



**Applied Project:**

**Exploring the implications of CBDC in developed and developing  
markets: case studies of Armenia and Belgium**

**(Agent-based modelling approach)**

Financial Technology Report

Student ID: 02161610

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## Client Specification

Dcurrency is a (fictitious) digital software company which develops and offers technology that provides central bank digital currency and stablecoin solutions to central banks, governments and participants within financial ecosystem worldwide. The company has a sales department that reaches out to central banks and other beneficiaries offering its products. Additionally, Dcurrency outsources research analysts that conduct various analytical models to identify a country that would suit best to contact.

Hi Daniel,

Active discussions on CBDC adoption have started in Eurasia and we expect that some countries will move from research status to development in the upcoming years. Hence, the sales team of Dcurrency would like to approach first to those countries to establish agreements before our competitors. Therefore, we need an analysis on CBDC adoption and impacts on these countries. What would you suggest?

Kind regards,

Amelie Watson.

Head of Sales team

Dcurrency Inc.

Hi Amelie,

Thank you for your email.

Keeping track of current developments, I would suggest starting with one developed and a developing country to see which direction should be taken in the future as the advantages CBDC provides for these markets are different and needs can also vary. Therefore, I would suggest conducting an agent-based model, which is getting very popular in the CBDC context, in Armenia and Belgium. Would be interesting to compare the adoption possibilities, what do you think?

Kind regards,

Daniel Smith.

Analyst

ChainSearch

Dear Daniel,

I think that is a great idea. The AGM model will not only contribute to their current research, but also support our cooperation plans and secure an agreement.

Please provide more details on the research results date, I can schedule a call to discuss things further.

Thank you.

Kind regards,

Amelie Watson.

Head of Sales team

Dcurrency Inc.

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## **Introduction and background**

Central Bank Digital Currencies (CBDC), a digital form of national fiat currency (Seth, 2023), has already been launched in 11 countries (CBDC tracker, 2023), and 130 countries are exploring the adoption of the latter. The aim of CBDC is to enlarge the access to central bank reserves beyond the commercial banks to consumers, creating the concept of 'reserves for all' (European Central Bank, 2020) and providing a new way for the public to interact with the fiat money beyond cash and card payments. While the centralised digital currency holds various benefits such as faster and more efficient cross-border payments, an increase in financial inclusion, liquidity, and a decrease in the underground economy, it also holds several risks. Firstly, financial stability has been a center of discussion as CBDC is expected to 'lower the cost of liquidity circulation and become a strong substitute for demand deposits' (Jun and Yeo, 2021: p.1) increasing bank run and bank failure risk. The latter is also risky, as it can result in larger CB balance sheets and respectively, smaller balance sheets of commercial banks, which can negatively impact their risk exposures, force to change their business model drastically, and CB, being the regulator, would need to implement actions against CBDC (Papavassiliou, 2021).

However, despite the increasing amount of research conducted around CBDC, there is a lack of quantitative analysis undertaken. The aim of this report is to use an agent-based model to explore the impact of CBDC adoption on the economy of 2 countries with different levels of development to assess the possible implications and implementation of CBDC. Particularly, Armenia and Belgium have been chosen as both have nearly the same size, while the financial system is significantly different and unconnected. Hence, the impacts can vary from economy to economy.

### **Armenia**

The financial sector of Armenia is dominated by 17 banks accounting for 83.8% of the market (Black Sea Trade and Development Bank, 2021), which makes the banking system more sensitive to changes by CB. Card payments are generally accepted in the country and the CB restricted cash payments for any transaction over 300,000 AMD, nearly 711 Euros (Arlis, 2022). However, society heavily relies on cash payments, especially the older generation in cities outside the capital Yerevan (Vardanyan, 2023). The decentralised market is not quite spread in Armenia, although trusted cryptocurrency exchanges such as Binance, and Kraken operate in the country. DEKIS Research group at the University of Avila ranks Armenia 56th in the global crypto mining potential ranking, however the country has not yet adopted a cryptocurrency-specific regulatory regime, and the 'status of cryptocurrency remains in a degree of controversy' (Freeman Law, 2023), which suggests that introduction of CBDC can require regulatory changes. The status of CBDC in Armenia is still under discussion level, nevertheless, CB of Armenia has recently issued its first research paper showing interest.

### **Belgium**

Belgian economy is characterised as developed and it is the 43rd freest economy in the 2023 Index (Belgium economic overview, 2023). The financial system is widely diversified offering a range of financial services by investment banks, asset and wealth management firms, hedge funds, traditional banks, etc. The banking system is robust, there are 84 banks, including 21 domestic ones, however, the latter is highly concentrated: 5 largest banks comprise together about 75% of consolidated banking assets (TheBanks.eu, 2021). The share of cash payments in total transactions gradually decreases over the years: it reached 28% in 2019 from 44% in 2008 (Sia Partners, 2022), meanwhile card payments dominate the total number

of payment transactions in Belgium from 2000 to 2021, comprising 52.02% of the payment services (Raynor, 2023). Because financial inclusion is high in the country (99% in 2021 according to the World Bank), it is not surprising that Belgium has 6.3% of crypto assets adoption in the world (Feyen, 2022), however, as in majority of countries, the cryptocurrencies remain unregulated in Belgium. The Central Bank of Belgium (NBB) is currently in the initial phases of investigating the potential for introducing a CBDC. In 2021, the NBB published a report on the potential benefits and risks of a CBDC, but it doesn't plan to issue CBDC in the upcoming years.

