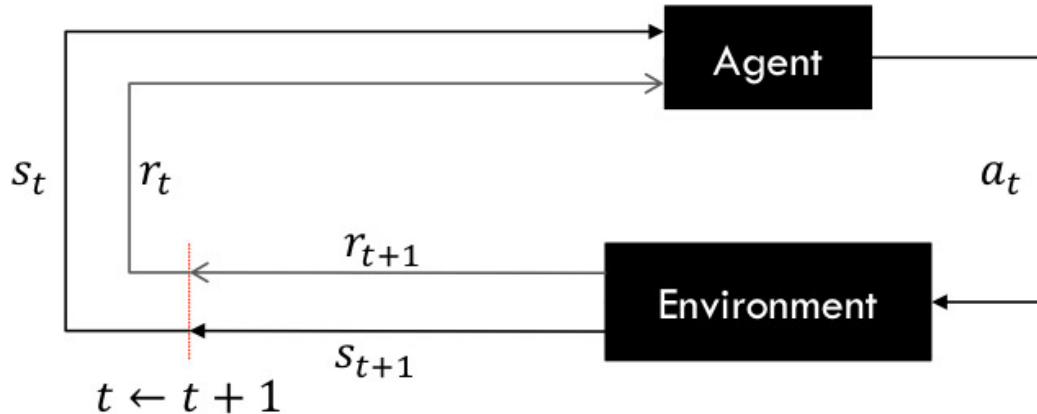
- Lacks intelligence
- Agents buy and sell at random (just depends on the curve we set for them)
- Even over 1000s of rounds → did not learn from past “mistakes”

How should we approach this? 2.0

LO
1

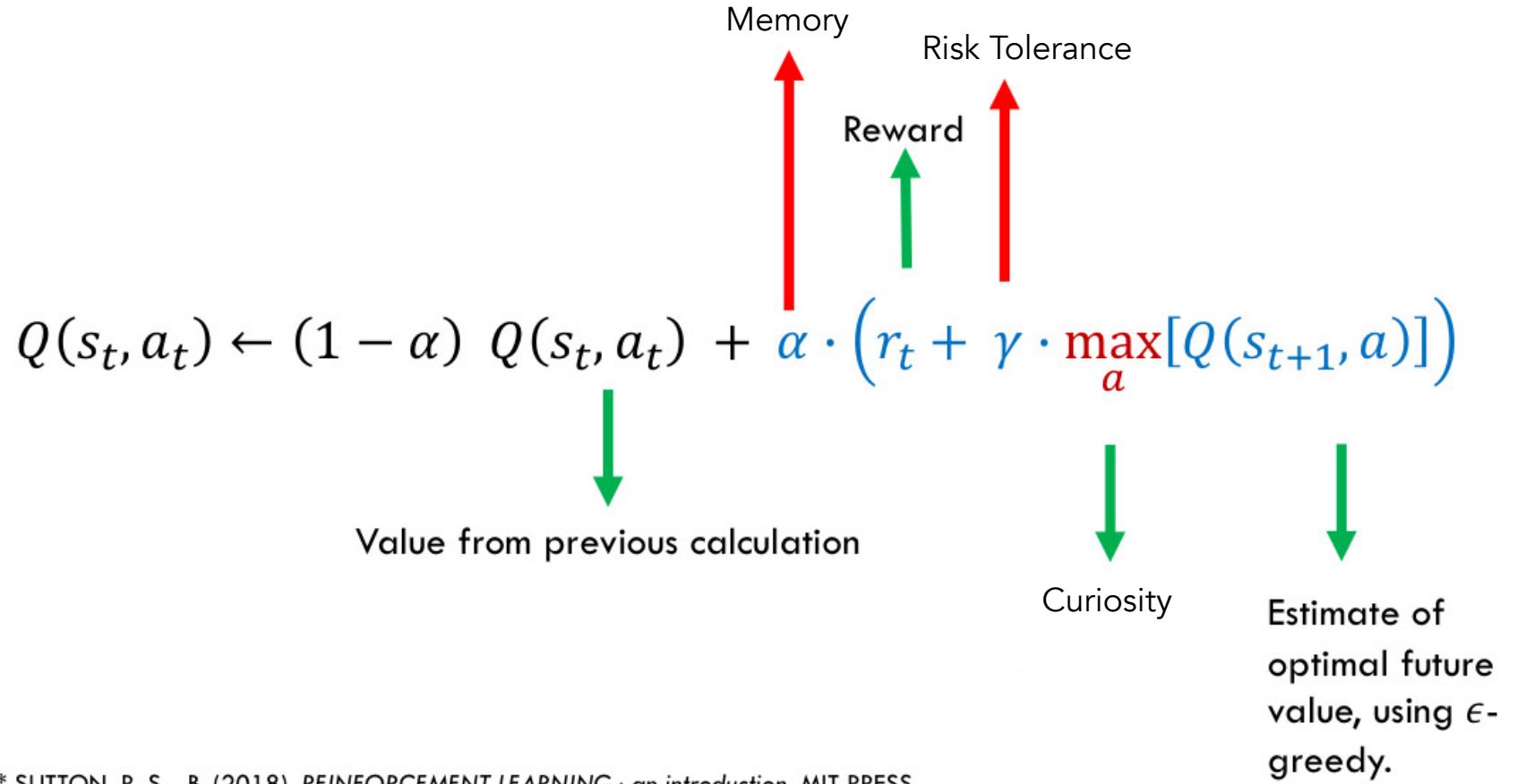
Approach 2

- Model agents in the market as a Markov Decision Process?
- Agent takes action a_t based on observing state S
- Rewarded based on consequence of action



