



Simulating the Adoption of a rCBDC

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About FNA

FNA is a leader in advanced network analytics and simulation.

FNA's software is used to uncover hidden connections and anomalies in large, complex datasets, to predict the impact of stress events, and to optimally configure financial systems and infrastructures.

FNA is trusted by the world's largest central banks, government authorities, commercial banks and financial infrastructures.



Monetary Authority
of Singapore



US Department
of Defense



Payments Canada



Hong Kong
Monetary Authority



The World
Bank



CLS Group



RTGS.global



ICE Clear
Credit



The Clearing
House



Bank for International
Settlements



Giesecke +
Devrient



UK Finance



Banco de la
República-Colombia



Fnality



Bank of England

About today

- Main takeaways
- Why should central banks simulate rCBDC?
- Agent-based simulation of rCBDC adoption
- rCBDC Spanish market adoption
- Further work



Main Takeaways





Main takeaways

- Simulating rCBDC adoption can help central banks to iterate design options.
- Without attractive design features or stimulus policies, we found low adoption of rCBDC.
- Reverse waterfall functionality, government payments, and positive remuneration spread can increase rCBDC adoption.
- Balance limits, top-up limits effective to restrain rCBDC adoption.
- In general, rCBDC won't compete with cash but with deposit-related payment instruments—unless the government fosters targeted use of rCBDC

| Why should central banks simulate rCBDC?



CBDC - Many Stakeholders with Many Interrelated Concerns

100+ countries are exploring CBDC, of which 26 are in development, and 15 are making pilots*

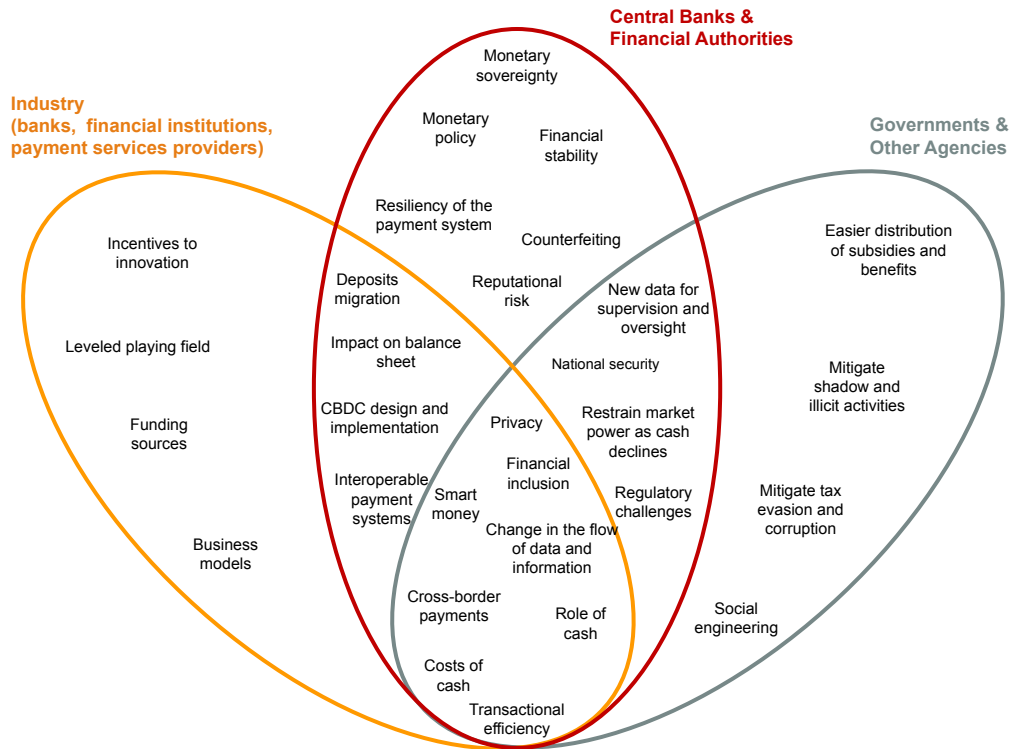
What model are we looking for?

A model of selected macro-financial effects from deploying a CBDC

A parsimonious and tractable model that enables scenario analysis

A modular, flexible and extendable modelling approach

To add new features and answer new questions opportunistically



Our Goals

Shed light on crucial macro-financial and payments questions

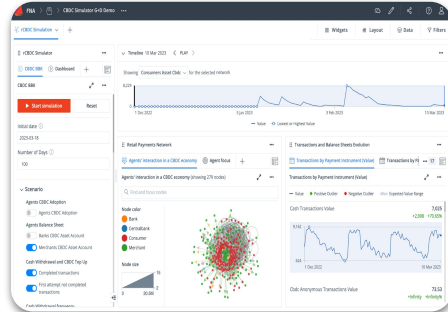
Measure the impact on the economy, financial system and payment ecosystem

Analyse and substantiate the design of CBDCs

Encourage research on CBDC

(*) Sources: Atlantic Council (<https://www.atlanticcouncil.org/cbdctracker/>) and CBDC Tracker (<https://cbdctracker.org>)

Learning by simulation - rCBDC simulation is the key to modelling the impact of CBDC introduction on the economy and the payment ecosystem



Design | Validate | Optimize



Learning by doing and simulation with FNA's out-of-box **maximum virtual product** to reduce rCBDC project risk and accelerate the time to value



It enables **effective communication** and **shared understanding** among stakeholders by **visualising insights** through **interactive** user interfaces



It allows central banks and market participants to **design a safe and efficient CBDC** by testing **multiple policy** inputs and **tailored CBDC** configurations



Learning by doing and simulation



Substantiates qualitative analysis with quantitative insights



Is modular - and configurable for specific features of each jurisdiction



Is data agnostic - and configurable on publicly available and proprietary data



Is technology agnostic - and compatible with any infrastructure underpinning a CBDC



Provides value beyond the design phase - and crucial for continuous monitoring and stress testing

Agent-based simulation of rCBDC adoption



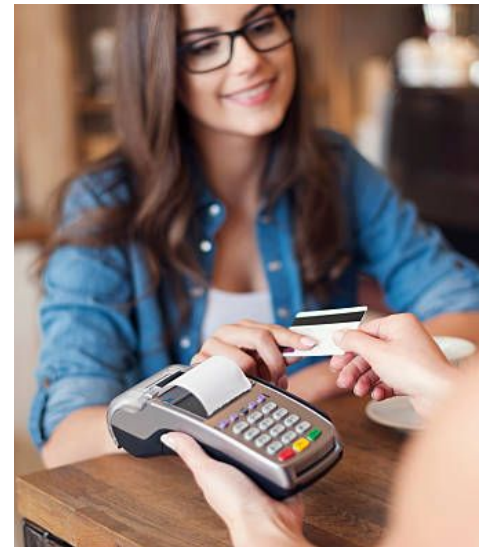
Anything in common?



Forest fires



Ants



Retail payments

Yes. To understand them, it is better to simulate.

Anything in common?



Yes. They are complex adaptive systems.

Forest fires



Ants



Retail payments



- Large number of individuals (i.e., agents)...
- That interact and adapt or learn...
- With the **emergent (aggregate) behavior** neither explained nor predicted by individual behavior...
- Which commonly show several features, such as
 - **Path dependence** (i.e., particularly sensitive to changes in initial conditions)
 - **Non-linearity** (i.e., size of input change is unrelated to size of output change)
 - **Self-organization** (i.e., without an authority, the system tends to organize)
 - May display **phase transitions** (i.e. tipping points)
 - Do not operate under equilibrium

This is why top-down approaches are not very helpful to understand the adoption of an rCBDC—or other type of digital currency.

(*) In bold, this is the definition of Holland (2006)

Anything in common?

Forest fires



Ants



Retail payments



One good way to model them is Agent Based Models (ABM).

They comply with the four key assumptions of ABM:

- **Each agent is autonomous:** no central agent organizes the system top-down (i.e., self-organization)
- **Agents are interdependent:** agents are influenced by other agents and by the environment
- **Agents follow simple rules:** simple behavior by the agents leads to non-simple emergent behavior
- **Agents are adaptive and backward-looking:** agents adapt by learning from their history



Agent-Based Models in Money & Banking

Congestion and Cascades in Payment Systems
Walter F. Beyeler, Robert J. Glass, Morten Bech, and Kimmo Soramäki
October 2006, Bank of New York Staff Reports, no. 203
September 2006
JEL classification: C61, G20

Abstract

We develop a parsimonious model of the interbank payment system to study congestion and the role of liquidity markets in alleviating congestion. The model incorporates an endogenous interbank market for liquidity, with free supply of payments between banks, but limited liquidity for the banks' capacity to process incoming payments, and a global market for interbank liquidity. We find that, in the liquidity, the system between agents and payments is efficient. Each participant will process as much as it can, increasing liquidity across the network. The cost of congestion is relatively small in the early stages of the system. The time for banks to process payments is not a binding constraint in the early stages of the system. The time for banks to process payments is not a binding constraint in the early stages of the system.

Key words: networks, topology, interbank, payment, money market, liquidity model, congestion

Published on 12 August 2008

Working Paper No. 352
By Marco Galbiati and Kimmo Soramäki

This paper lays out and simulates a multi-agent, multi-period model of an RTGS payment system. At the beginning of the day, banks choose how much costly liquidity to allocate to the settlement process. Then, they use it to execute an exogenous, random stream of payment orders. If a bank's liquidity stock is depleted, payments are queued until new liquidity arrives from other banks, imposing costs on the delaying bank. The paper studies the equilibrium level of liquidity posted in the system, performing some comparative statics and obtaining a liquidity demand curve which links liquidity to delay costs and to insights on the efficiency of alternative system configurations.