## **Model and Methodology**

Every change made by the central bank should have a research basis before the main implementation and one of the best methods is the adaptation simulation. There are several techniques to understand the effects of the change such as surveys, research based on other countries' experience, etc. One of the most common methods is Dynamic Stochastic General Equilibrium (DSGE) model, which despite serving an important basis for analysis, according to the Austrian school of economic thought, fails 'to adapt to economic changes, particularly in dealing with the diversity of agents, preferences, and information sets' (Syarifuddin, 2022). In this paper, we use Agent-based model (AGM) in R (R studio), which is a simulation approach that delves into the analysis of a system through its individual agents, that engage in interactions among themselves in a system (Karami, 2021). The model development is inspired by Ramadiah et al. paper where they conduct the AGM simulation for Germany.

The model has a discrete time, each  $t$  ( $t=1,2, \dots$ ) representing a day for Belgium and a week for Armenia. The timing difference arises from the number of cash and card transactions held in each country. There are four main agents in the model: consumers, merchants, commercial banks, and central banks. The process is the following: Central bank issues CBDC and distributes it to consumers via commercial banks, after which consumers make purchases with CBDC from merchants. There are various scenarios on how consumers make purchases depending on the means of payment: cash, card, transfers or CBDC. This decision is highly dependent on the consumer's personal financial management style, financial literacy and their type of innovation adopting. It is noteworthy that any changes in monetary policy impact commercial banks with their vulnerability tied to the risk level of their portfolio composition.

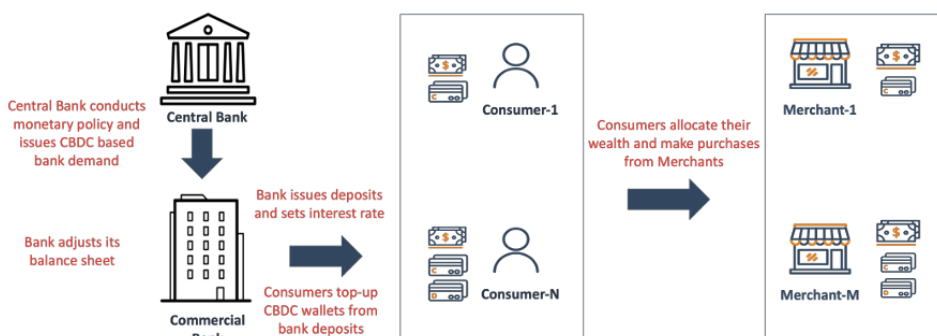
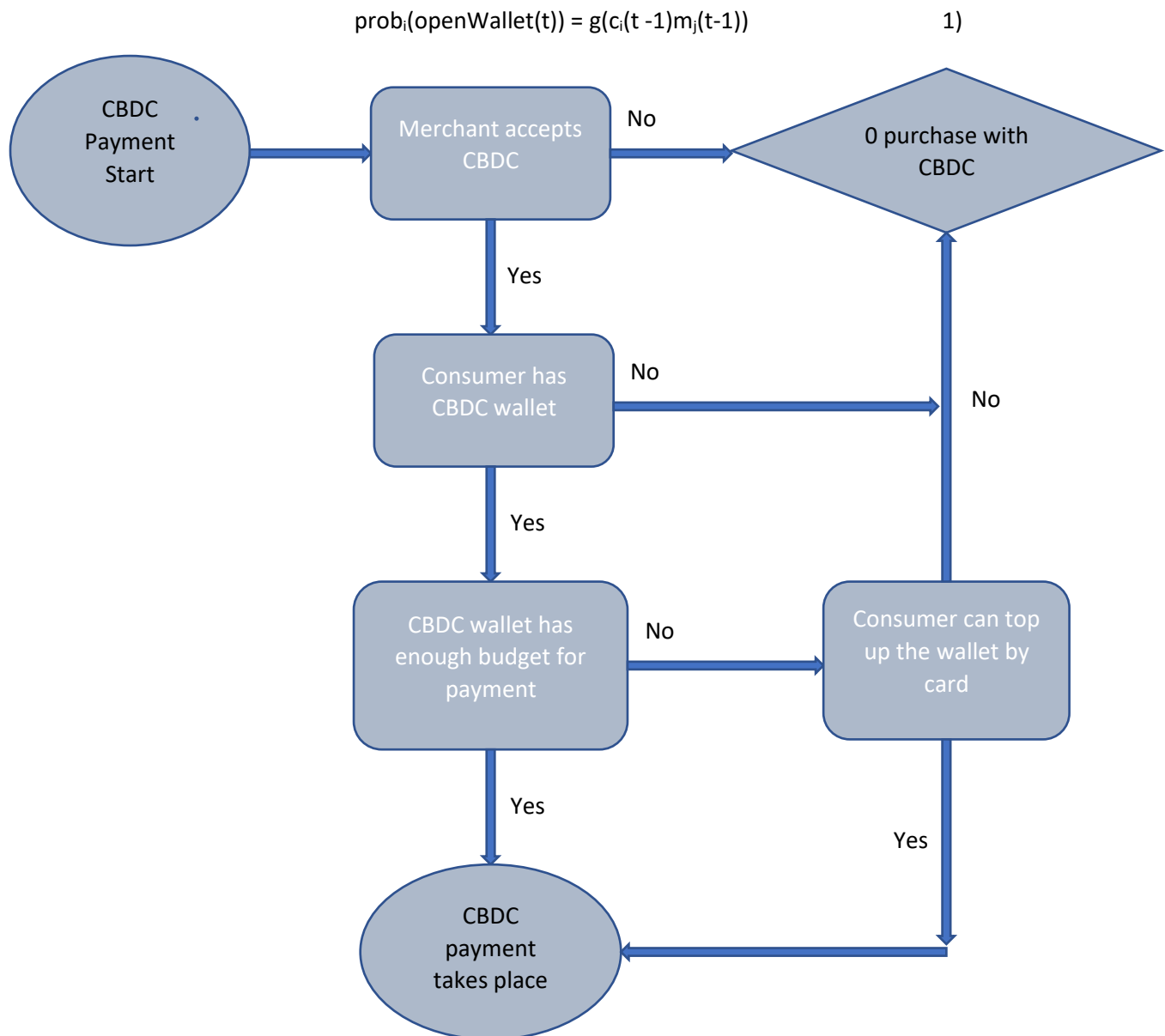