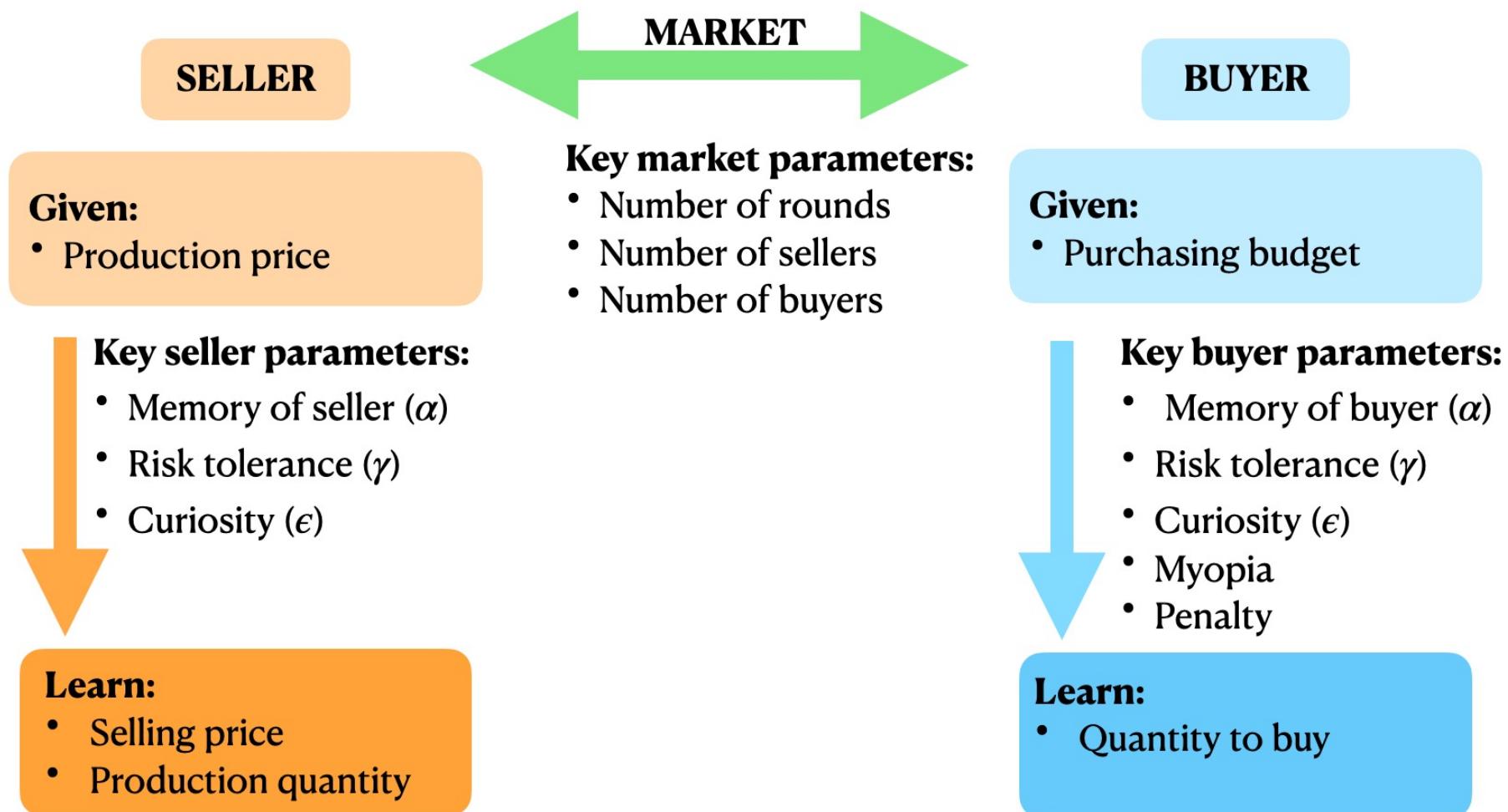
s_1
 s_2
·
·
·
 s_T Terminal or Goal State

Reinforcement Learning & Q-Learning



* SUTTON, R. S. . B. (2018). REINFORCEMENT LEARNING : an introduction. MIT PRESS.
Ch.6 Temporal Difference Learning, p.131

Reinforcement Learning & Q-Learning



Reinforcement Learning & Q-Learning

Q-table structure

Sellers

- Only one state
- Two actions, price and quantity

		Actions		
States		Price x1, quantity y1	Price x2, quantity y2	...
<i>Market state</i>	Q(x1, y1)	Q(x2, y2)	...	

Reinforcement Learning & Q-Learning

Q-table structure

Buyers

- Two indexes for state – budget left and price offered
- One action - how much to buy

States	Actions		
	Buy 1	Buy 2	...
Budget b1, offer o1	$Q((b1, o1), 1)$	$Q((b1, o1), 2)$...
Budget b2, offer o2	$Q((b2, o2), 1)$	$Q((b2, o2), 2)$...
...