An agent-based model of payment systems

BANK OF ENGLAND

No. 686 - Exploring agent-based methods for the analysis of payment systems: A cross model for Eurozone TMS



This paper presents an exploratory agent-based model of the Eurozone payment system (RTGS) payment system. Banks are represented as agents who manage their liquidity stocks and execute payment orders. The model is designed to explore the role of liquidity markets in the payment system. The model is designed to explore the role of liquidity markets in the payment system. The model is designed to explore the role of liquidity markets in the payment system.

BANK OF ENGLAND

Staff Working Paper No. 619
Macprudential policy in an agent-based model of the UK housing market
Rafa Baptista, J Doyne Farmer, Marc Hinterschweiger, Katie Low, Daniel Tang and Arzu Uluc

October 2016



Working Paper Series

Grzegorz Hajaj
Agent-based model of system-wide implications of funding risk

BANK OF ENGLAND

Staff Working Paper No. 809
System-wide stress simulation
David Aikman,¹ Pavel Chichkanov,² Graeme Douglas,³ Yordan Georgiev,⁴ James Howat,⁵ and Benjamin King⁶

Abstract

We present a model for assessing the risk of the UK system of market-based finance – an increasingly important source of credit to the real economy since the financial crisis – night before under stress. The core of the model is a set of representative agents, which interact to give rise to the UK financial system. These agents interact in asset, funding, and derivatives markets and face a range of economy and liquidity constraints on their behaviour. Our model generates 1000 periods, each of which are large, as if the system were to experience a small, lower asset prices can cause solvency/liquidity constraints to bind, resulting in forced deleveraging and large endogenous liquidity pressure. We illustrate such an outcome via a stress scenario in which a deteriorating corporate sector is offset by losses on commercial banks, investment funds and life insurers in dropping their dynamics.

Key words: Systemic risk, market-based finance, fire sales, stress testing

JEL classification: G20, G21, G22, G23

2006



Congestion and
Cascades in Payment
Systems
FRBNY
Walter Beyeler
Kimmo Soramäki
Robert Glass
Morten Bech

2008



An agent-based model
of payment systems
BoE
Marco Galbiati
Kimmo Soramäki

2008



Exploring ABM for the
analysis of payment
systems
Bol
Luca Arciero
Claudia Biancotti
Leandro D'Aurizio
Claudio Impenna

2016



Macprudential policy
in ABM of the UK
housing market
BoE
Rafa Baptista
J Doyne Farmer
Marc Hinterschweiger
Katie Low
Daniel Tang
Arzu Uluc

2018



ABM of system-wide
implications of funding
risk
ECB
Grzegorz Hajaj

2019



System-wide stress
simulation
BoE
David Aikman
Pavel Chichkanov
Graeme Douglas
Yordan Georgiev
James Howat
Benjamin King

Agent-Based Models in Money & Banking



Staff Working Paper No. 861
Foundations of system-wide financial stress testing
with heterogeneous institutions
J Doyne Farmer¹, Alissa M Kleinnijenhuis², Paul Nahai-Williamson³
and Thom Wetzlar⁴

Abstract
We propose a structural framework for the development of system-wide financial stress tests with multiple interacting components, capitalisation channels and heterogeneous financial institutions. This framework conceptualises financial systems through the lens of the leading banks' financial institutions, contracts, markets, customers, and behaviour.
Using this framework, we implement a system-wide stress test for the European financial system. We obtain three key findings. First, the financial system may be stable or unstable for a given macroprudential stress test outcome, depending on the system's shock and policy response. Second, the stability of bank capital buffers (the willingness of banks to absorb losses) is a key determinant of the system's response to system-wide stress. Third, there is a risk that the size of capital buffers expands and system-wide risk could be severely underestimated if captured in the absence of system-wide agencies.
Key words: Systemic risk, stress testing, financial contagion, financial institutions, capital requirements, macroprudential policy.

No. 1338 - Macroprudential policy analysis via an agent-based model of the real estate sector



by Gennaro Catapano, Francesco Franceschi, Michele Loberto and Valentina Michelangeli
June 2021
This paper studies the effects on the Italian residential property market of the hypothetical adoption of two borrower-based measures: an 80 percent loan-to-value (LTV) cap and a 30 percent loan-to-income (LTI) ratio cap. The analysis is conducted using an agent-based model that has been calibrated using machine learning algorithms.
In Italy, the adoption of LTV and LTI caps will likely lead to a modest and short-term reduction both in house prices and in the number of house sales. The reduction in mortgage defaults is also found to be relatively modest. These results reflect the high degree of financial soundness of Italian households and the already low LTV and LTI ratios in the Italian mortgage market.

Agent-Based Simulation of Central Bank Digital Currencies^{*}

Amanah Ramadiah¹, Marco Galbiati², and Kimmo Soramäki¹

¹ Financial Network Analytics Ltd
² S&P Global

November 9, 2021

UNIVERSITY OF TWENTE

Adoption and Implications of CBDC: An Agent-Based Modelling Approach

Thom Wetzlar, MSc Industrial Engineering & Management
(Financial Engineering Specialisation)

Menno Martens

Final report for the Master's Thesis of the University of Twente
Thom Wetzlar, MSc Industrial Engineering & Management
(Financial Engineering Specialisation)

September 2021

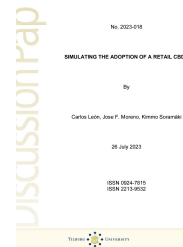
Abstract
We investigate the adoption and implications of a central bank digital currency (CBDC) in the Netherlands using a multi-agent simulation. The simulation is based on a stylised representation of the Dutch financial system, including households, banks, and the central bank. The simulation results show that the adoption of a CBDC is likely to be gradual and that it will have a significant impact on the financial system. The simulation also shows that the adoption of a CBDC is likely to be more successful if it is accompanied by a reduction in the cash supply and a corresponding increase in the digital supply.



To Demand or Not to Demand: On Quantifying the Future Appetite for CBDC

Marco Gross and Elisa Letizia
WP/23/5

IMF Working Paper describes research in progress. It is preliminary and subject to change. It is not intended for distribution outside the IMF. The views expressed are those of the authors and do not necessarily reflect those of the IMF. The paper is subject to external review and may be revised.



Simulating the Adoption of a Retail CBDC

by
Carlos León, José P. Moreno, Kimmo Soramäki

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2020



Foundations of system-wide financial stress testing with heterogeneous institutions
BoE

J Doyne Farmer
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Thom Wetzlar

2021



Macroprudential policy analysis via ABM of the real sector
Bol

Gennaro Catapano
Francesco Franceschi
Michele Loberto
Valentina Michelangeli

2021



Agent-Based Simulation of Central Bank Digital Currencies
FNA

Amanah Ramadiah
Marco Galbiati
Kimmo Soramäki

2021



Adoption and implications of CBDC: an agent-based modelling approach
U. of Twente

