# Could CBDCs lead to cash extinction? Insights from a "merchant-customer" model

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# DISCLAIMER

# Motivation

- The payments system is rapidly evolving with the introduction of new electronic forms of money (digital assets, cryptocurrencies, stablecoins, etc)

- Many central banks are also contemplating or working on the introduction of central bank-issued digital currencies (CBDCs)

- What can be the impact of these innovations on the nature of the payments system, and can there be unintended effects (such as the disappearance of specific payments instruments, like cash, from the market)?

# Why is this important?

- Each payments instrument performs some specific functions that may not be as effectively carried out by others (for instance, cash has some specific properties in terms of anonymity, payments finality, resilience to outages, that are not fully replicated by electronic instruments);

- The disappearance of one instrument from the system is likely to be irreversible (reintroducing it can be costly and may require significant efforts)

- It is therefore important to predict the possibility of such events and to assess in advance their potential repercussions and whether action should be taken to prevent their occurrence

# This study is not specifically about cash, cards, or CBDCs

- We approach the question from a “neutral” theoretical perspective that can apply to *any type* of payments instruments

- Potential innovations include not only CBDCs but “private” digital currencies (or “digital assets”) such as stablecoins and cryptocurrencies

- Other “traditional” payments instruments could cease to be used (not only cash or credit/debit cards)

- The words “cash,” “cards” and “CBDCs” are used here for merely narrative purposes

# Method

- Merchant-Customer (M-C) model

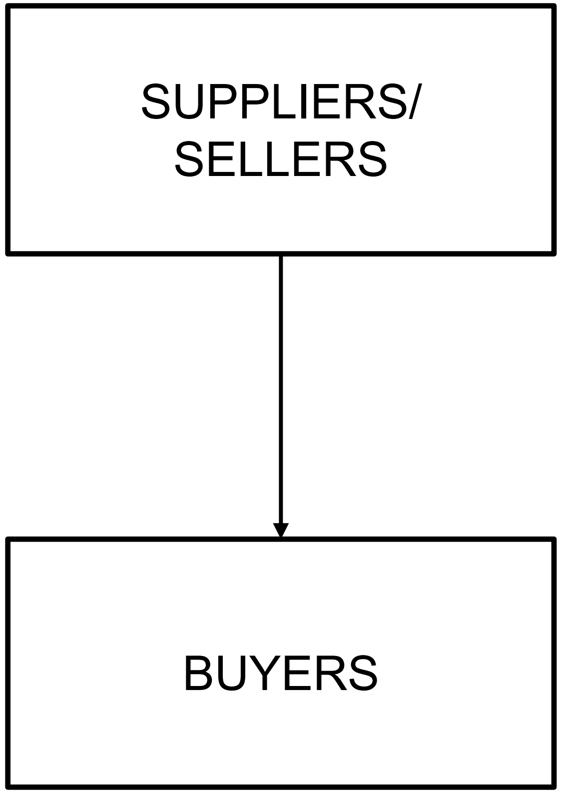
  builds on the literature on **two-sided markets:** e.g.

  Armstrong, *Rand Journal* 2003
  Ellison and Fudenberg, *QJE* 2003
  Rochet and Tirole, *JEEA* 2003
  Rysman, *JEP* 2009
  Schmalensee, *JIE* 2003

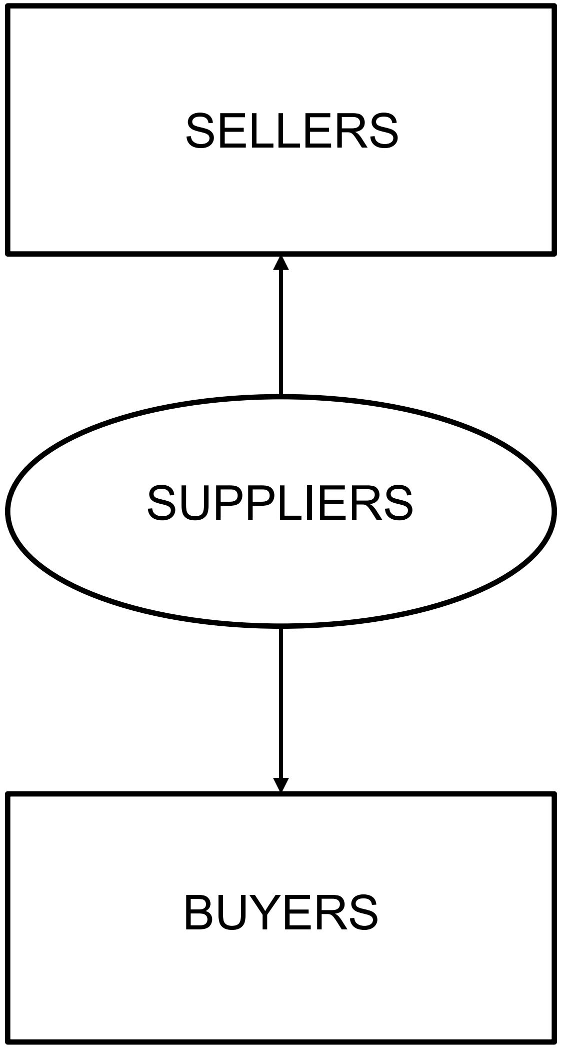
- Analytical results

- Numerical simulations

**ONE-SIDED MARKET**
**(APPLES)**




**TWO-SIDED MARKET**
**(CREDIT CARDS)**



# We run two models

- Model I: two currencies (“cash” and “cards”) – used to examine the type of equilibria and analyze the dynamics