Figure 1: Illustration of agents interaction in the model (Ramadiah, 2021: p.4)

## Consumers

Each consumer has a wealth allocation ( $W$ ) distributed in form of a) cash, b) deposit or card, c) CBDC. The payment type for daily purchases (online and offline) depends on the wealth of consumers and the acceptance methods of merchants. As a basis, all merchants accept cash payments for offline purchases, and cards are accepted by the majority. While for online payments, we assume that all merchants accept card payments. The scenarios described in Graph 1 suggest that online and offline purchases can take place with CBDC only if both merchants and consumers are prepared with technology. Since CBDC will be an innovation, we assume that 'early adopters' will accept it for the first year, afterwards the 'early majority' will follow for the next 5 years. The increase of merchants ( $m_j$ ) and consumers ( $c_i$ ) accepting CBDC at each time  $t$  assumes a higher probability of acceptance for future.



Graph 1: CBDC payment variations in the model

## Merchants

Merchants create consumer products and services and face decisions such as accepting and changing payment methods. If one payment method doesn't have enough demand by consumers, they might remove it, because it is costly, and the opposite (Martens, 2021). According to the model, with the increase of consumers demanding a CBDC payment method, the number of merchants accepting CBDC will grow, hence the probability of acceptance is equal to the CBDC adoption function, where  $P^*Cons$  is the share of the merchant's consumers having CBDC at  $t-1$ .

$$Prob_j(\text{accepts}(t)) = P^*Cons(t-1) \quad 2)$$

For the model purposes, the merchant's main role is to contribute to the CBDC adoption. It is noteworthy that for online and offline purchases, card acceptance by merchants is mandatory if they choose to incorporate CBDC payments, which means that order of payments would be the following: cash, card, CBDC. However, it's important to note that the acceptance of cash isn't a mandatory requirement for facilitating card payments.

## Commercial bank

Firstly, to simplify the model, we assume that there is one commercial bank to represent the banking sector. Besides the main function of collecting deposits and providing, it also distributes the CBDC to consumers (Vardanyan, 2023). To do so, the bank needs to borrow CBDC from the Central bank paying a rate  $r$ . With these assets, the bank ensures the withdrawals, as well as invests in risky assets, that later yield a return.

A commercial bank has the following limitations: it should not exceed the leverage ratio set in the parameters and should always be able to meet its obligations to consumers (Ramadiah, 2021). The purpose behind this is to control the investment amounts in assets with high levels of risk.

Additionally, it is assumed that the deposit interest rate includes the  $r$ , the cost of borrowing CBDC ( $U$ ), specified by the central bank:

$$rD(t) = r(t) + U, \quad 3)$$

where  $U > 0$  and  $< 1\%$  (Ramadiah, 2021).

## Central bank

Central bank sets the CBDC borrowing rate for and the maximum leverage ratio to control the amount of CBDC reserves and choices of commercial banks when investing in risky assets. Furthermore, according to Ramadiah (2021), the following rules will be set to the model for central banks:

- Constant policy: The parameters of CB are constant over time, reflecting current conditions.
- Growth-Targeting Rate Policy: CBDC borrowing rate  $r$  is set to increase with risky investments  $X(1) - X(t-1)$
- Macroprudential policy: Maximum leverage ratio is set to decrease over time based on the average of risky investments  $X(t) - X(t-1)$ .