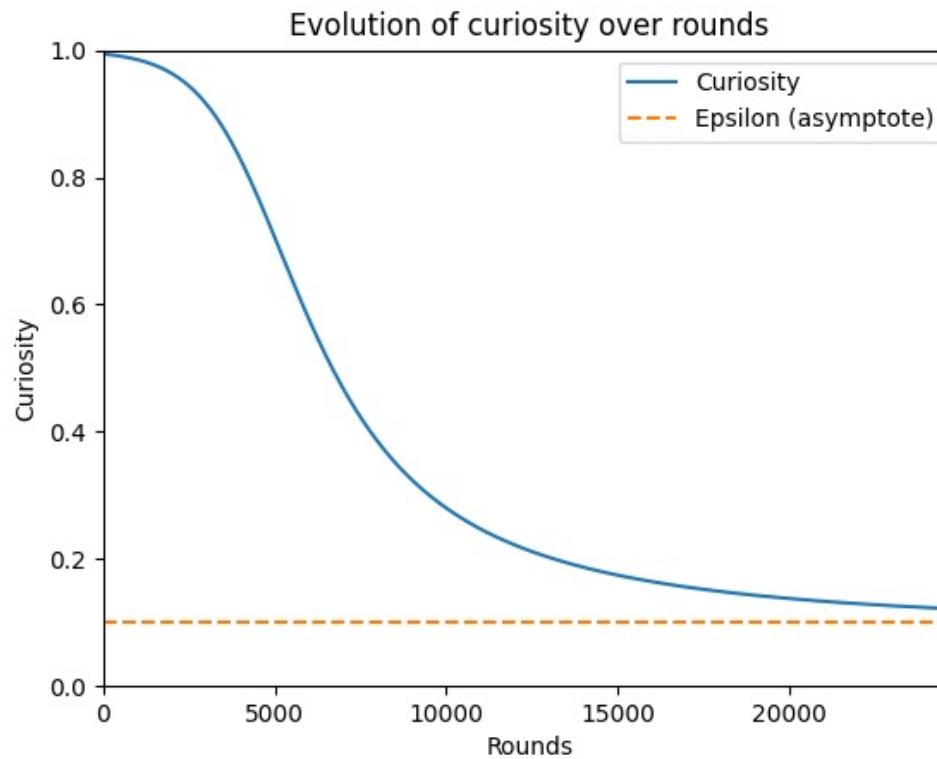
Reinforcement Learning & Q-Learning

Balancing exploration/exploitation

20

Sigmoid-like function

$$f_\lambda(x) = f(\lambda x) = \frac{1}{1 + e^{-\lambda x}}$$



Reinforcement Learning & Q-Learning

Q-values

Sellers

$$P_{seller} = n_{sell} \cdot p_{sell} - n_{prod} \cdot p_{prod}$$

$$R_{seller} = P_{seller}$$

Buyer

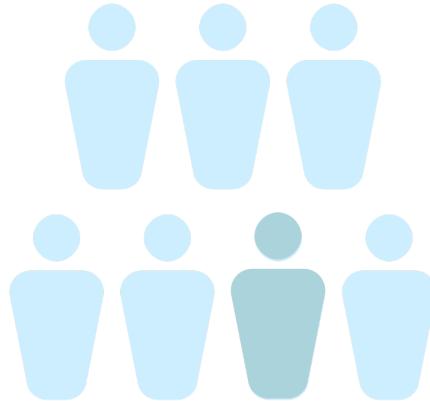
$$R_{buyer} = (1 - m) \cdot r_{local} + m \cdot r_{global}$$

$$r_{local} = n_{bought \ from \ seller} - \mu \cdot b_{left \ after \ interaction}$$

$$r_{global} = n_{bought \ after \ this \ seller} - \mu \cdot b_{left \ after \ round}$$

Market System

1. Shuffle buyers randomly



2. For each buyer select a random number of sellers



4. Get how much the buyer wants to buy (based on Q-table learning)

5. If buyer wants to buy → make seller sell

6. Buyer learn after each transaction

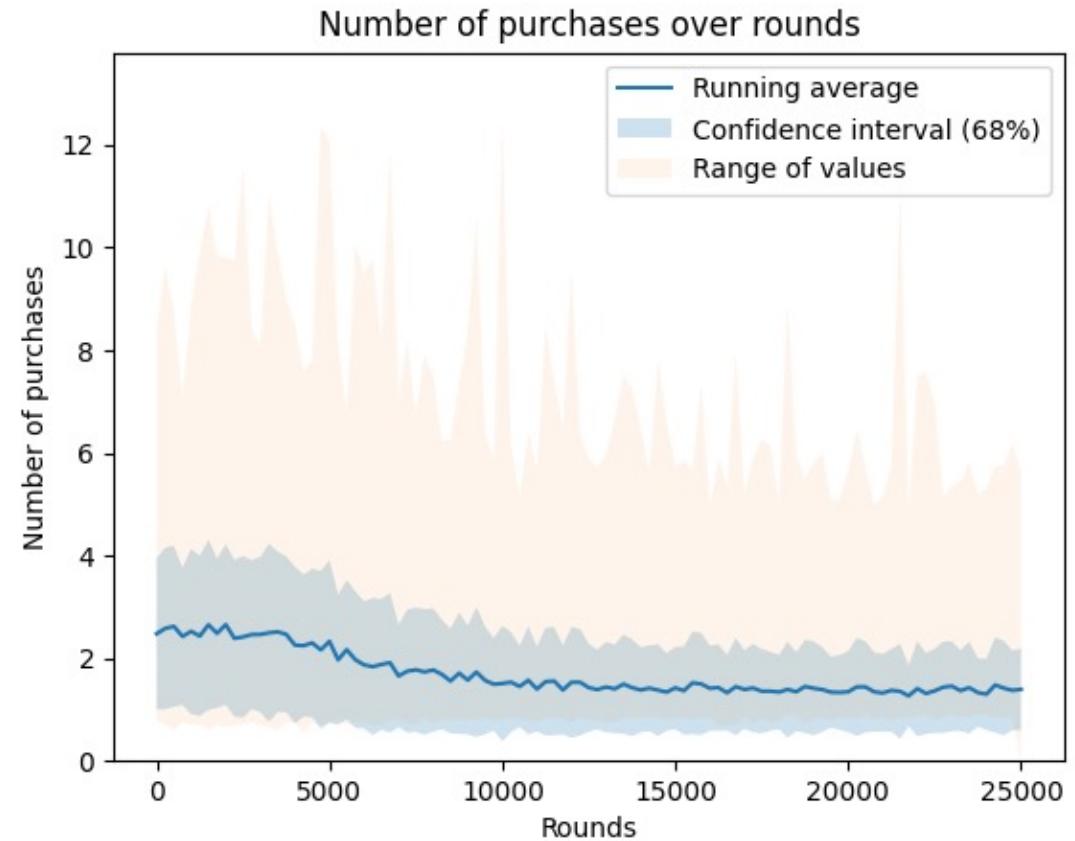
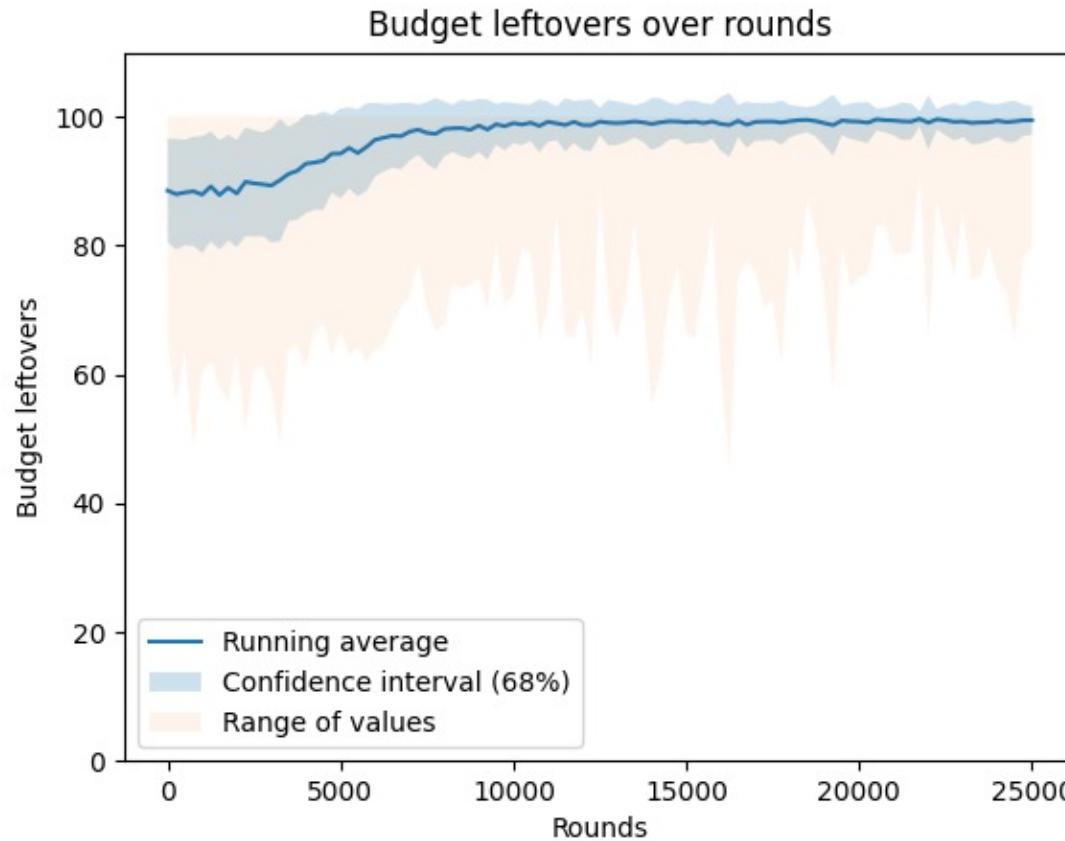
Seller learns after interacting with every buyer they'll see