Menno Martens

2023



To demand or not to demand: On quantifying the future appetite for CBDC
IMF

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Elisa Letizia

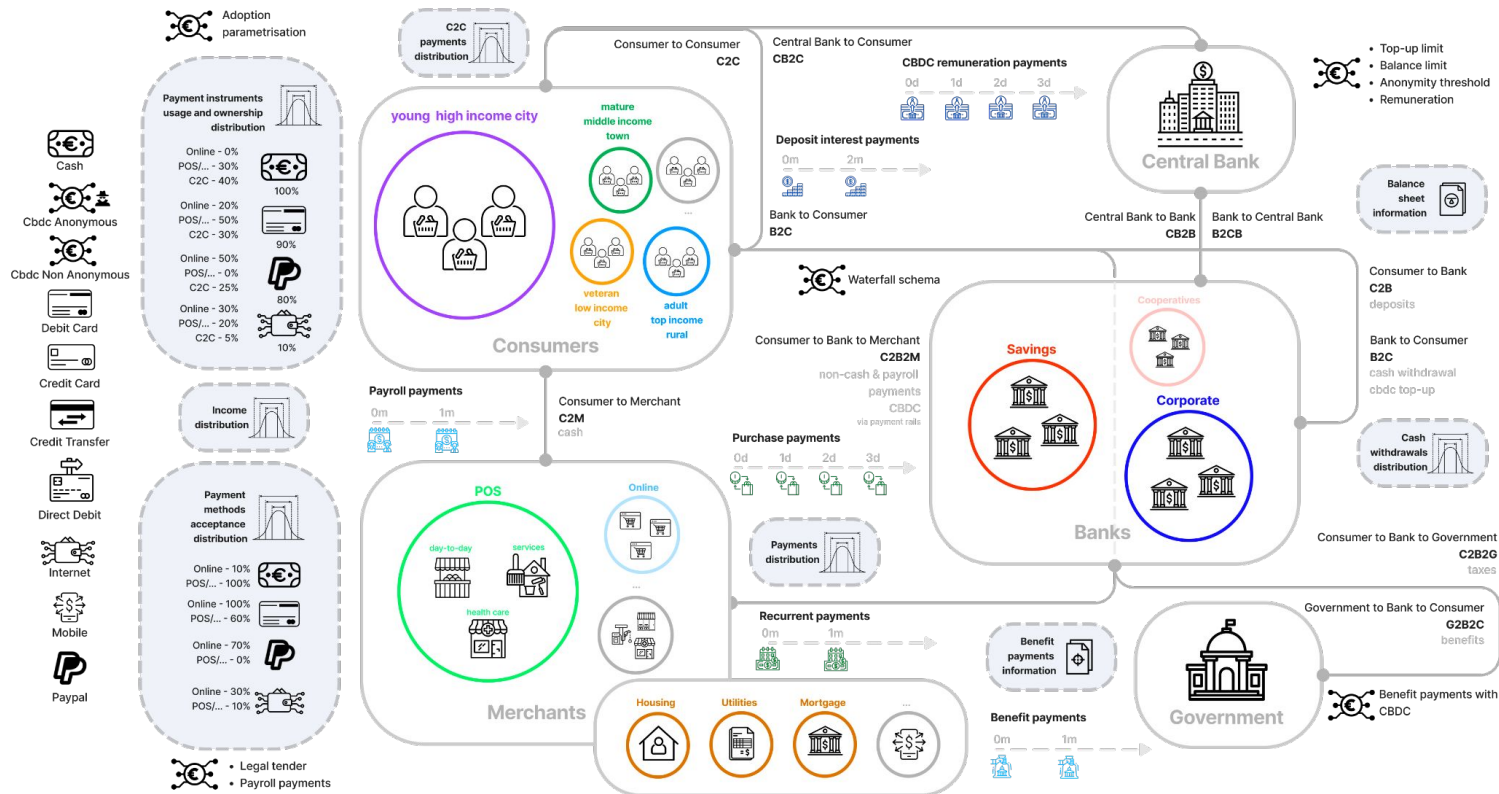
2023



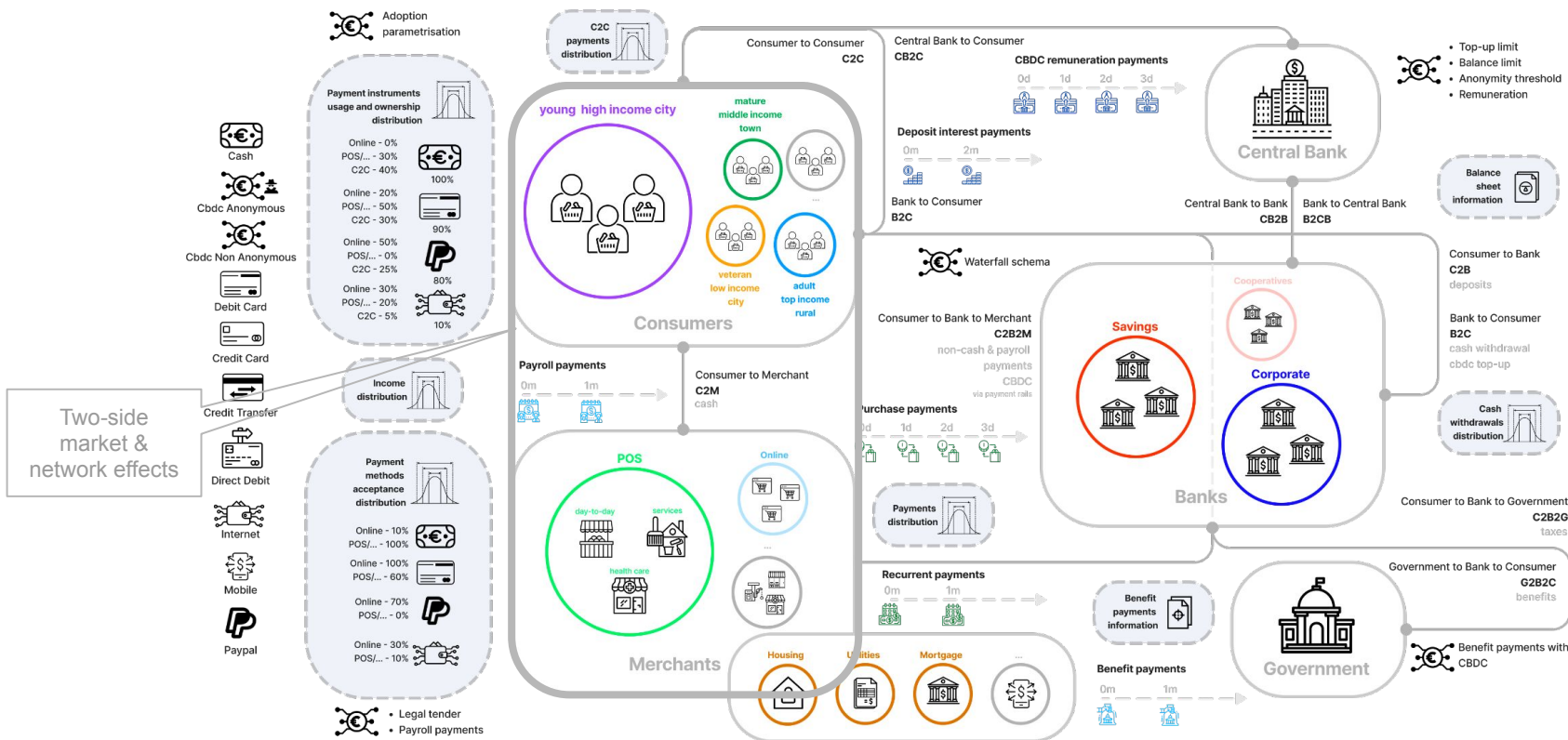
Simulating the Adoption of a rCBDC
FNA

Carlos León
José Moreno
Kimmo Soramäki

rCBDC ABM: consumer, merchant and bank personas provide heterogeneous decision-making and get us closer to the payment ecosystem



rCBDC ABM: consumer, merchant and bank personas provide heterogeneous decision-making and get us closer to the payment ecosystem



CBDC Simulation Inputs



Payments statistics, surveys, diaries

Distribution of number and amount of retail payments



Income distribution

Income distribution in your economy, e.g GDP per capita, Gini distribution, household surveys



Payment instruments usage

The proportion of transactions that are settled in different payment instruments



Payment instruments acceptance

Merchants' acceptance ratio of payment instruments



Banks' statistics

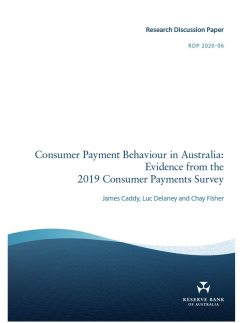
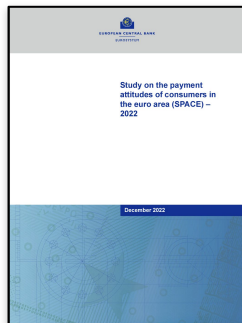
Aggregated balance sheet information, assets returns, deposits interest rate



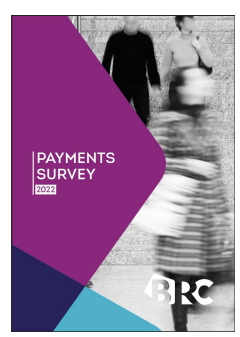
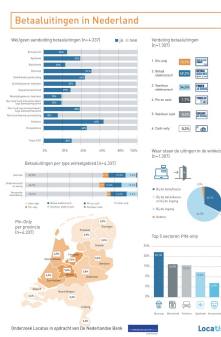
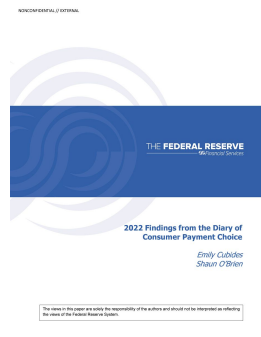
Policy instruments

CBDC top up, balance and anonymity limits, CBDC two-tier interest rate, scenarios configuration

CBDC Simulation Inputs - What info do you need?