## Data gathering and model assumptions

Data gathering for each parameter has different sources. Furthermore, where applicable, model assumptions were included as CBDC is not yet introduced and only assumptions can be taken.

### Consumers

The number of consumers varies from country to country because of the population differences.<sup>1</sup> Hence, for Belgium 8000 consumers were selected, while Armenia has 2000 to be consistent with population number.

According to the NBB, the average number of transactions per person by cash and card is 1.38 in Belgium. According to the Household's Integrated Living Conditions Survey, the average monthly payments value 99052 AMD, which represents 1 daily payment in Armenia.

Considering the proportion of innovation adopters in two countries, as well as levels of card payments: 52% (Raynor, 2023) and 42% (Hergnyan, 2021), the adoption function, where  $c$  ( $m$ ) is the proportion of consumers (merchants) who have adopted CBDC assumes that Belgium and Armenia will have 30% and 20% adoption level.

The income data for Armenia is calculated from average monthly nominal wages obtained from Armstat (2023), which is 65,344 AMD weekly. Similarly, the data for Belgium is 128 Euro daily calculated from Belgium Average Monthly Salary obtained from CEIC Data (2020).

Return on assets is in accordance with corporate short term bond yield in 2023. The source for Armenia is the market data from Armenia Securities Exchange in AMD, while source for Belgium is the Moodys seasoned AAA corporate bond yield.

Parameter	Description	Value (weekly)	DataSource	Value (daily)	DataSource
		Armenia		Belgium	
Cons	Number of consumers	2000	Approximation based on population	8000	Approximation based on population
Pa i,t	Distribution of daily (weekly) purchases	14000	Armstat, 2021, Household's Integrated Living Conditions Survey anonymised microdata database (by households)	11040	National Bank of Belgium, 2020
Ponline	Share of online purchases	0.051	E-commerce data (Statista)	0.092	E-commerce data (Statista)
b(c + m)	Adoption function, where $c$ ( $m$ ) is the proportion of consumers (merchants) who have adopted CBDC	$0.2(c + m)$	Model assumption	$0.3(c + m)$	Model assumption

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<sup>1</sup> Armenia has 2.8 mln population and Belgium has 11.6 mln population.



$\kappa$	Income/salaries	EUR 155	Average weekly nominal wage, ArmStat, 2023	EUR 128	Average daily salary, CEIC Data, 2020
$r_A$	Return on asset	10% / 52	Armenia Securities Exchange, 2023	4.66%/365	Moodys, 2023
$\tau$	CBDC top-up horizon	2 weeks	Vardanyan, 2023	10	Ramadiah, et al., 2021
$\tau_C$	Cash withdrawal horizon	Every week	Vardanyan, 2023	10	Ramadiah, et al., 2021

Table 1: Merchant data description for the model

### Merchants

The number of merchants is calculated as following: in Armenia the approximate number of small and medium enterprises (SMEs) in 2022 gathered from the Armstat is 89,964, aligning it with the number of consumers, we get 64 merchants; same data is gathered for Belgium in 2022 based on DIW estimates (684,000 SMEs) and we get 471 merchants. This implies that the number of merchants per capita for Armenia and Belgium is 31 and 16 respectively. According to Bagnol (2016), the card acceptance is highly related to the level of cash payments. Hence the initial share of merchants accepting card (BC) would be assumed by this estimate: in Armenia cash transactions in 2022 made 68% (Armbanks, 2023) meaning that card acceptance is assumed to be approximately 32%. Similarly, in Belgium cash transactions in 2021 is 20.5% (Raynor, 2023), hence the card acceptance is 80%. The share of merchants accepting CBDC (DC) is lower than BC, hence, being consistent with Ramadiah (2021), we assume that only 10% will accept CBDC at time  $t=0$ . Lastly, the CBDC adoption by consumers is described as the percentage of the latter ( $P^*Cons$ ) willing to pay by CBDC.

Parameter	Description	Value	DataSource	Value	DataSource
		Armenia		Belgium	
$M_c$	Number of merchants	64	Approx. of number of SMEs in RA	471	DIW
$BC$	Initial share of merchants accepting bank card payments	32%	Model assumption, Armbanks, 2023	79.5%	Model assumption, Statista, 2023
$DC$	Initial share of merchants accepting CBDC payments	$0.1 \times PB$	Model assumption	$0.1 \times PB$	Model assumption
$(P^*Cons(t-1))$	CBDC adoption function, where $P^*Cons$ is the share of the merchant's consumers having CBDC at $t-1$	$0.2 \times ((P^*Cons(t-1)))$	Model assumption	$0.25 \times (P^*Cons(t-1))$	Model assumption

Table 2: Merchant data description for the model

## Commercial Banks

The data needed for the commercial banks is described in Table 3. The volume of deposits is the total deposits in May 2023 gained from CEIC data for both countries. Afterwards, the numbers are adjusted to the consumers data. Moreover, with the aim of being consistent in the model, both are represented in the same currency (EUR). The initial CBDC borrowing is assumed to be at a very low level at  $t=0$  followed by the proportion (30%) of  $D(0)$  assumed by Ramadiah (2021). The source for deposit interest rate and return on risky assets for Armenia is the World Development Indicator (WDI) and Global Financial Development (GFD) respectively, while for Belgium the source for  $D(0)$  rate is NBB. Assumptions on friction in liquidating and mark-up on the cost of borrowing CBDC are in accordance with the Ramadiah (2021) and Vardanyan (2023) papers.