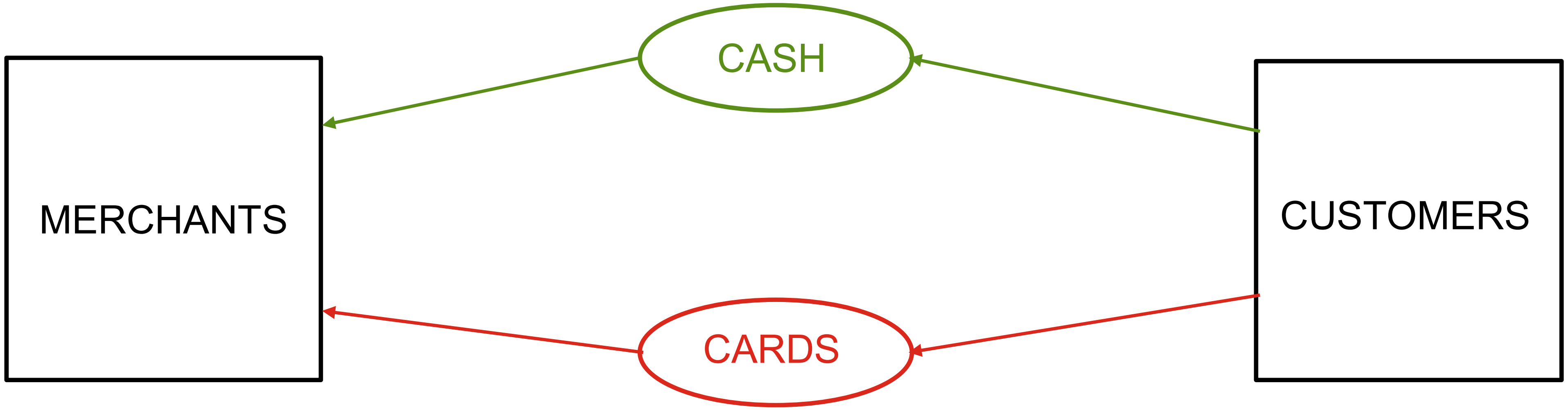
- Model II: three currencies (the above, plus “CBDCs”) – used to analyze what happens when a third currency is introduced perturbing a two-currency equilibrium

# Model I – two currencies

# The M-C Model

- We consider here two payments instruments (“platforms”), that we call “**cash**” and “**cards**”

- Both merchants and customers choose *individually* whether to accept/carry only cash, only cards, or both



MERCHANT AND CUSTOMER ARE RANDOMLY MATCHED

MERCHANT

CUSTOMER

| | ACCEPTS CASH | ACCEPTS CARDS | ACCEPTS BOTH |
|---|---|---|---|
| CARRIES CASH | PAYMENT IN CASH | **NO SALE** | PAYMENT IN CASH |
| CARRIES CARDS | **NO SALE** | PAYMENT IN CARDS | PAYMENT IN CARDS |
| CARRIES BOTH | PAYMENT IN CASH | PAYMENT IN CARDS | **CUSTOMER DECIDES** |

# Heterogenety:

- Merchants have different (uncorrelated) fixed costs $p_c$ and $p_d$ for both instruments, uniformly distributed between 0 and $p_{cH}$ for cash and between 0 and $p_{dH}$ for cards;

- Customers have different variable benefits (negative costs) $\beta_i$ for using cash (while they all perceive the same variable benefit, $r_d$, if they pay with cards)

- Hence each player has different incentives *ex ante* concerning the choice of instrument

- Model parameters are common knowledge; all players observe the decisions of the players on the other side of the market

# Parameters of the game
(costs/benefits of using cash and cards)

| | CUSTOMER carrying CASH | CUSTOMER carrying CARDS | MERCHANT accepting CASH | MERCHANT accepting CARDS |
|---|---|---|---|---|
| FIXED COST | $c_f$ | $c_d$ | $p_c$ (varies among merchants) | $p_d$ (varies among merchants; uncorrelated with $p_c$) |
| VARIABLE COST | -- | -- | $q_c$ | $q_d$ |
| VARIABLE BENEFIT | $\beta_i$ (varies among customers) | $r_d$ | -- | -- |
| COST OF MISSING A TRANSACTION | $w$ | $w$ | $\xi$ | $\xi$ |

# Customer’s payoff matrix

Merchant accepts:

Customer carries:

| | Cash | Cards | Both |
|---|---|---|---|
| Cash (fixed cost $c_f$) | $c_f - \beta_i$ | Missed transaction: $c_d + x$ | $c_f - \beta_i$ |
| Cards (fixed cost $c_d$) | Missed transaction: $c_d + x$ | $c_d - r_d$ | $c_d - r_d$ |
| Both (fixed cost $c_f$ | $c_f + c_d - \beta_i$ | $c_f + c_d - r_d$ | $c_f + c_d - \max(\beta_i, r_d)$ |

# Merchant's payoff matrix

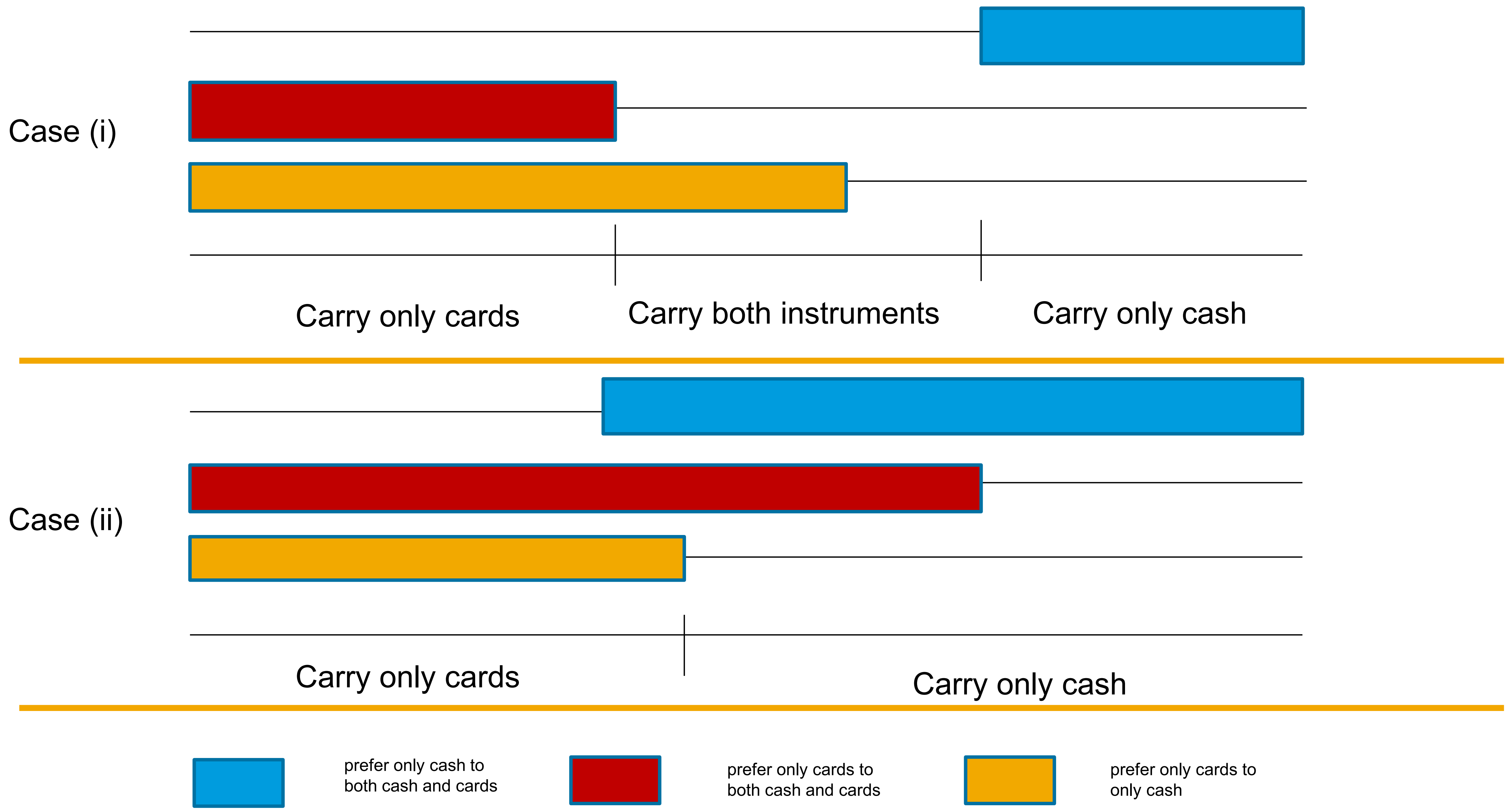
Merchant accepts:

Customer carries:

| | Cash (C) (fixed cost $p_c$) | Cards (D) (fixed cost $p_d$) | Both (B) (fixed costs $p_c$ $p_d$) |
|---|---|---|---|
| Cash (C) | $p_c + q_c$ | Missed transaction: $p_d + \xi$ | $p_c + p_d + q_c$ |
| Cards (D) | Missed transaction: $p_c + \xi$ | $p_d + q_d$ | $p_c + p_d + q_d$ |
| Both (B) | $p_c + q_c$ | $p_d + q_d$ | $p_c + p_d + q_c$ *or* $p_c + p_d + q_d$ (customer decides) |

# Outcome on the customers' side

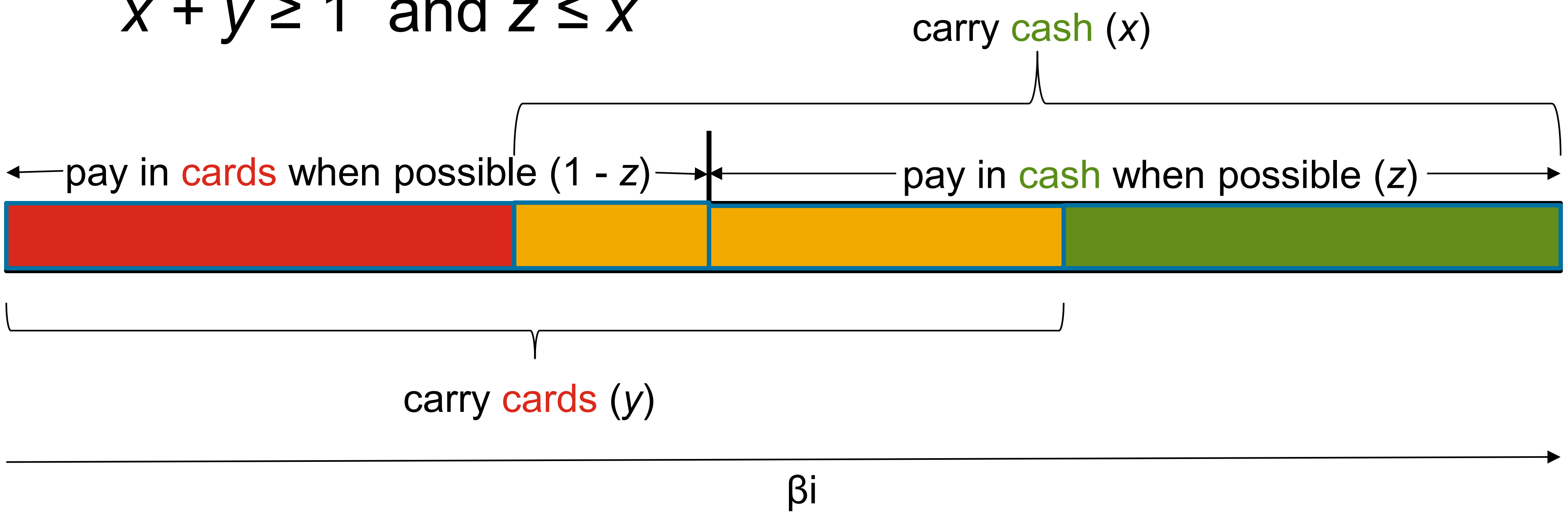
- A share $x$ of customers carry cards, a share $y$ carry cash; $x + y \geq 1$
- A share $z$ actually pays in cash *when given the option;* $z \leq x$
- The values of $x$, $y$, $z$ depend on the parameters of the model *and on the merchants' decisions*
- *The vector* $\omega = \{ x, \mathrm{y}, \mathrm{z} \}$ represents the customers' decisions
- Let the vector $\pi$ represents the merchant's decisions; then a vector $\omega = f(\pi)$ represents the customers' best response to $\pi$


Case (i)
Carry only cards
Carry both instruments
Carry only cash
Case (ii)
Carry only cards
Carry only cash
prefer only cash to both cash and cards
prefer only cards to both cash and cards
prefer only cards to only cash