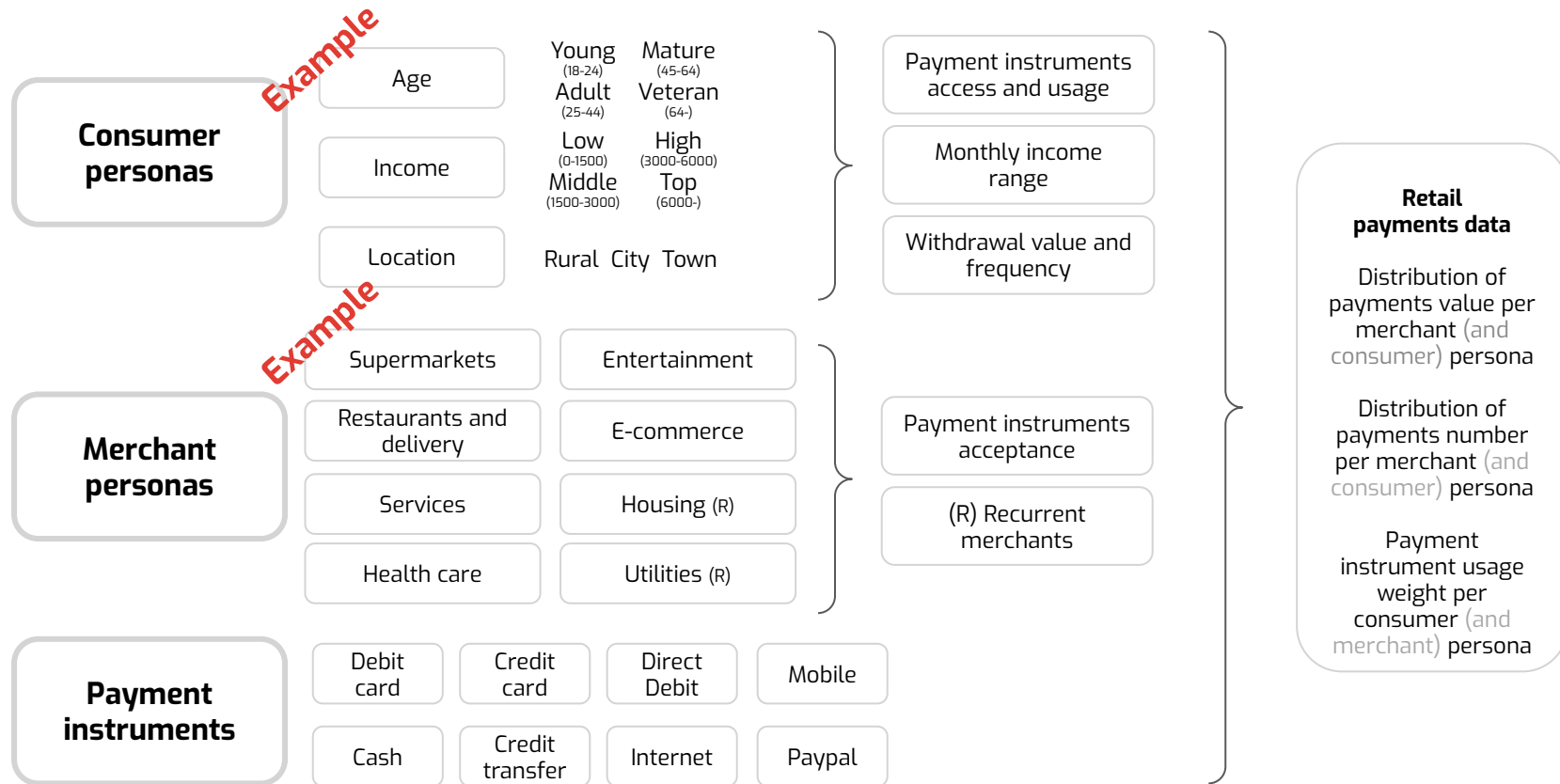


2021年度消費者インサイト調査
報告書

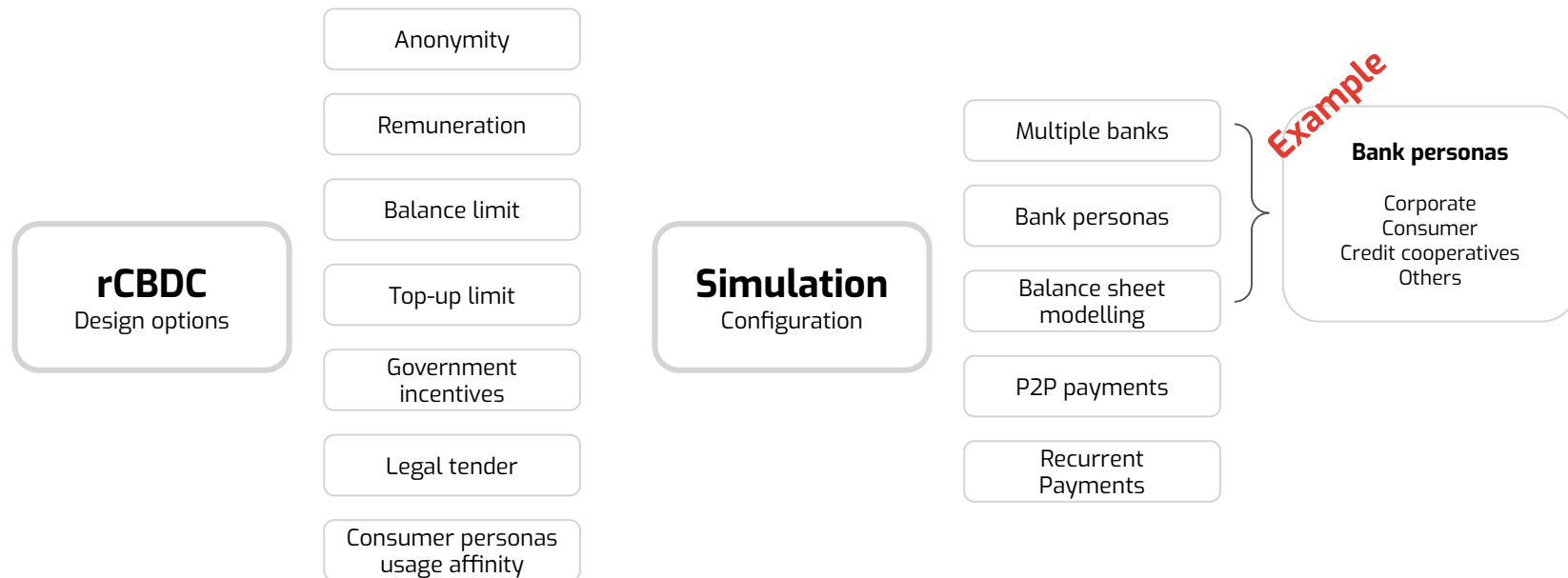


2022年3月
一般財団法人キャッシュレス推進協議会
JAPAN PAYMENTS JAPAN
JAPAN PAYMENTS ASSOCIATION

Main Inputs – to calibrate and configure



rCBDC design and simulation configuration options



CBDC Simulation Scenarios



Merchant adoption scenarios

Legal tender scenario
Two-side market adoption
Merchants payments with CBDC?



Consumer adoption scenarios

Privacy and anonymity
Government or Central bank incentives
Merchant incentives



CBDC balance sheet scenarios

CBDC waterfall behaviour
Merchants CBDC holdings
Banks CBDC holdings



Disintermediation scenarios

CBDC balance and topup limits
CBDC two-tier (or not) remuneration rate



CBDC topup scenarios

Income/salary transfer to CBDC
Cash-like CBDC topups



Commercial bank balance sheet scenarios

Driven by margin
Driven by solvency
Central Bank facilities

CBDC Simulation Outputs



Adoption rate

The pace at which CBDC is acquired and used by the public (financial inclusion effect)



Composition of consumers' wealth

The amount of asset, cash, CBDC, deposit in consumers' portfolios



Diffusion of payment instruments

The proportion of transactions that are settled in card, cash, or CBDC



Banking disintermediation

The amount of bank deposits that are migrated to CBDC.



Banks balance sheet

The composition of asset side (e.g., reserves, cash) and liability side (e.g., deposits)



Scenario analysis

Comparing the impact of different design choices and initial conditions

rCBDC Spanish market adoption



ECB Space Survey Data

Merchant personas

26

Medicine

Home

Street

Clothes

Travel

Insurance (R)

Durables

Day-to-day

Charity

Loans

Entertainment

Transport

Vending Machines

Rent / Mortgage

Outhome services

Petrol

Home services

Taxes

Luxury

Financial

Restaurants

Phone / Internet

Public

Subscriptions

Utilities

Other

Consumer personas

20

Age

Young
(18-30)
Adult
(31-50)

Mature
(51-70)
Veteran
(71-)

Low
(0-750)
Middle
(751-1500)

High
(1501-2500)
Very High
(2501-4000)

Top
(4001-)

Income

Payment instruments

Cash

Credit transfer

Mobile

Cards

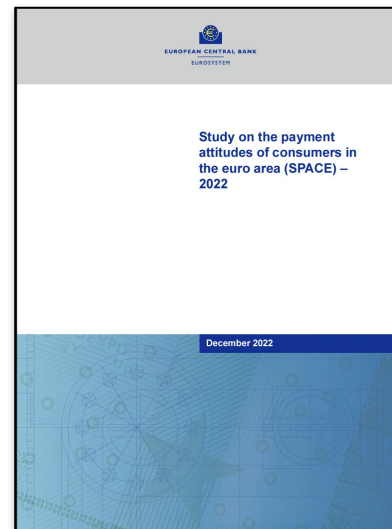
Direct Debit

Internet

Paypal

CBDC anon.

CBDC non-an.



C2M and C2C networks

Agent

- Bank
- Centralbank
- Consumer
- Government
- Merchant

Payment Instrument

- Cash
- Cbdc anonymous
- Cbdc non anonymous
- Credit transfer
- Debit card
- Direct debit
- Internet
- Mobile
- Paypal

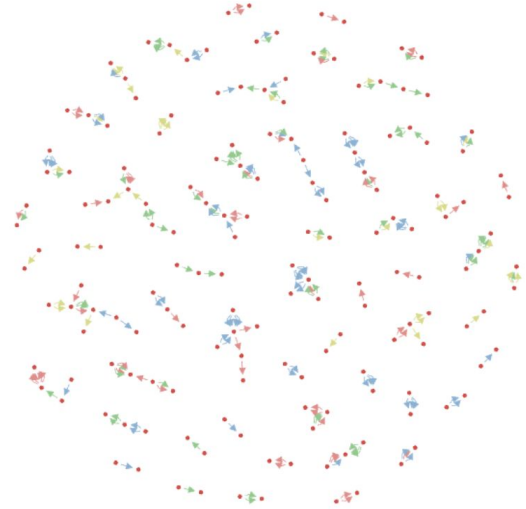


Agent

- Bank
- Centralbank
- Consumer
- Government
- Merchant

Payment Instrument

- Cash
- Cbdc anonymous
- Cbdc non anonymous
- Credit transfer
- Debit card
- Direct debit
- Internet
- Mobile
- Paypal



Extracted from the 180th day of the basic scenario simulation.