Parameter	Description	Value	DataSource	Value	DataSource
		Armenia		Belgium	
<b>D(0)</b>	Initial volume of deposits	EUR 8.7M	CEIC DATA	EUR 914M	CEIC DATA
<b>DCbank(0)</b>	Initial CBDC borrowing	EUR 2.9M	Model assumption, Ramadiah, 2021	EUR 304M	Model assumption, Ramadiah, 2021
<b>X(0)</b>	Initial investment in risky assets	EUR 12M	Computed from the model	EUR 1310M	Computed from the model
<b>r, D(0)</b>	Deposit interest rate	8.47%/ 52	WDI, 2021	3.02%/ 365	WDI, 2021
<b>ROA</b>	Return on risky assets	0.7% /52	GFD, 2021	0.6%/ 365	GFD, 2021
<b>ε</b>	Friction in liquidating	0.95	Model assumption, Ramadiah, 2021	0.95	Model assumption, Ramadiah, 2021
<b>€</b>	Mark-up on the cost of borrowing CBDC	0.5%/ 52	Model assumption, Vardanyan 2023	0.5% /365	Model assumption, Ramadiah, 2021

Table 3: Commercial bank data description for the model

## Central Bank

Taking into account the value of the monthly market basket and cost of living we can assume a slightly higher balance allowed for CBDC to promote spending with CBDC rather than saving, avoiding the sharp decrease of deposits in the short term. The data for Armenia and Belgium is the following in 2023: 236 Euro (80,710 AMD) and 890 Euro respectively. The Maximum cash withdrawal is set by the proportion (30%) of Maximum allowed CBDC balance assumed by Ramadiah (2021). The maximum leverage ratio is adjusted with the Basel framework equivalent to 3% (Ramadiah, 2021). The CBDC borrowing rate is a model assumption aligned with Vardanyan, 2023 paper.

Parameter	Description	Value	DataSource	Value	DataSource
		Armenia		Belgium	
<b>β</b>	Maximum allowed CBDC balance	EUR 350	Model assumption, Socio-Economic Situation of RA, Armstat 2023	EUR 1,000	Model assumption, Cost of living in Belgium, Numbeo, 2023
<b>βc</b>	Maximum cash withdrawal	EUR 105	Model assumption, Ramadiah, 2021	EUR 300	Model assumption, Ramadiah, 2021

$\Gamma$	Maximum leverage ratio	32.3	Model assumption, Ramadiah, 2021	32.3	Model assumption, Ramadiah, 2021
$r$	CBDC borrowing rate	0.3%/52	Model assumption, Vardanyan, 2023	0.3%/365	Model assumption, Vardanyan, 2023

Table 4: Central bank data description for the model

## Results

With the abovementioned data the Agent-based model has been run in R to identify behavioural changes in two economies after introducing CBDC.

### Armenia

We have simulated 2000 consumers and 64 merchants along with a commercial bank and a central bank. From Figure 1, which shows the CBDC adoption rate over time, we can see that adoption starts from merchants, which enables consumers to pay with CBDC. Only in week 50, which represents approximately a year, their adoption rate equals. We can conclude that it takes a year for consumers to start actively using CBDC and demand for such payment service to merchants. After 100<sup>th</sup> week the rate takes a constant pace, meaning that CBDC becomes a part of daily payments.