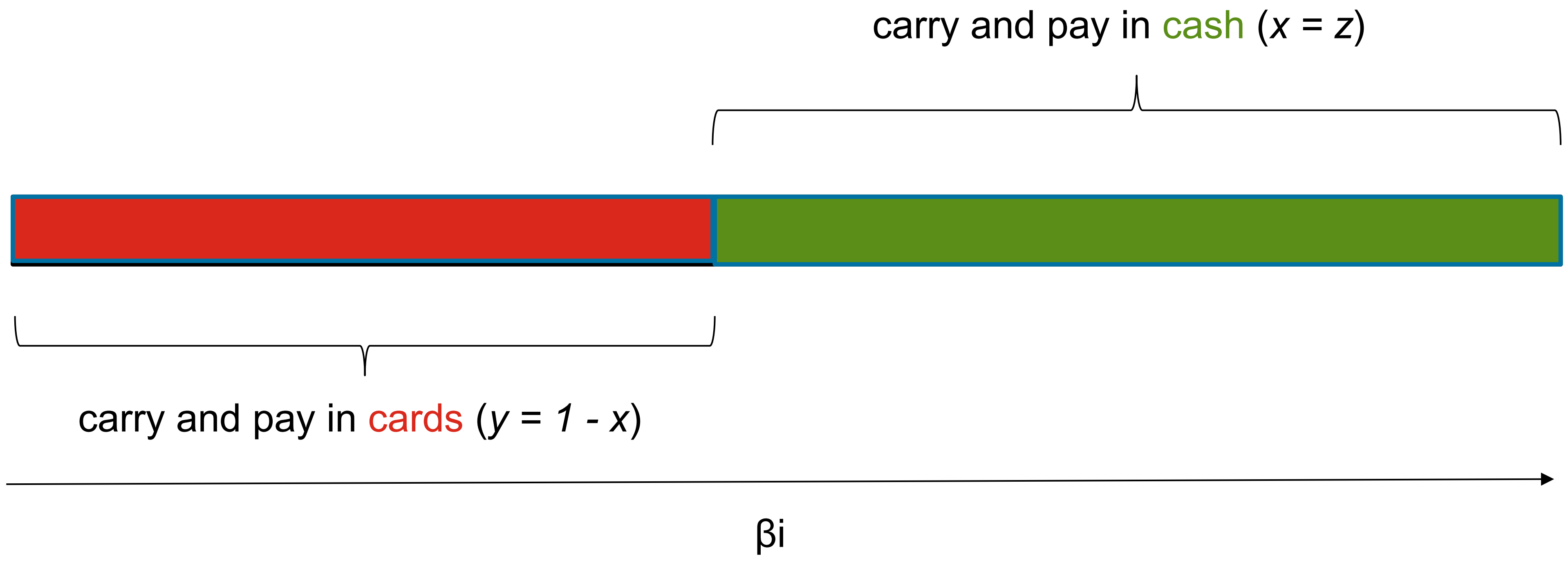
# Outcome on the customers' side

- $x$% of customers carry cash
- $y$% of customers carry cards
- $z$% of customers use cash when given the option

$$x + y \geq 1 \quad \text{and } z \leq x$$



# If $x + y = 1$ then $z = x$ and each customer carries only one instrument

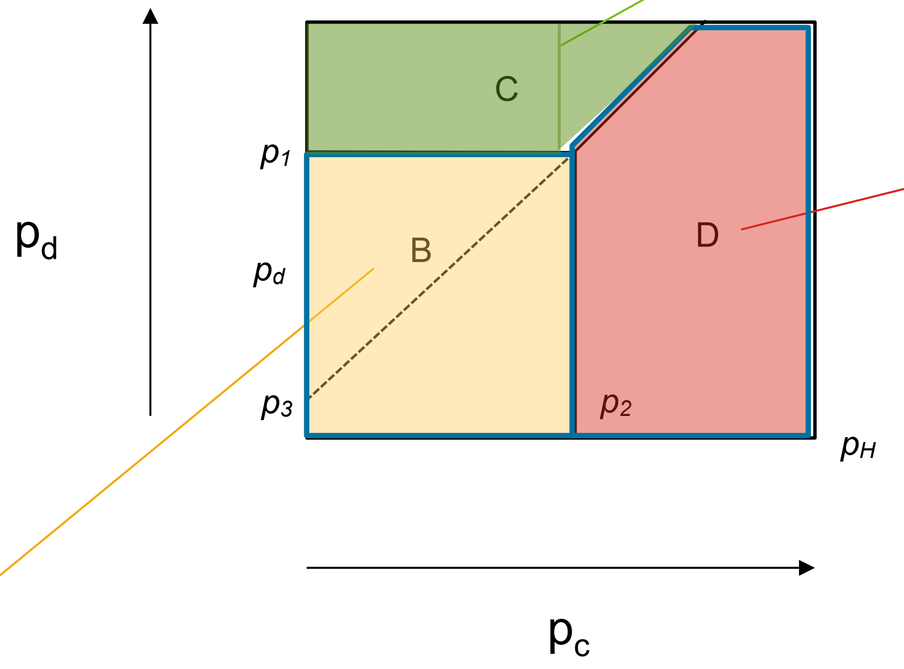



OTHER CASES ARE POSSIBLE DEPENDING ON THE MERCHANTS’ DECISIONS AND ON THE VALUE OF THE PARAMETERS

# Merchant's decision

- The merchant prefers:
  - C to B if $p_d > p_1 = (\xi - q_d) + (q_c - \xi)x + (q_d - q_c)z$
  - D to B if $p_c > p_2 = \xi - q_d + (q_d - \xi)y + (q_d - q_c)z$
  - C to D if $p_d - p_c > p_3 = (q_c - \xi)x - (q_d - \xi)y$
- The space of fixed costs $\{p_c, p_d\}$ which represents the population of merchants can thus be divided in *three regions* depending on each merchant's preferred choice, *given the values of the parameters and the choices made by customers*
- The size of Region C ($\pi_c$) measures how many merchants accept only cash; the size of Region D ($\pi_d$) measures how many accept only cards, and the size of Region B ($1 - \pi_c - \pi_d$) measures how many merchants accept both instruments

# Like customers, merchants are (generally) divided in three groups




DEPENDING ON THE VALUES OF THE PATRAMETERS AND ON THE CUSTOMERS' ACTIONS, ONE OR TWO OF THESE GROUPS CAN BE EMPTY

# Outcome on the merchants' side

- $\pi_c$% of merchants accept only cash
- $\pi_d$% of merchants accept only cards
- The rest ($1 - \pi_c - \pi_c$) accept both cash and cards

$$\pi_c + \pi_d \leq 1$$

- The values of $\pi_c$ and $\pi_d$ depend on the parameters of the model *and on the customers' decisions* (vector $\omega$)