Scenarios

Design options	Baseline	Basic	Sce. 1	Sce. 2	Sce. 3	Sce. 4	Sce. 5	Sce. 6
Legal tender	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Balance limit	NA	€3,000	€3,000	€3,000	€3,000	€3,000	€3,000	€1,000
Top-up limit	NA	NA	€500	NA	NA	NA	NA	NA
Anonymity threshold	NA	∞	∞	€200	∞	∞	∞	∞
Reverse Waterfall	NA	Yes	Yes	Yes	No	Yes	Yes	Yes
Government benefits	NA	NA	NA	NA	NA	Yes	NA	NA
Remuneration spread	NA	NA	NA	NA	NA	NA	Yes	Yes

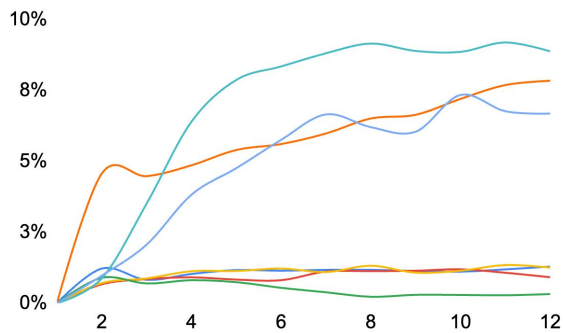
Adoption Scenarios Comparison

Scenario	Cash	rCBDC		Cards	Credit transfer	Direct debit	Internet	Mobile	Paypal
		anonymous	non-anon.						
Baseline	24.77%	0.00%	0.00%	46.93%	5.34%	6.80%	0.03%	13.41%	2.71%
Basic	25.08%	1.29%	0.00%	45.87%	5.19%	6.41%	0.02%	13.73%	2.40%
1	23.34%	0.91%	0.00%	47.06%	5.03%	6.60%	0.01%	14.29%	2.75%
2	25.64%	1.23%	0.02%	46.46%	4.70%	6.68%	0.00%	12.76%	2.51%
3	27.20%	0.32%	0.00%	44.50%	3.91%	6.48%	0.01%	15.08%	2.50%
4	10.93%	7.84%	0.00%	49.06%	5.76%	7.59%	1.14%	13.98%	3.70%
5	29.62%	8.88%	0.00%	39.61%	4.09%	5.48%	0.00%	10.41%	1.92%
6	28.67%	6.68%	0.00%	41.00%	4.27%	5.99%	0.02%	11.41%	1.95%

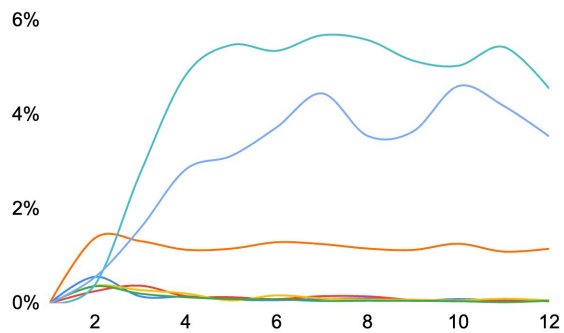
Payments made during the last month of the simulation, as per cent of the number of payments.

Adoption Scenarios Comparison

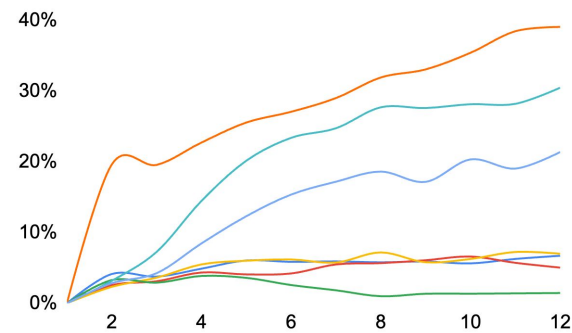
CBDC Total Share (% , #)



CBDC C2M Share (% , #)



CBDC C2M Share (% , #)



— basic — Sce. 1 — Sce. 2 — Sce. 3 — Sce. 4 — Sce. 5 — Sce. 6



Main takeaways

- Simulating rCBDC adoption can help central banks to iterate design options.
- Without attractive design features or stimulus policies we found low adoption of rCBDC in the Spanish retail payments ecosystem.
- Reverse waterfall functionality, government payments, and positive remuneration spread can increase rCBDC adoption.
- Balance limits, top-up limits effective to restrain rCBDC adoption.
- In general, rCBDC won't compete with cash but with deposit-related payment instruments—unless the government fosters targeted use of rCBDC

Future Work





Future work

- Explore more scenarios with different combinations of design options and stimulus policies.
- Study the adoption of rCBDCs in different jurisdictions.
- Analyze results by consumer and merchant personas.
- Explicitly model commercial banks' balances and make them adaptive decision-makers.
- Enhance the model by calculating confidence intervals, using data about the costs of holding forms of money, and testing other network-generating models.
- Model M2M payments.



Thank you |

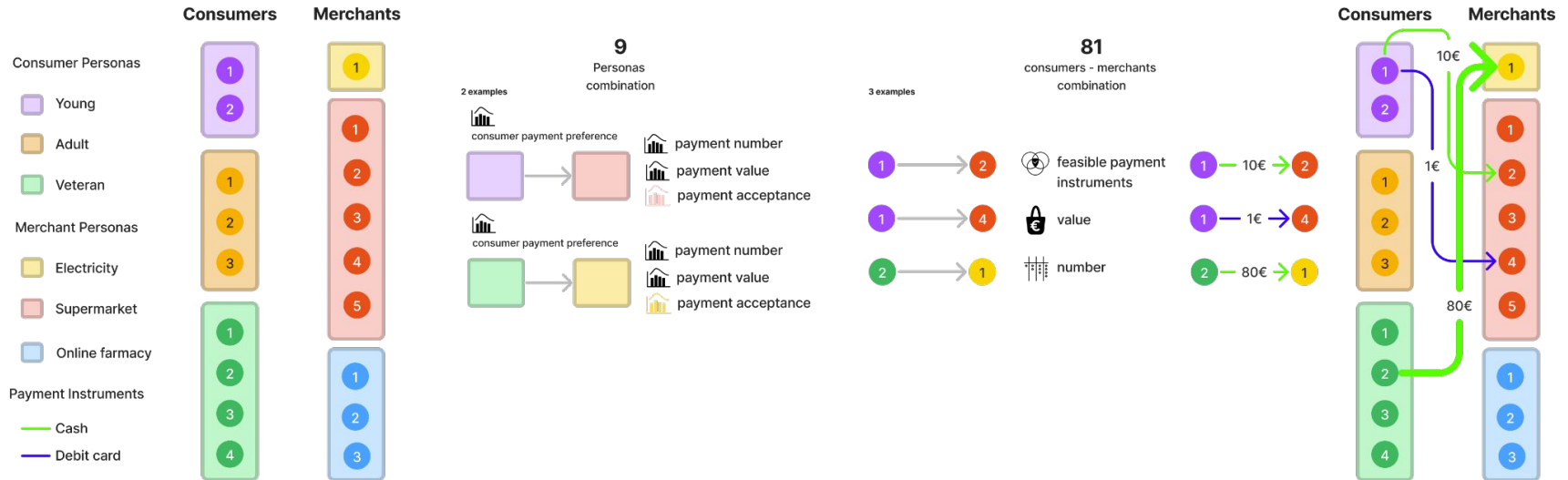


Agent-based simulation of rCBDC adoption

Details (Appendix)

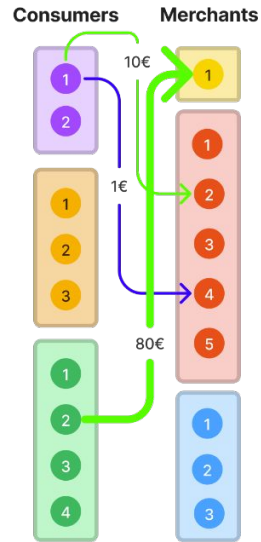


The consumer and merchant decision making process – C2M network generation



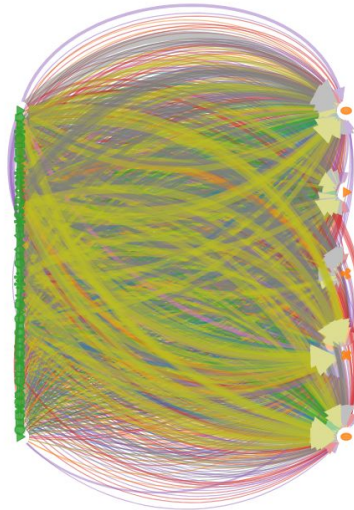
The consumer and merchant decision making process – C2M network generation