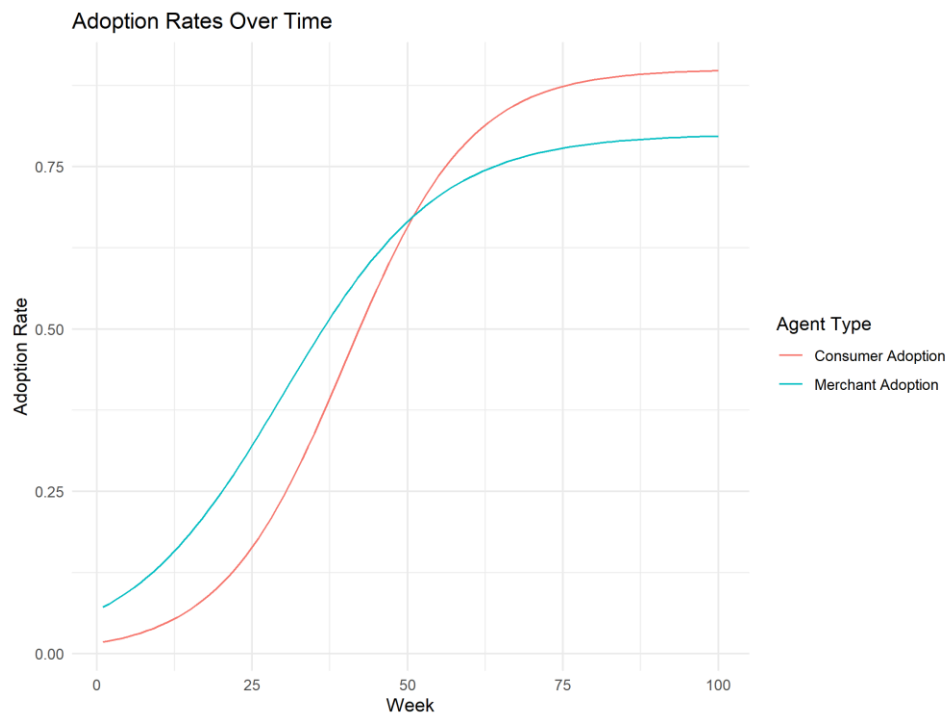


Figure 1: CBDC Adoption rates in Armenia over time

Next, from Figure 2, which shows the demand of payment types over time, we can observe that with the increase of CBDC, the cash usage declines, which is one of the goals of introducing CBDC (cashless society). However, the CBDC never takes over cash, considering the high level of cash transactions in Armenia (68%), the simulation result provides an accurate forecast for the real life. Despite the initial decrease in

card payments accompanied by CBDC increase, card payments are not much affected, as they are a necessary tool for CBDC top ups. It is interesting to observe deposits: the latter exhibits a reverse trend compared to CBDC path, however, as Armenian population has a slow adoption rate to innovation, deposits don't experience sharp decline, which explains the steady adoption of CBDC in 4-5 years (250 weeks).

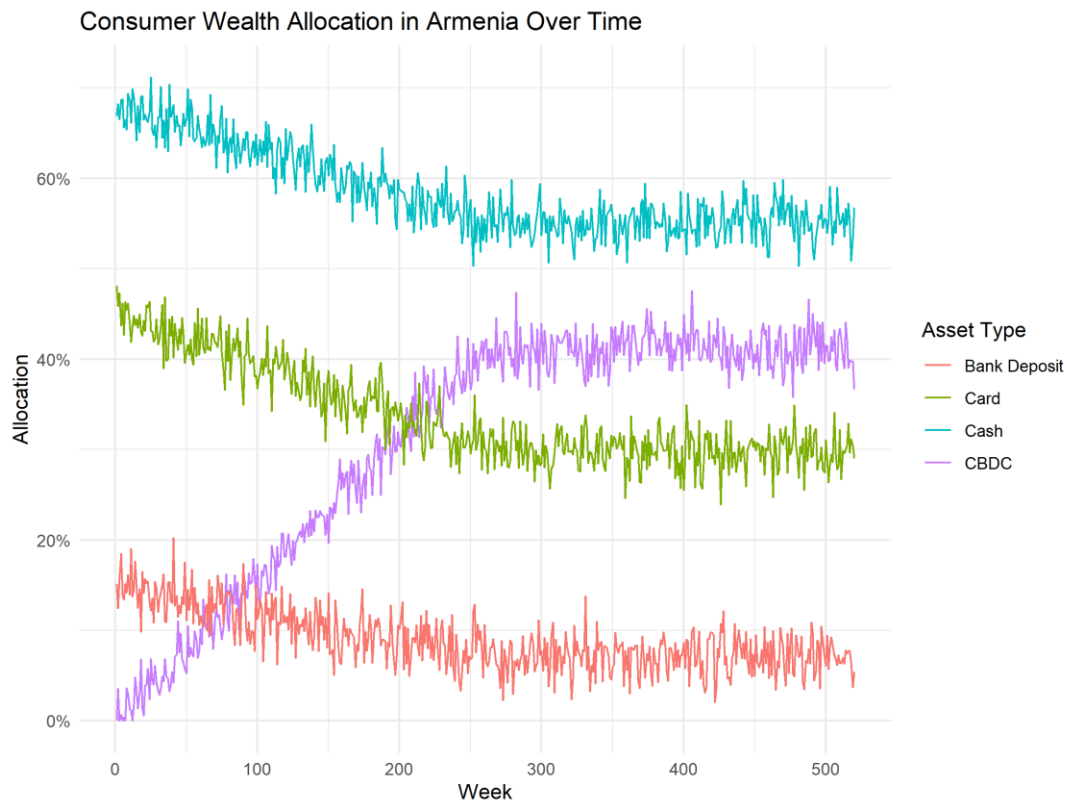


Figure 2: Consumer Wealth Allocation in Armenia over time

## Belgium

Moving forward to Belgium, we have simulated 8000 consumers and 471 merchants along with a commercial bank and a central bank. Unlike Armenia, the adoption of CBDC is quite fast in Belgium: over the first 3 months, consumers' acceptance rate exceeds the merchants, after which it takes a steady pace. This can be explained by the high number of card payments, that make the transition from cash to CBDC easy as there is no need for cash holders to open bank accounts since the majority of them already have one (79.5% for % age 15+).