Parameter Testing and Findings

- Baseline parameters first established with preliminary exploration
- Distinctive evolution of all metrics
- Most parameters only altered the scale, not the evolution

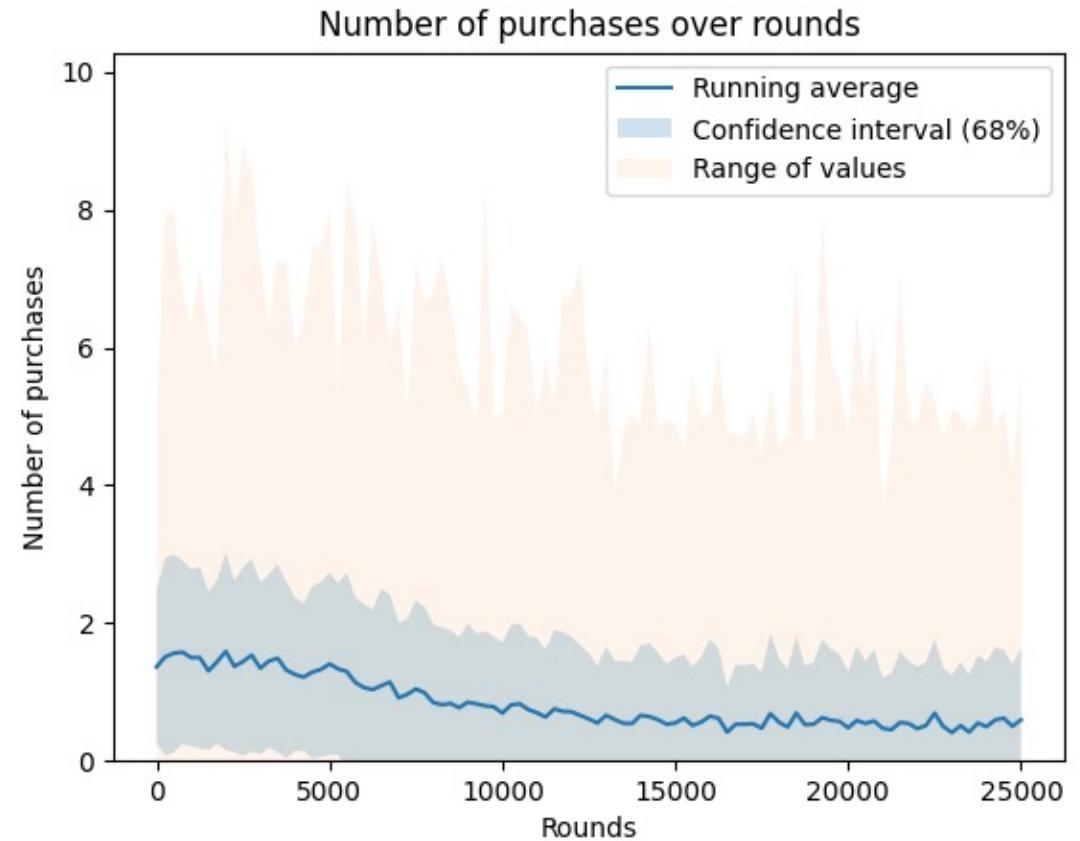
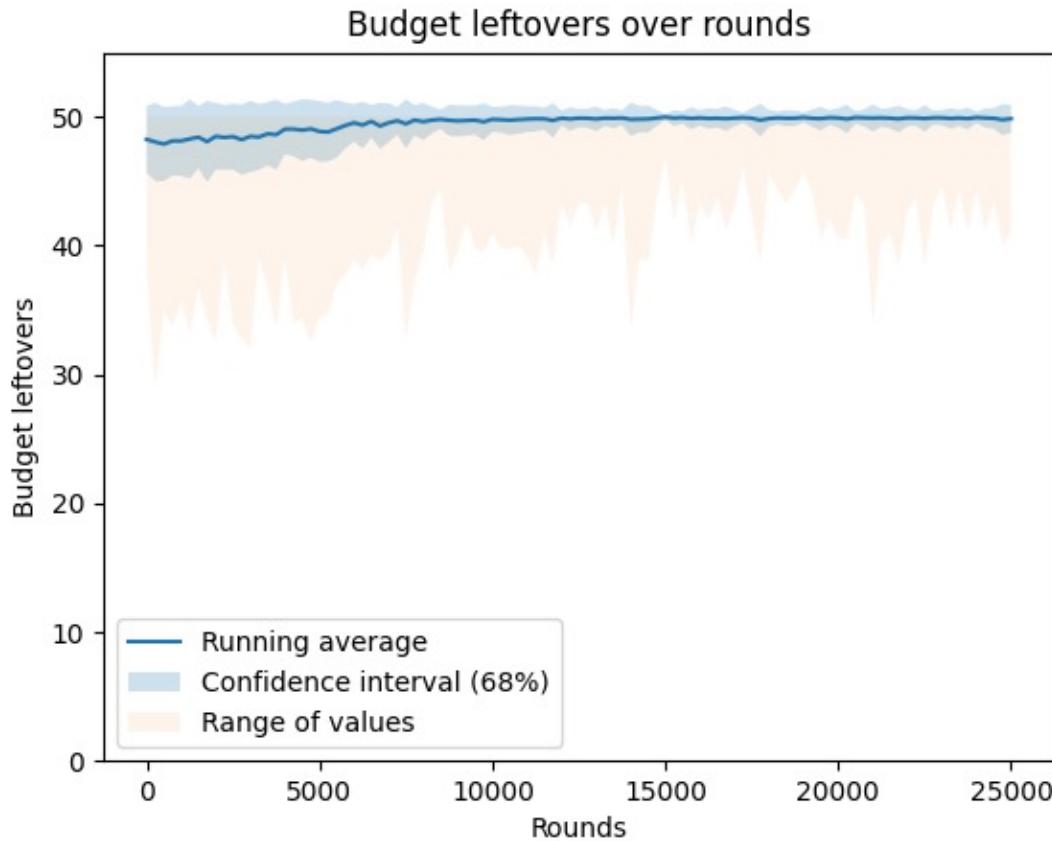
Parameter Testing and Findings