Example



CBDC Simulation Actual Result

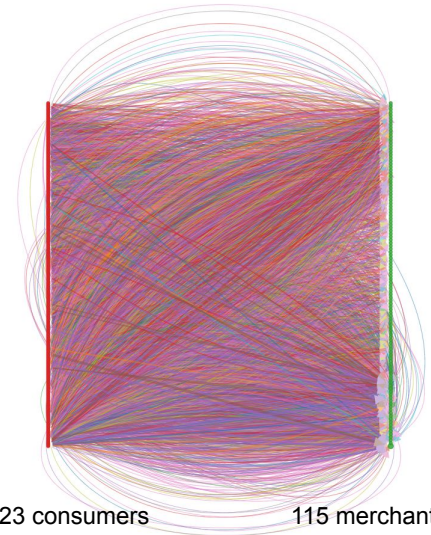
By consumer and merchant persona



48 consumer
personas

7 merchant
personas

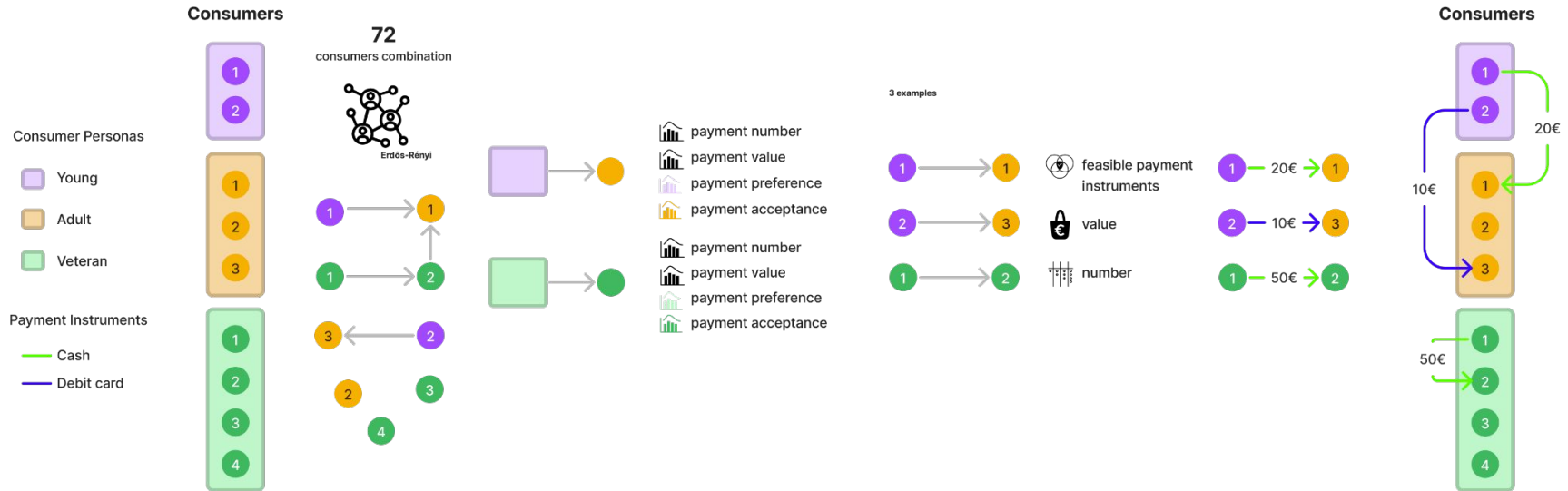
By agent



523 consumers

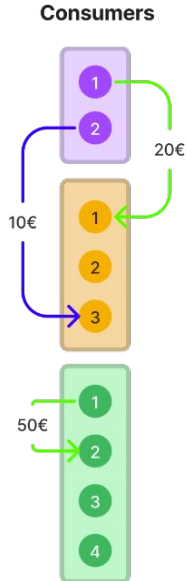
115 merchants

The consumer and consumer decision making process – C2C network generation



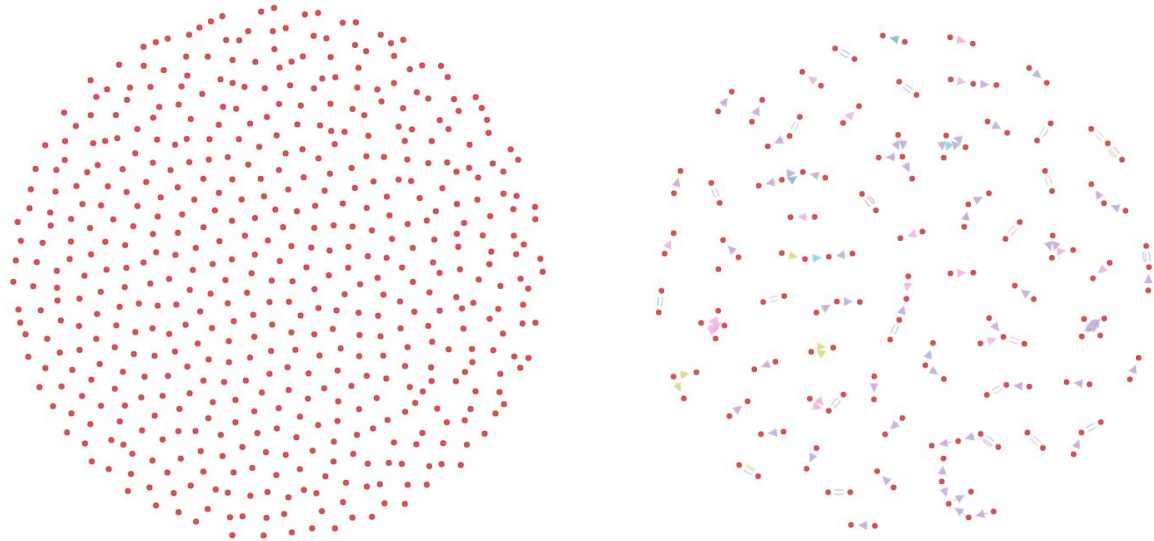
The consumer and merchant decision making process – C2C network generation

Example



CBDC Simulation Actual Result

By agent

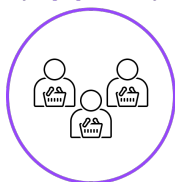


523 consumers
159 connected consumers

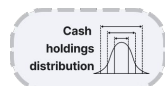
Consumers initialisation

Initialisation Info

young high income city



3000€ - 6000€



min median mean max
10€ 20€ 25€ 100€



1% income

	Accessibility Probability		Accessibility Probability
✓ Cash	100%	✓ Credit Transfer	99%
✗ Cbdc Anonymous	0%	✓ Direct Debit	99%
✗ Cbdc Non Anonymous	0%	✓ Internet	98%
✓ Debit Card	99%	✓ Mobile	98%
✓ Credit Card	99%	✓ Paypal	98%

Initialisation Mechanics

Simulation 1st day



Income → 4350€

Cash → 25€

Benefits → 43.5€

Salary → 4306.5€



Cash Account → 25€

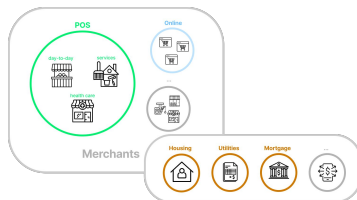
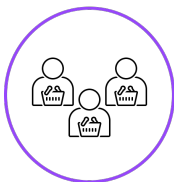
Deposit Account → 4325€

Monthly payments

Consumer recurrent, merchant payroll, and banks deposit interest payments

Initialisation Info

young high income city



By recurrent merchant persona

	min	median	mean	max
value	50€	200€	250€	400€
number per month	1	2	2	5

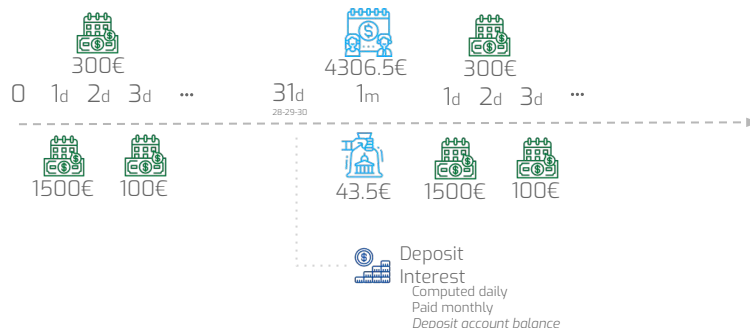
Benefits → 43.5€
Salary → 4306.5€

Mechanics

Payroll Payer → POS merchant 3 ↗

Recurrent payments*

- day: 2, value: 300€, merchant: utilities 1
 - day: 3, value: 100€, merchant: utilities 3
 - day: 1, value: 1500€, merchant: housing 1
- TOTAL: 1900€**

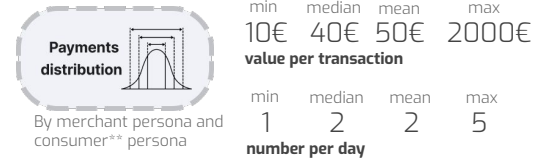
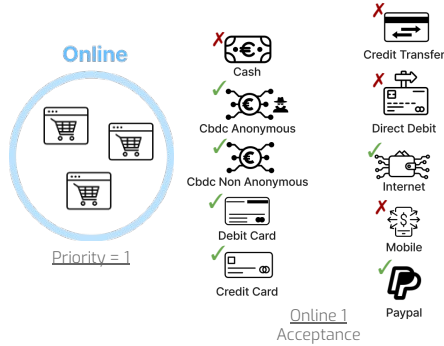
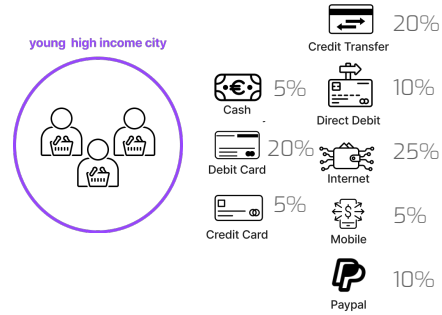


* Prioritised payments. No default allowed. It means consumers always pay and save money for making these payments.