- The best responses of customers and merchants to the decisions taken on the other side of the market are not, generally, mutually compatible: *one side's* action is *NOT in general equal to that side's best response to the other side's best response to that action:* $f(g(\omega)) \neq \omega$ and $g(f(\pi)) \neq \pi$

# Equilibria

- An equilibrium is a set of mutually compatible decisions (where decisions on both sides are the best response to decisions on the other side) – formally, when

$$g(f(\omega)) = \omega \text{ and } f(g(\pi)) = \pi$$

- The equilibria depend on the value of the exogenous parameters

# Dynamics

- We assume that **customers respond *instantaneously* to merchants' decisions** (which are common knowledge); merchants respond with a lag; in each period, **a fraction $\gamma$ of merchants responds to customers' *previous period*'s decisions**, the rest do not change their decisions

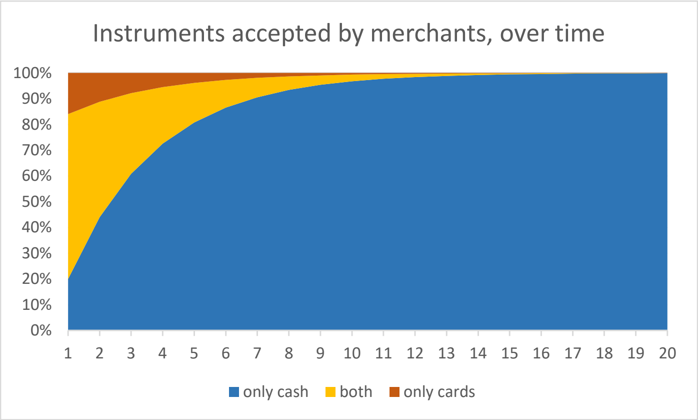
- Vector $\pi_t$ (and $\omega_t = f(\pi_t)$) represents the ***state of the system*** at time $t$

- The ***law of motion*** of the system is thus

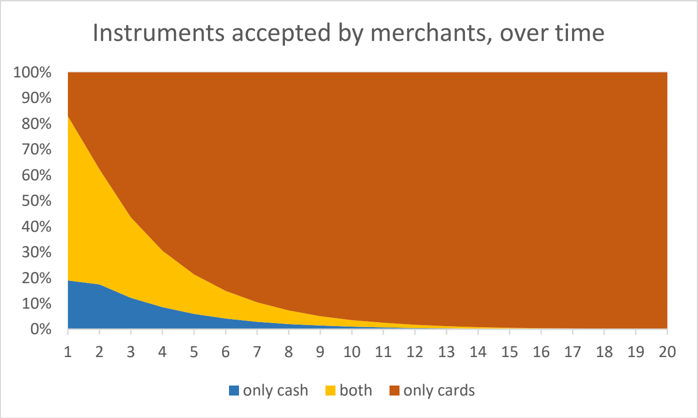
$$\pi_{t+1} = \gamma g(\omega_t) + (1 - \gamma)\, \pi_t = \gamma g(f(\pi_t)) + (1 - \gamma)\, \pi_t = \zeta(\pi_t)$$

- A succession of states $\{\pi_0, \pi_1, \pi_2 \ldots\}$ such that $\pi_{t+1} = \zeta(\pi_t)$ is **a *path* or *trajectory* of the system**. Since the law of motion only depends on the current state, each state lies only on one path.

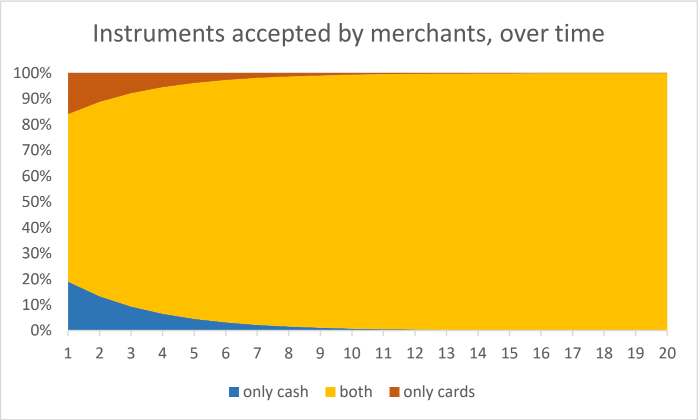
# As the system proceeds along a path, the share of merchants accepting only cash, only cards, or both changes over time, converging to…