Baseline – Buyers' metrics



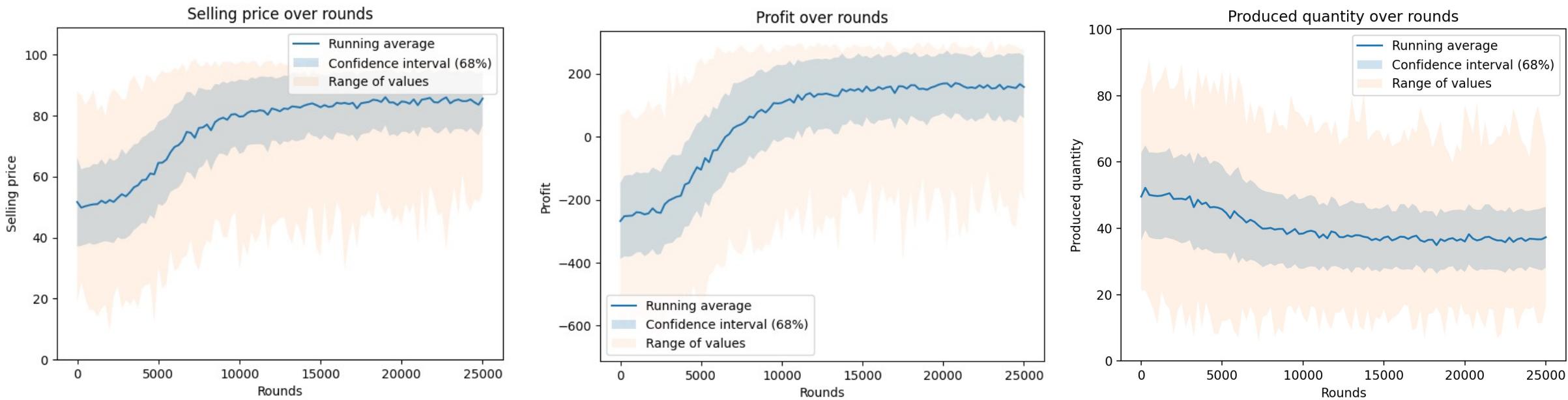
Parameter Testing and Findings

Low budget for Buyers – Buyers' metrics



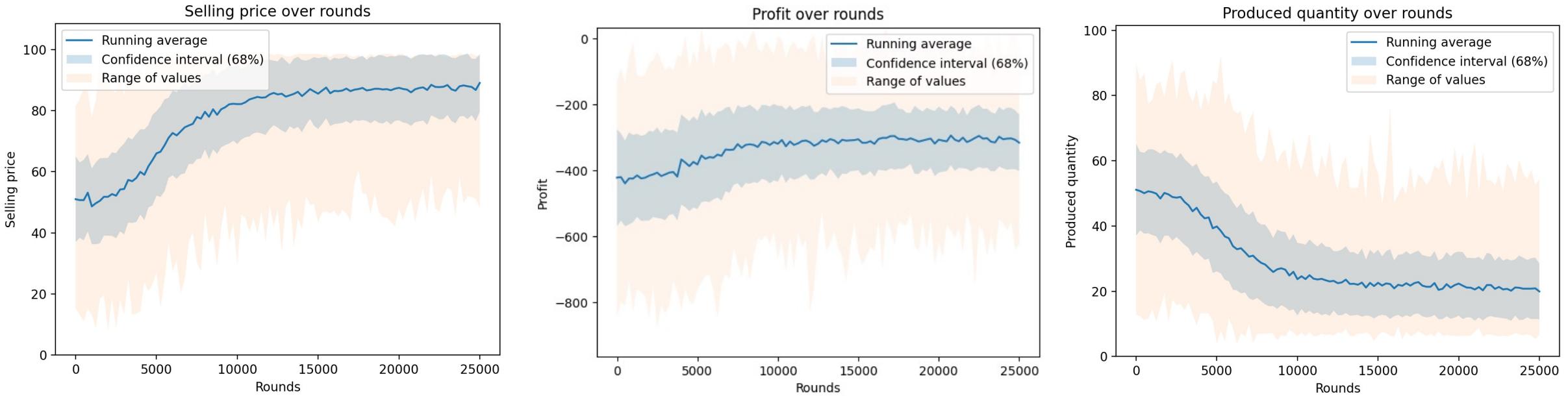
Parameter Testing and Findings

Baseline – Sellers' metrics



Parameter Testing and Findings

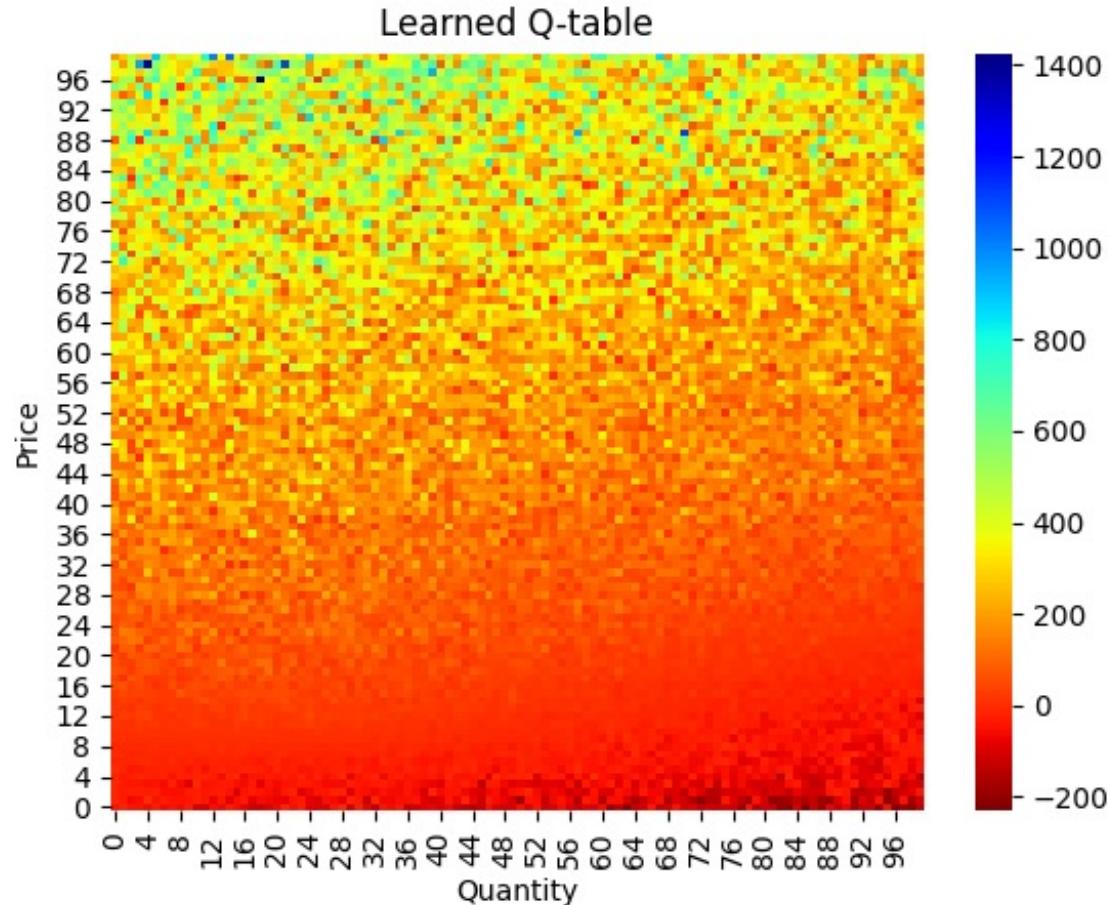
Low budget for buyers – Sellers' metrics