Daily purchase payments

Selected payment instrument

Payment Info



Assets → 4350€

→ Deposits: 4325€

→ Cash: 25€

Recurrent payments → 1900€

Budget → 2450€

Mechanics

per consumer and merchant persona

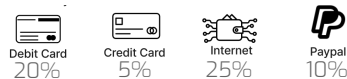


Payments

→ value: 20€, merchant: online 1

→ value: 40€, merchant: online 5

Feasible Payment Instruments*



Budget check

→ 20€ ≤ 2450€ (budget) ✓

Payment instrument*

→ 20€ ≤ 4325€ (deposits) ✓



Internet

Transaction

→ from: consumer Y-HI-C 1

→ to: merchant online 1

→ value: 20€

→ payment instrument: internet

→ status: completed

→ type: purchase

Assets C → 4330€

→ Deposits: 4305€

→ Cash: 25€

Assets M → +20€

→ Deposits: +20€

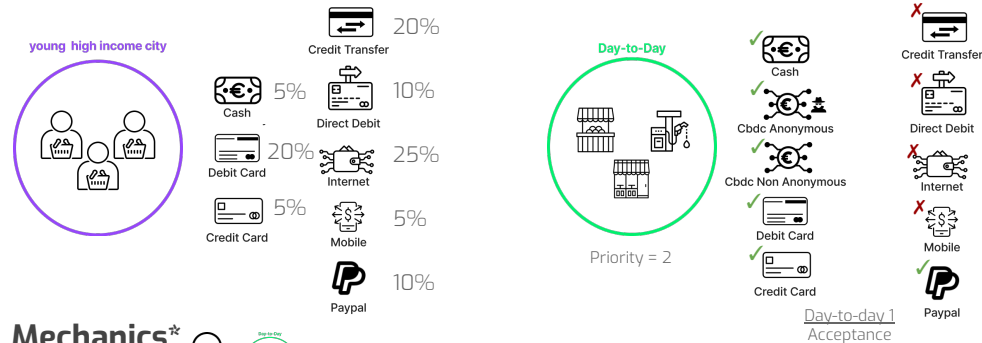
→ Cash: 0€

* This mechanics also applies to recurrent payments.

Daily purchase payments

Multiple payment instruments transfer

Payment Info



Mechanics*

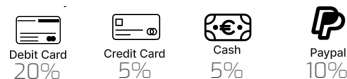
per consumer and merchant persona



Payments

- value: 40€, merchant: day-to-day 2
- value: 2€, merchant: day-to-day 5

Feasible Payment Instruments



Budget check

→ 40€ ≤ 50€ (budget) ✓

Payment instrument

→ 40€ ≤ 25€ (deposits) ✗



Transaction 1

- from: consumer Y-HI-C 1
- to: merchant day-to-day 2
- value: 25€
- payment instrument: debit card
- status: completed
- type: **purchase**

Assets C → 10€

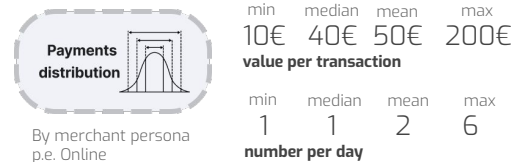
- Deposits: 0€
- Cash: 10€

Transaction 2

- from: consumer Y-HI-C 1
- to: merchant day-to-day 2
- value: 15€
- payment instrument: **cash**
- status: completed
- type: **purchase**

Assets M → +40€

- Deposits: +25€
- Cash: +15€



By merchant persona
p.e. Online

Assets → 50€

→ Deposits: 25€

→ Cash: 25€

Recurrent payments → paid

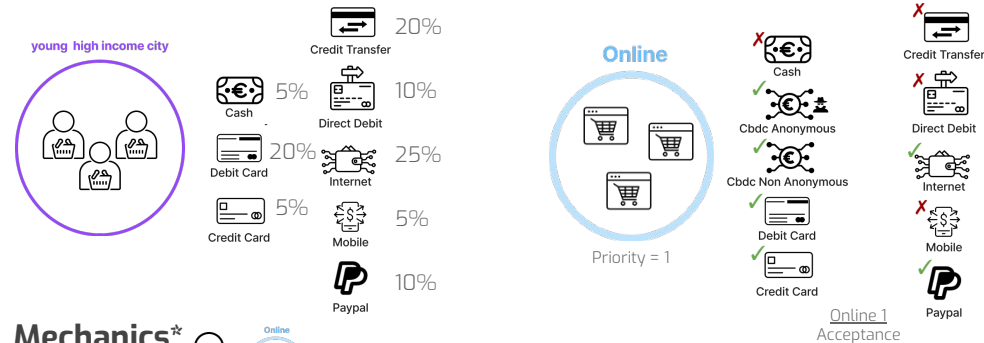
Budget → 50€

* This mechanics also applies to C2C payments.

Daily purchase payments

Money transfer

Payment Info



Mechanics*

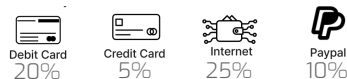
per consumer and merchant persona



Payments

- value: 350€, merchant: online 1
- value: 100€, merchant: online 5 X

Feasible Payment Instruments



Budget check

→ 350€ ≤ 350€ (budget) ✓

Payment instrument

→ 350€ ≤ 325€ (deposits) X



Transaction 1

- from: consumer Y-HI-C 1
- to: consumer Y-HI-C 1
- value: 25€
- payment instrument: cash
- status: completed
- type: **deposit top-up**

Assets C → 0€

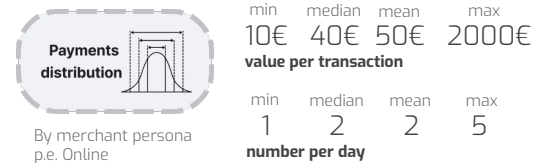
- Deposits: 0€
- Cash: 0€

Transaction 2

- from: consumer Y-HI-C 1
- to: merchant online 1
- value: 350€
- payment instrument: debit card
- status: completed
- type: purchase

Assets M → +350€

- Deposits: +350€
- Cash: 0€



Assets → 350€

→ Deposits: 325€

→ Cash: 25€

Recurrent payments → paid

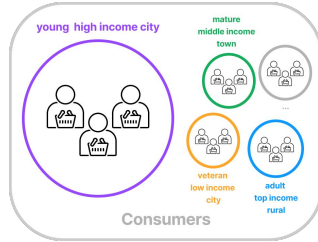
Budget → 350€

* This mechanics also applies to C2C payments.

C2C Network



Consumer Y-HI-C 1



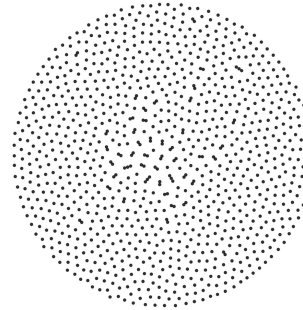
Consumers number $\rightarrow 1000$
Network density $\rightarrow 0.00005$

Erdős-Rényi network model

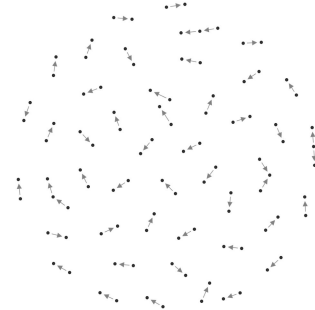
for consumer in consumers:

- \rightarrow if consumer \neq Y-HI-C 1:
 - \rightarrow if $\text{random.uniform}(0, 1) \leq \text{network density}$:
 - \rightarrow add consumer to my c2c network

All

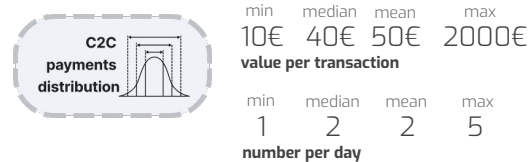
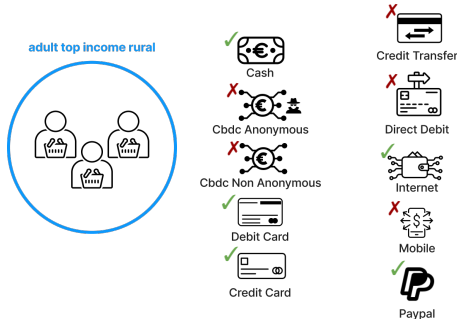
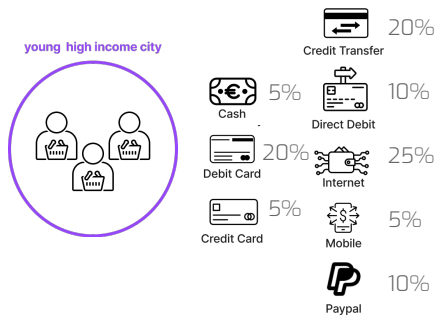