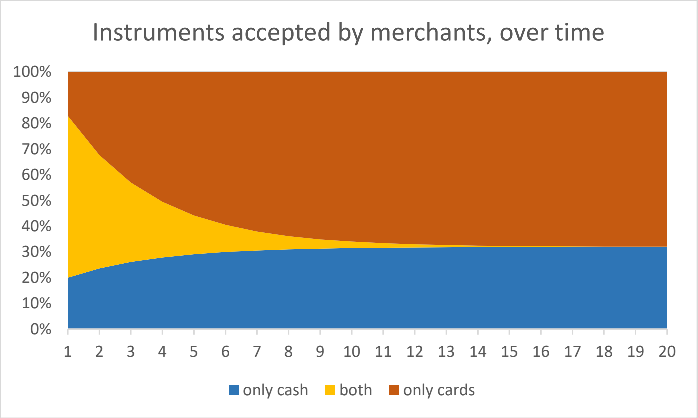

A cash-only equilibrium




A cards-only equilibrium

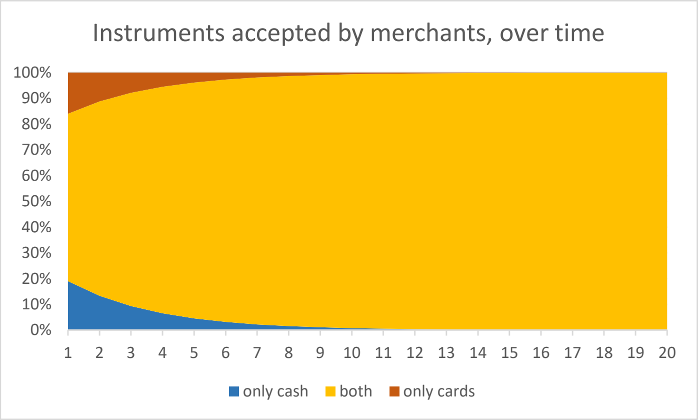



An equilibrium where all merchants accept both cash and cards

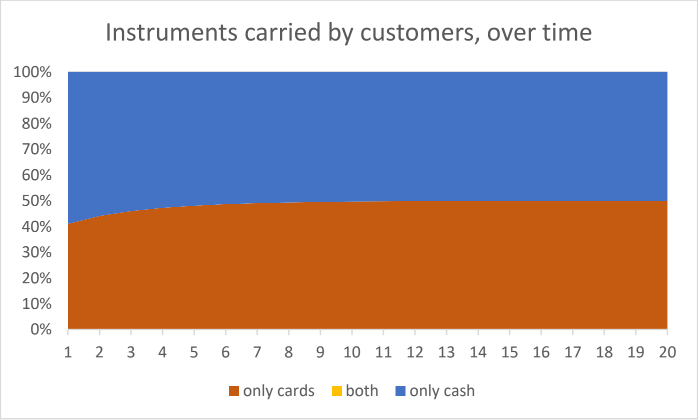



An equilibrium where some merchants accept only cash and others only cards

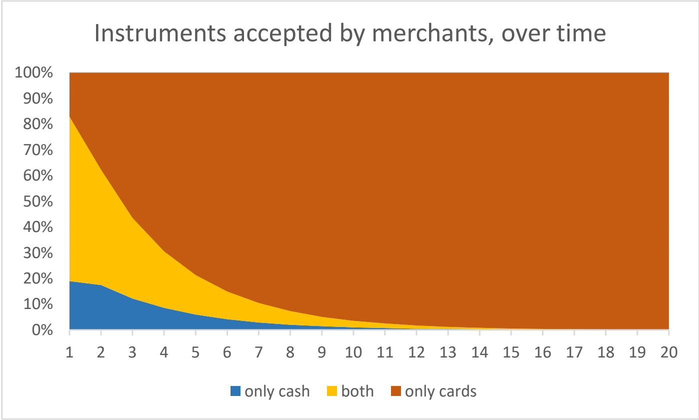
# The share of customers carrying cash, cards, or both also changes, in response to merchants’ decisions

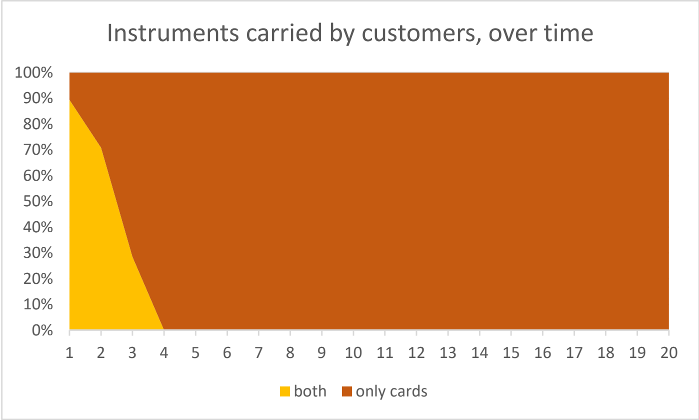



Here all customers carry both instruments




Here each customer carries either cash or cards, and the share of the two groups stabilizes over time




Here the number of customers carrying cash falls gradually to zero

# Question 1: can more instruments coexist indefinitely in the market?

- Some configurations of parameters admit only single-platform equilibria (in the long run one of the two instruments disappears)
- Others however exhibit also equilibria where both instruments are used
- These typically include equilibria where all agents on one side (e.g. merchants) use both instruments while every agent on the other side (e.g. customers) uses only one (but their choice of instrument differs)

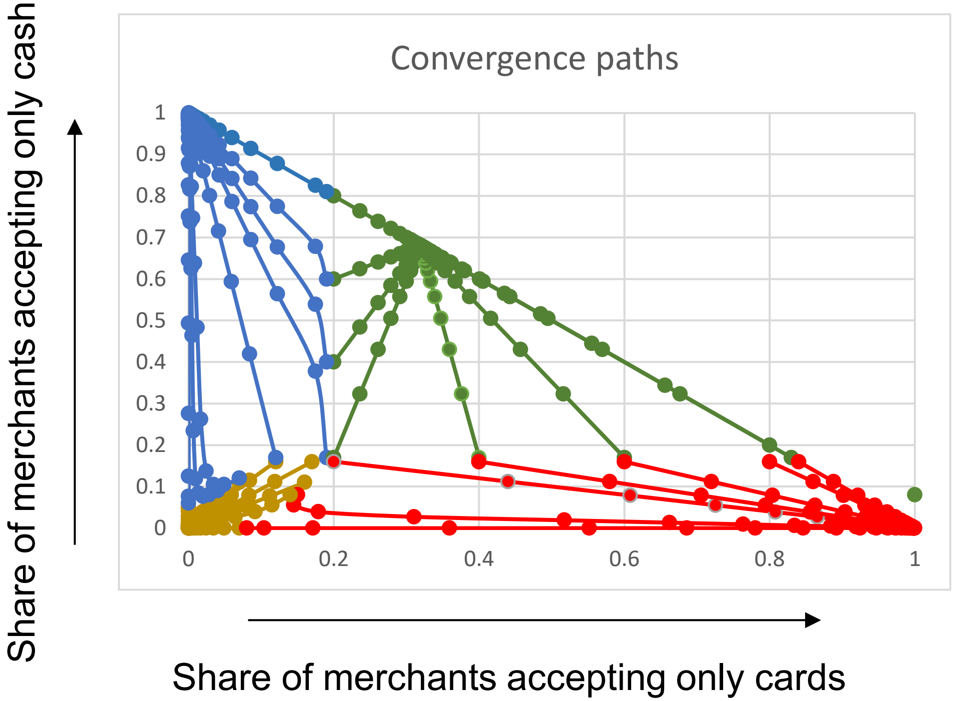
# Question 2: is the final outcome predictable?