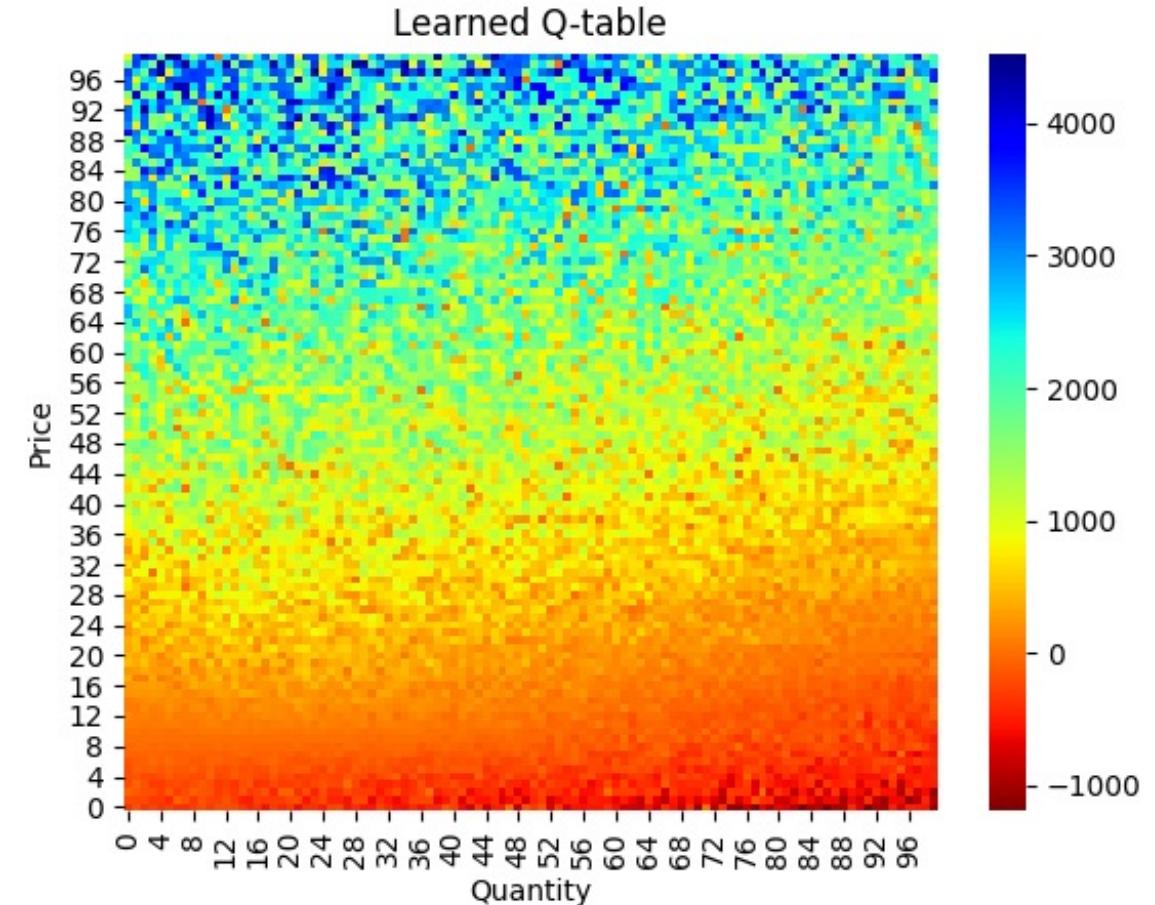
Parameter Testing and Findings

Sellers' Q-table

Baseline

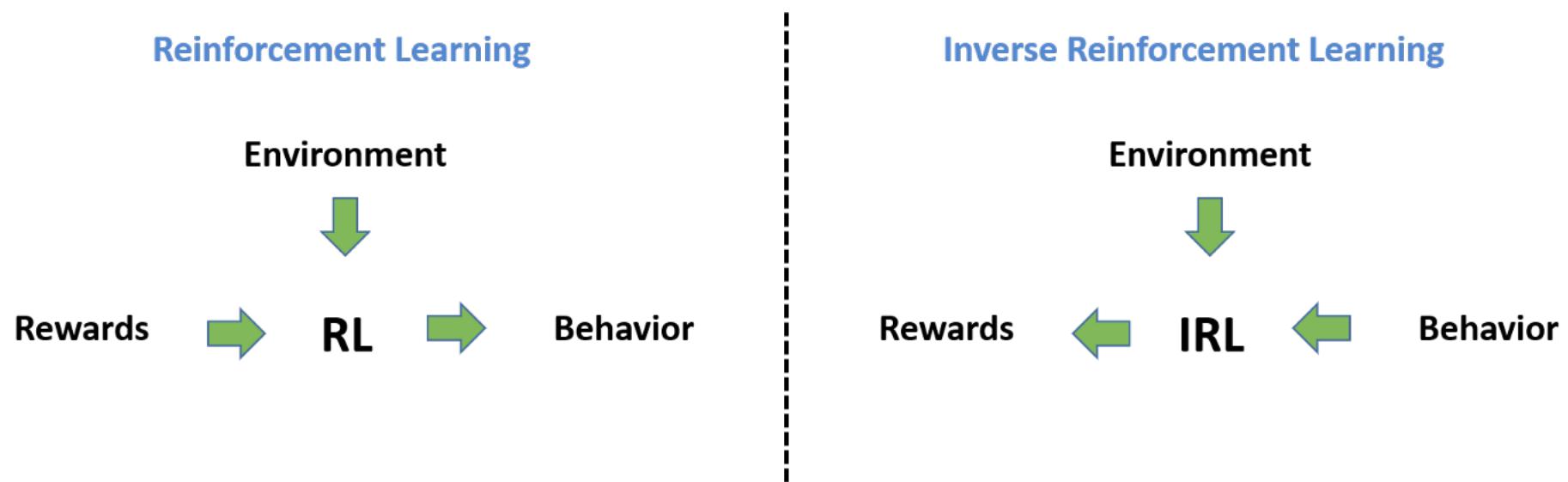


High memory



Next Steps

- Danger of reward-maximizing systems – lack control over what they will do to reach the reward
- Instead, try Inverse Reinforcement Learning (IRL) – Infer the reward based on demonstrated desirable behavior



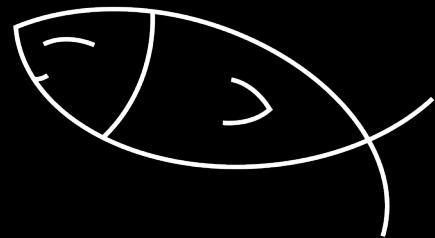
Thank you for your attention!

Les truites saumonées

Florian Abeillon

Sverrir Arnórsson

Yilin Huang



Appendix: Market System

Shuffle the buyer order to consider them in a random order;

foreach *buyer* **do**

 Select a random number of sellers k so that $k \in \{1, \dots, n_{\text{sellers}}\}$;

foreach *selected seller* **do**

 Get price and quantity from seller;

 Get how much the buyer wants to buy, based on Q-table with

$p = 1 - \epsilon$ or at random with $p = \epsilon^a$;

if *buyer wants to buy something* **then**

 | Make seller sell

end

 Make buyer learn based on transactions

end

end

Make all sellers learn

Algorithm 1: Market interaction and agent learning process

Appendix: Seller, Buyer baseline values

Table 1: Seller baseline parameter values

Parameter	Value
Range of possible selling prices	[1,100]
Range of possible production quantities	[1,100]
Seller production price	10
Memory (α)	0.1
Risk tolerance (γ)	0.5
Curiosity (ϵ)	0.2

Table 2: Buyer baseline parameter values

Parameter	Value
Range of possible budget allocations	[1,100]
Initial budget	100
Memory (α)	0.1
Risk tolerance (γ)	0.2
Curiosity (ϵ)	0.1
Myopia (Short-sightedness) factor	0.2
Penalty for having budget remaining	0.5

Appendix: Effect of Parameters on Sellers

Table 3: Effect of altering the sellers' parameters

Parameter	General effect
Production Price	
High	Fewer purchases, less production, extremely high losses, Q-table slanted with positive in top-left, low in bottom-right, lower prices
Low	Higher profits, production quantity stagnant
Memory	
High	Negligible difference
Low	Q-table near zero, a bit higher quantities produced, otherwise negligible difference