Connected



Daily C2C payments

Payment Info



Assets → 4350€

→ Deposits: 4325€

→ Cash: 25€

Recurrent payments → 1900€

Budget → 2450€

Mechanics*

per consumer
bounded by her
c2c network

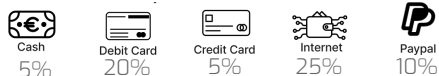


Payments

→ value: 10€, consumer: A-TI-R 2

→ value: 25€, consumer: Y-HI-C 5

Feasible Payment Instruments*



Budget check

→ 10€ ≤ 2450€ (budget) ✓

Payment instrument*

→ 10€ ≤ 4325€ (deposits) ✓



Paypal

Transaction

→ from: consumer Y-HI-C 1

→ to: consumer A-TI-R 2

→ value: 10€

→ payment instrument: paypal

→ status: completed

→ type: purchase

Assets Y-HI-C 1 → 4340€

→ Deposits: 4315€

→ Cash: 25€

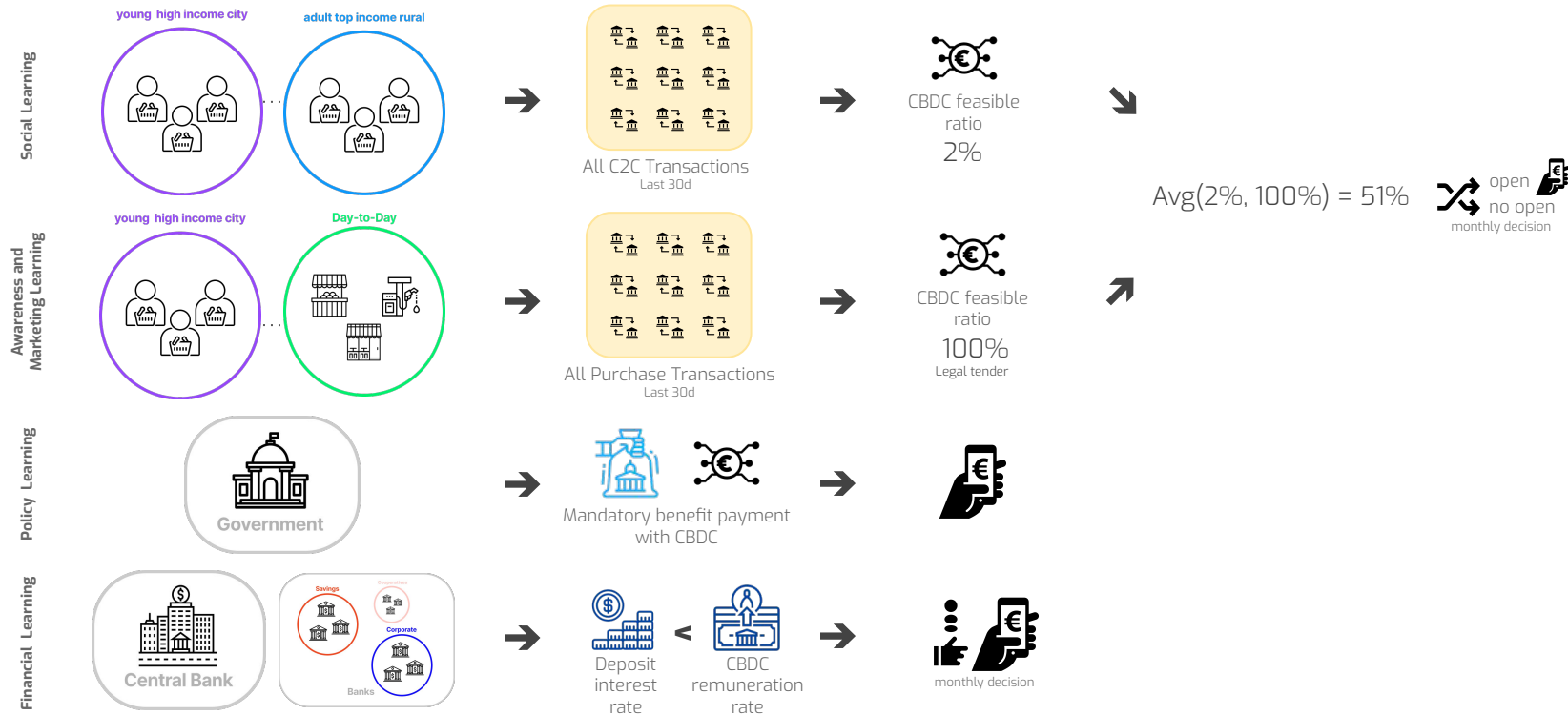
Assets A-TI-R 2 → +10€

→ Deposits: +10€

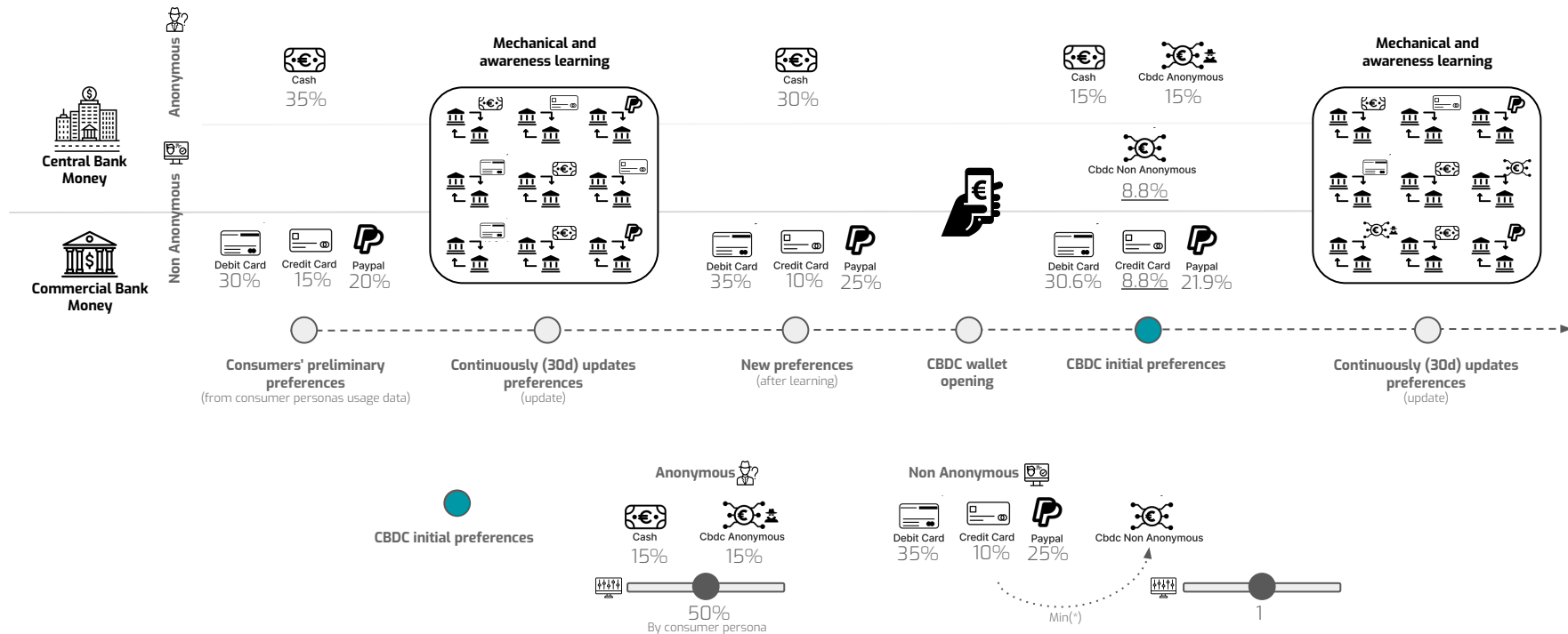
→ Cash: +0€

* Multiple payment instruments and money transfer mechanics also apply here.

Consumers opening a CBDC wallet

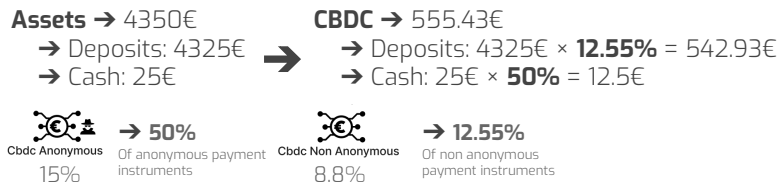


Payment instruments preferences and CBDC adoption



CBDC details

First top-up*





Anonymity

 **Threshold** → 0€
→ completely non anonymous

 **Threshold** → ∞€
→ completely anonymous

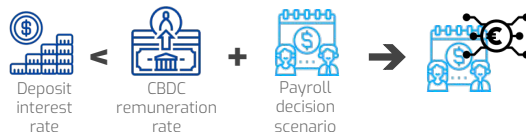
 **Threshold** → 200€

→ if transaction value > 200€ →  CBDC Non Anonymous

→ if transaction value ≤ 200€ →  CBDC Anonymous

Remuneration

Daily remuneration to avoid **default** in the **negative remuneration** scenario

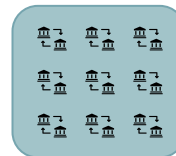


Top-ups*

Frequency → As cash withdrawal
→ Daily
→ Weekly
→ Consumer persona

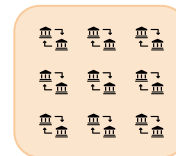


Completed with
CBDC value
(last frequency transactions)




and
or

First attempt with
CBDC failed value
(last frequency transactions)



*Limits

 **Balance limit**
→ max CBDC account balance value
→ waterfall behaviour (e.g. salary > limit)

 **Top-up limit**
→ max top-up value
→ subject to balance limit