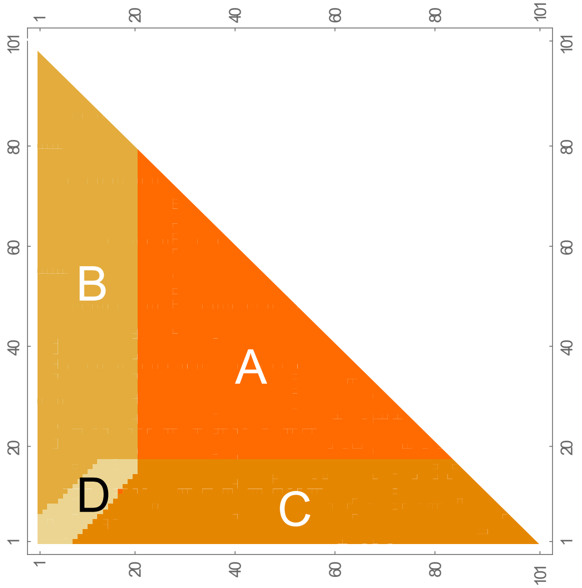
- In theory yes (this model is deterministic)

- In practice in some situations it can be unclear where the system will converge: states that are very close to each other may lie on paths that converge to very different equilibria

- In these situations, a small perturbation can produce a lasting impact on the evolution of the system

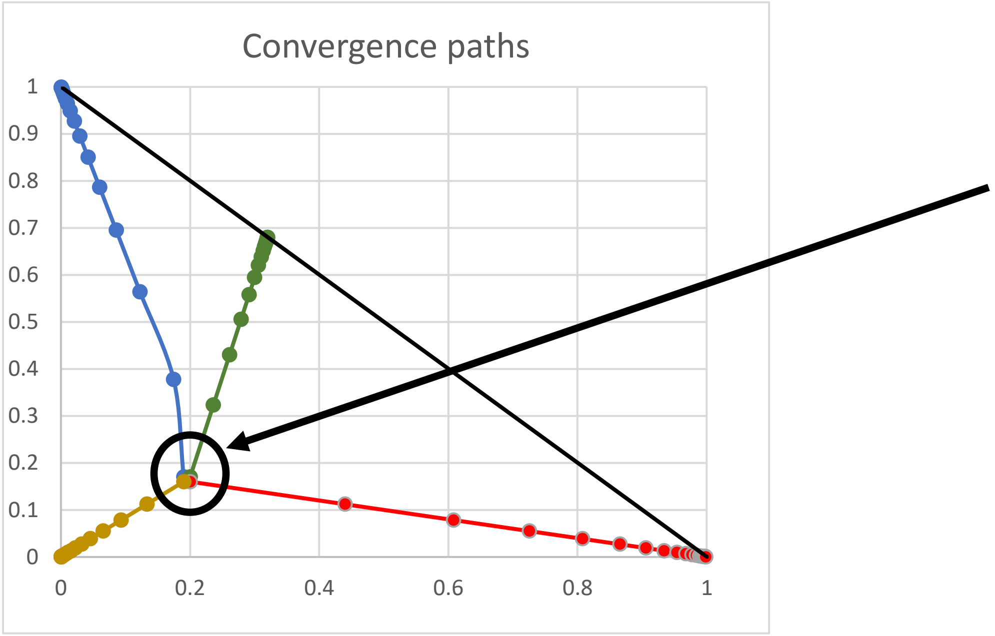
# The space of feasible states can be divided into different "basins of attractions" containing paths that converge to different equilibria




**Basins of attraction:**
A: mixed equilibrium – customers carry both instruments
B: cash-only equilibrium
C: cards-only equilibrium
D: mixed equilibrium – all merchants accept both instruments

# Some neighborhoods contain states that lie on paths converging to very different equilibria




When the system lies in such neighborhoods, its long-term evolution may be difficult to predict

# Question 3: can the system converge to a suboptimal equilibrium?

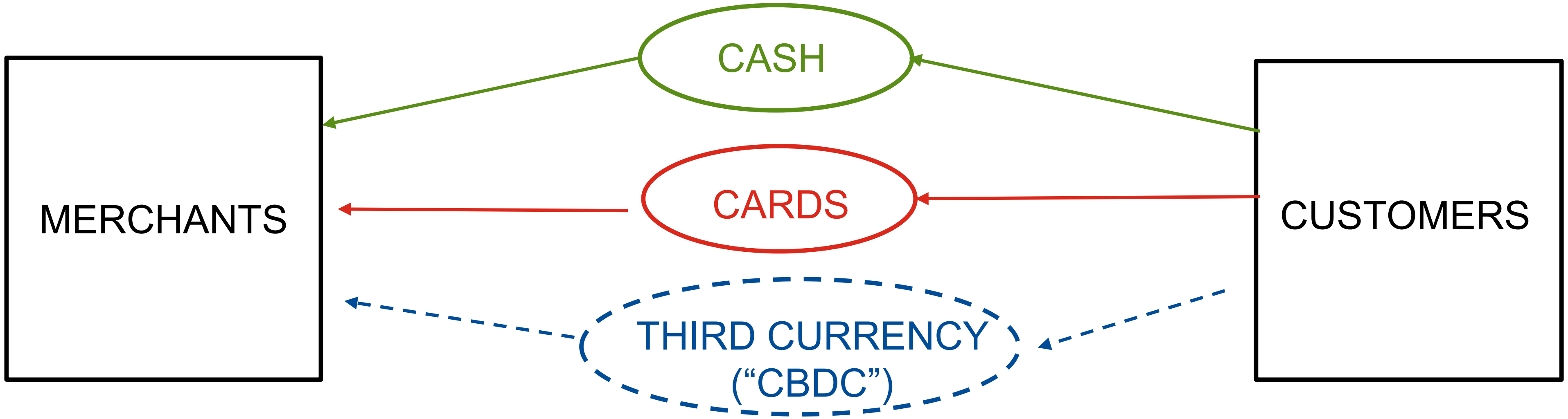
- Yes. The system can converge to an equilibrium that is stable but is Pareto-dominated by some other equilibrium (all players would prefer the other equilibrium).