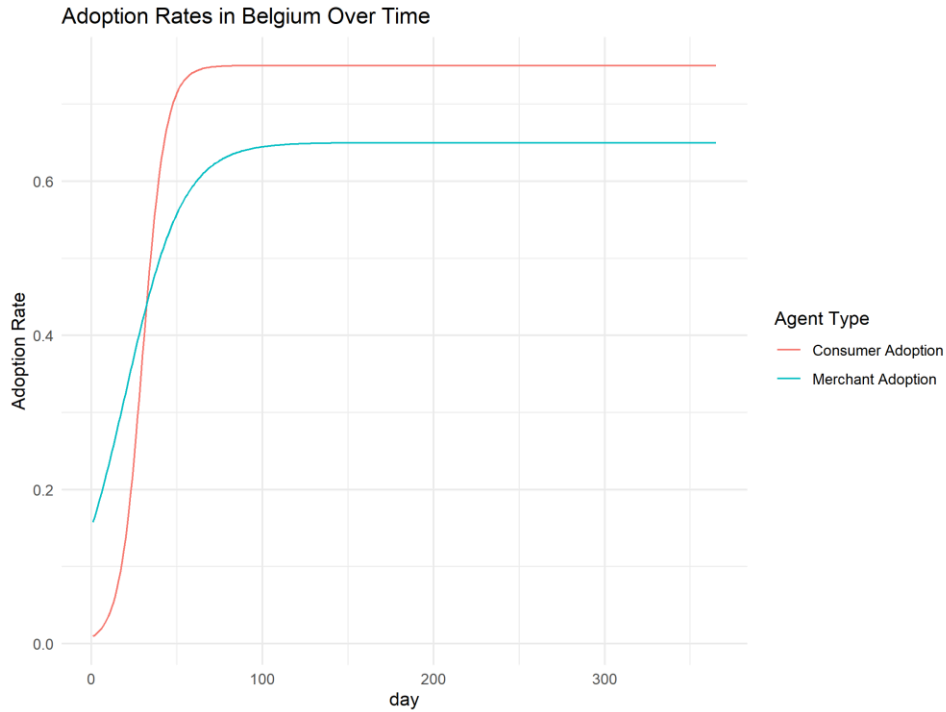


Figure 3: CBDC Adoption rates in Belgium over time

Figure 4 depicts that in less than 2 years CBDC disrupts the market and takes over all payment services and dominates the market. Both cash and card decline at 25% rate: in reality this is a 35 billion loss in cards and payments market size of Belgium. In the beginning 10% of deposit holders transfer their funds to CBDC, but then turn a constant rate.