Risk Tolerance	
High	Slightly lower profits, lower prices, and higher quantities
Low	Lower prices, similar profits,
Curiosity	
High	Significant difference: more purchases, lower prices, fewer quantities produced, more positive Q-table scores
Low	Lower profits, higher quantities produced

Appendix: Effect of Parameters on Buyers

Table 4: Effect of altering the buyers' parameters

Parameter	General effect
Budget	
High	Baseline model
Low	Fewer purchases, lower sales prices, less budget left, more negative Q-table scores, higher quantities produced, fewer sold quantities
Memory	
High	More variance in budget left for buyers, less quantity produced, lower profits, same quantities produced, lower selling prices
Low	More variance in budget left for buyers (but not as much of a difference as with high memory)
Risk tolerance	
High	Lower prices, slightly different profits
Low	Lower profits, higher prices, same prices
Curiosity	
High	Negligible, slightly higher lower profits
Low	Slightly higher quantities produced
Myopia	
High	Lower selling prices, substantially lower profits, quantity produced does not change
Low	Slightly lower profits (but not as much as with high myopia), higher quantities produced, slightly less sold quantity
Penalty	
High	Higher quantities produced, lower profits, slightly less sold quantity
Low	Fewer purchases, lower prices, lower profits, production quantity stagnant, very little sales overall

Appendix: Effect of General Parameters

Table 5: Effect of altering the general parameters on the seller's and buyer's actions

General parameters	
Number of sellers	
High	Less budget left over, sellers run at a loss, q-table is over a smaller range, selling price is higher, each seller sells fewer products
Low	Unreliable, values vary too much
Number of buyers	
High	Higher quantities, higher prices, higher profits
Low	Less budget left over, less profit, lower prices

Hier steht der Folientitel

Zwischenüberschrift (optional)

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex.

Hier steht der Folientitel

Zwischenüberschrift (optional)

Lorem ipsum dolor sit amet¹, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation² ullamco laboris nisi ut aliquip ex ea commodo equat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat³ non proident, sunt in culpa qui officia deserunt mollit anim id est laborum. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex.

1. Fussnote. Lorem ipsum dolor sit amet, consectetur adipiscing elit.
Ed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam quis
2. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu nulla pariatur.
Excepteur sint occaecat cupidatat eiusmod tempor incididunt ut labore.
3. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur.

Zwischenüberschrift (optional)

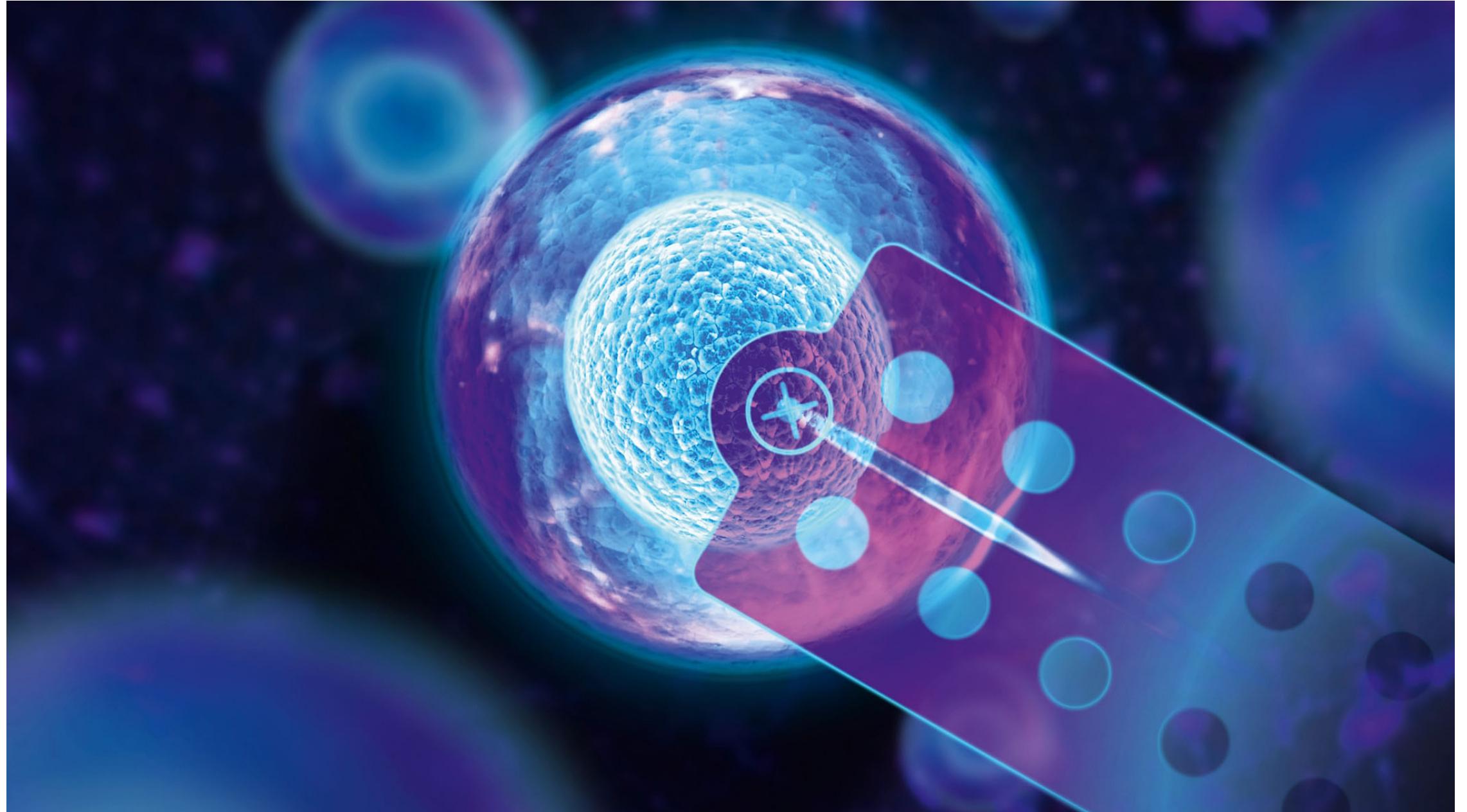
- Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation.
- Ullamco laboris nisi ut aliquip ex ea commodo equat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident.
- Sunt in culpa qui officia deserunt mollit anim id est laborum. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex in reprehenderit in voluptate velit esse cillum

Zwischenüberschrift (optional)

- Lorem ipsum dolor sit amet, consectetur adipis.
 - Lorem ipsum dolor sit amet, consectetur nostrud.
 - Tempor incididunt incididunt ut labore et dolore magna aliqua.
Ut enim ad minim veniam, quis nostrud exercitation.
- Lorem ipsum dolor sit amet, consectetur adipis.
 - Ut enim ad minim veniam, quis nostrud exercitation.
 - Tempor incididunt incididunt ut labore.
- Lorem ipsum dolor sit amet, consectetur adipis.
 - Tempor incididunt incididunt ut labore et dolore magna veniam.
Ut enim ad minim veniam, quis nostrud exercitation.
 - Lorem ipsum dolor sit amet, consectetur nostrud.

Hier steht der Folientitel,
ggf. auch über zwei Zeilen





Hier steht der Folientitel



- Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo equat.
- Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo equat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore.
- Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex.

Hier steht der Folientitel



Kombination Bild und Text

Lauftext. Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor.

Hier steht der Folientitel, ggf. auch über zwei Zeilen



Kombination Bild und Text

Lauftext. Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation

Hier steht der Folientitel

Titel der Tabelle

Spaltenüberschrift	2021	2020	2019	2018
Lorem ipsum dolor	1606	1678	2072	2196
Excepteur sint occaecat	373	281	381	410
Ut enim ad minim veniam	537	607	733	786
Nostrud exercitation	365	425	506	559
Consectetur adipiscing elit	318	349	355	359
Nim ad minim veniam	13	16	97	82

Prof. Dr. Beat Muster
Funktion des Präsentierenden
beat.muster@abcd.ethz.ch

ETH Zürich
Organisationseinheit
Strasse Hausnummer
0000 Ort

www.abcd.ethz.ch