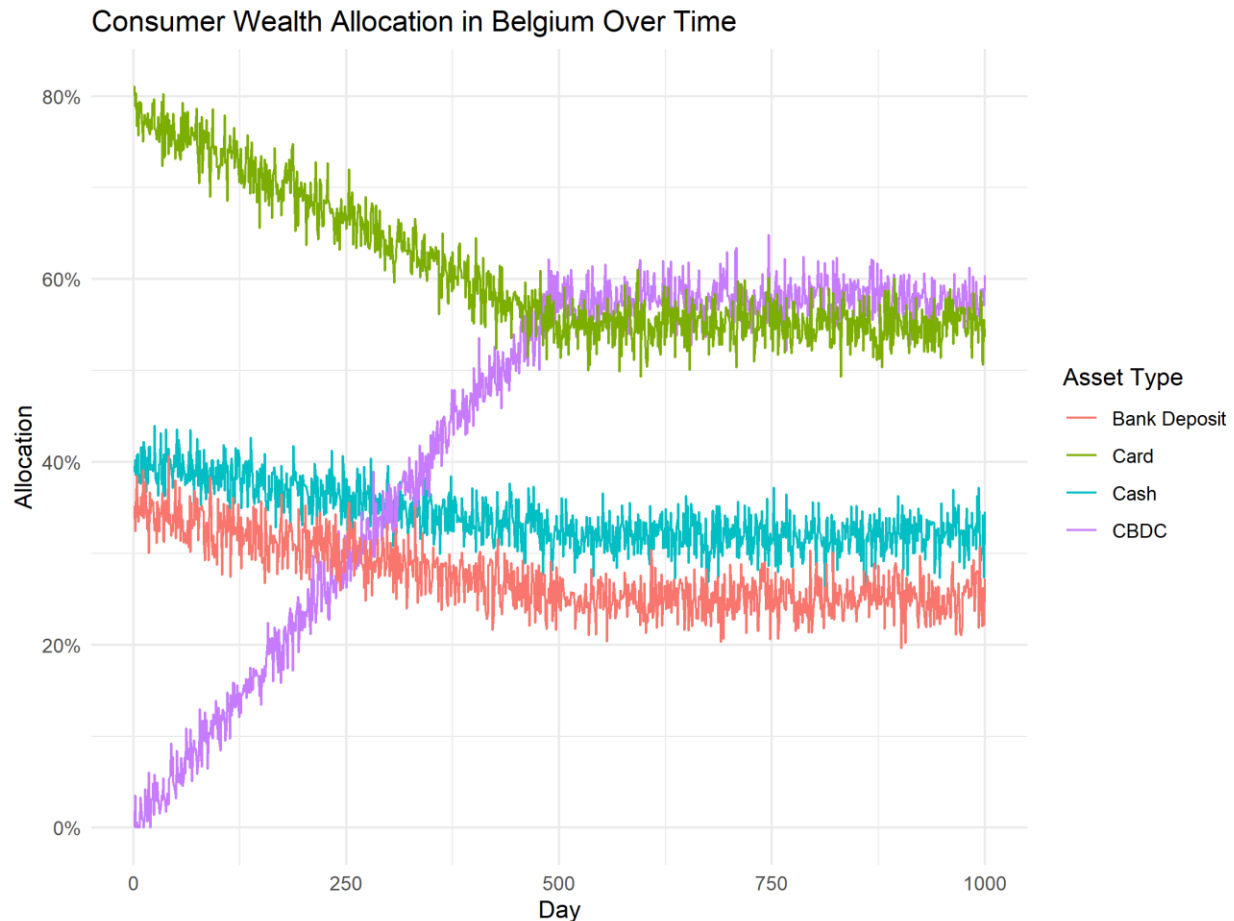


Figure 4: Consumer wealth allocation over time

## **Conclusion**

We have developed an agent-based model to simulate the adoption of CBDC in Armenia and Belgium considering their market situation and characteristics. The model observed the interactions between 4 agents: consumers, merchants, commercial bank and a central bank.

Thus, we found that Belgium has more optimistic results and adoption takes place faster than in Armenia. This was explained by the high financial inclusion in Belgium (99%) as CBDC top ups are done by cards. Nevertheless, in both countries, the cash and card transactions have a decline: in Armenia cash declines by nearly 10%, and card by 20%, while in Belgium both roughly have an equal decline rate of 25%, which indicates loss of 35 billion in cards and payments market size of Belgium, similarly the loss for Armenia 0.75 billion. Next, we studied the wealth allocation of consumers that displayed that over time consumers replaced some of their funds in cash to CBDC in both countries, yet deposits were mostly affected in Belgium due to the large number of demand deposit holders.

Given the results of ABM simulations and the current situation in Armenia, we can conclude that CBDC contributes to the replacement of cash, however, the change occurs gradually and only in the long term.

Hence, short term effects are limited, but in the midterm, an increase in financial inclusion and higher number of card holders can be expected.

In Belgium, the simulation results confirm both short and long-term effects. However, because of less domination of cash in Belgium, CBDC competes less with cash, than with other digital payment methods. This contains higher risks for commercial banks, as society chooses CBDC over deposits, causing a 3% loss of deposits in a year. Consequently, CBDC is expected to contribute to payments diversity and an increase in efficiency in Belgium, but the risks should be studied before implementation.

To contribute to the topic, additional simulations can be conducted to explore cross-border payment scenarios within the Eurozone markets for CBDC research.

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## Appendix

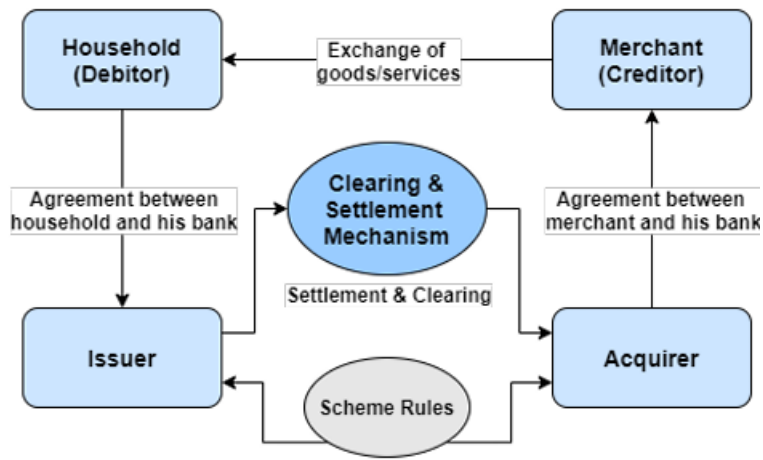


Figure 5: Corner model for card payments (Martens, M. (2021))

It is important to note that all currency-related values are converted to Euro to simplify the model. The conversion rate stands at: 1 Euro = 422 AMD.

Additional sources of consumers' parameters are the following:

The share of online purchases is taken from E-commerce data for Belgium (9.2%) and Armenia (5.1%).

The cash withdrawal and CBDC top up frequency is taken in accordance with Ramadiah (2021) and Vardanyan (2023) assumptions.