# Model II – three currencies

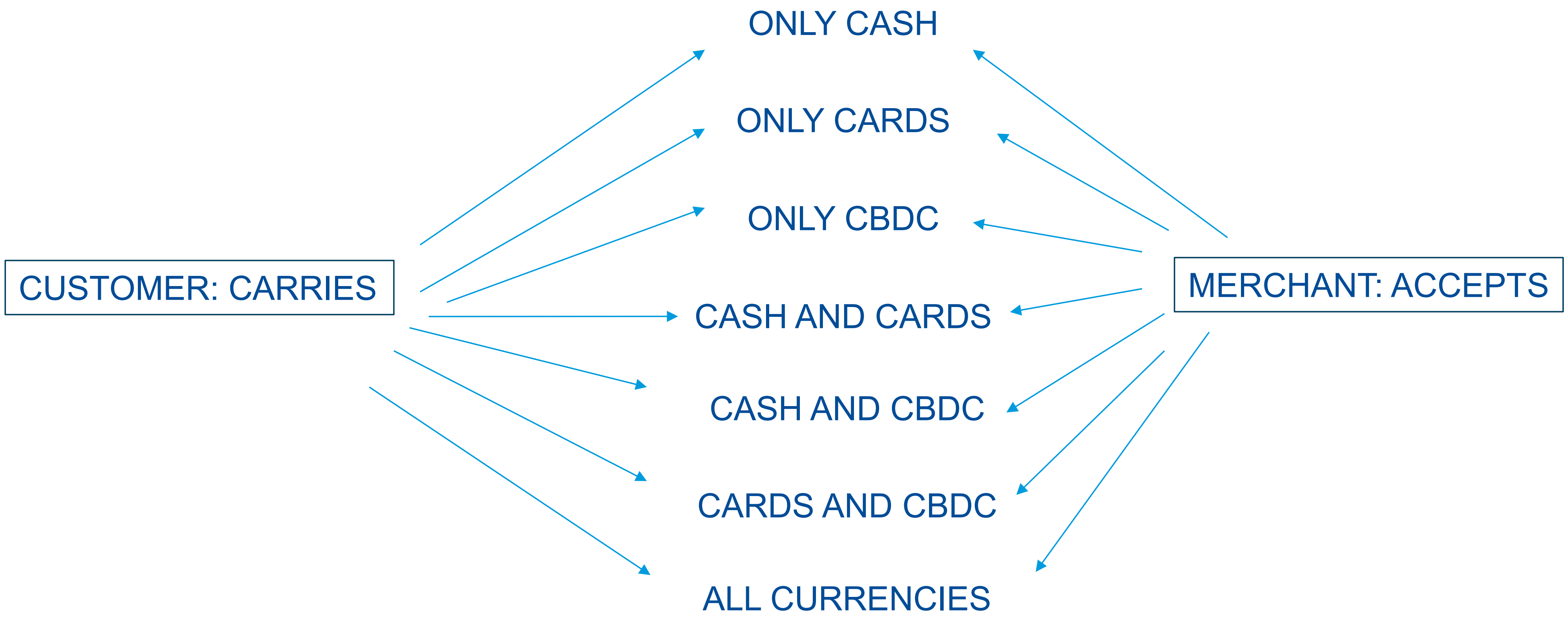
# The three-currency Model

- Besides "cash" and "cards", a third currency may be used, which we call "CBDC"

- As in the two-currency model, both merchants and customers *individually* choose which currencies they carry or accept; they may choose one, two, or all three



# Possible choices



# Parameters of the game
(costs/benefits of using cash and cards)

| | CUSTOMERS | | | MERCHANTS | | |
|---|---|---|---|---|---|---|
| | Carrying cash | Carrying cards | Carrying CBDC | Accepting cash | Accepting cards | Accepting CBDC |
| **FIXED COST** | $c_f$ | $c_d$ | $c_z$ | $p_C$ | $p_D$ | $p_z$ |
| **VARIABLE COST** | -- | -- | -- | $q_C$ | $q_D$ (varies among merchants) | $q_z$ |
| **VARIABLE BENEFIT** | $\beta_i$ (varies among customers) | $r_d$ | $r_z$ | -- | -- | -- |

# Customer's payoff matrix

ONLY FOUR COLUMNS OF SEVEN ARE SHOWN

Merchant accepts:

Customer carries:

| | Cash | Cards | Cash and cards |
|---|---|---|---|
| Cash (fixed cost $c_f$) | $c_f - \beta_i$ | Missed transaction: $c_d + w$ | $c_f - \beta_i$ |
| Cards (fixed cost $c_d$) | Missed transaction: $c_d + w$ | $c_d - r_d$ | $c_d - r_d$ |
| Cash and cards | $c_f + c_d - \beta_i$ | $c_f + c_d - r_d$ | $c_f + c_d - (\beta_i + r_d)/2$ |
| CBDC (fixed cost $c_z$) | Missed transaction: $c_z + w$ | Missed transaction: $c_z + w$ | Missed transaction: $c_z + w$ |
| Cash and CBDC | $c_f + c_z - \beta_i$ | Missed transaction: $c_f + c_z + w$ | $c_f + c_z - (\beta_i + r_z)/2$ |
| Cards and CBDC | Missed transaction: $c_d + c_z + w$ | $c_d + c_z - r_d$ | $c_d + c_z - r_d$ |
| All currencies | $c_f + c_d + c_z - \beta_i$ | $c_f + c_d + c_z - r_d$ | $c_f + c_d + c_z - (\beta_i + r_d)/2$ |

# Merchant's payoff matrix

ONLY FOUR COLUMNS OF SEVEN ARE SHOWN

Customer carries:

Merchant accepts:

| | Cash | Cards | Cash and cards |
|---|---|---|---|
| Cash<br><br>(fixed cost $p_c$) | $p_c + q_c$ | Missed transaction:<br><br>$p_c + \xi$ | $p_c + q_c$ |
| Cards<br><br>(fixed cost $p_d$) | Missed transaction:<br><br>$p_d + \xi$ | $p_d + q_d$ | $p_c + p_d + q_d$ |
| Cash and cards | $p_c + p_d + q_c$ | $p_c + p_d + q_d$ | $p_c + p_d + (q_c + q_d)/2$ |
| CBDC<br><br>(fixed cost $p_z$) | Missed transaction:<br><br>$p_z + \xi$ | Missed transaction:<br><br>$p_z + \xi$ | Missed transaction:<br><br>$p_z + \xi$ |
| Cash and CBDC | $p_c + p_z + q_c$ | Missed transaction:<br><br>$p_c + p_z + \xi$ | $p_c + p_z + q_c$ |
| Cards and CBDC | Missed transaction:<br><br>$p_d + p_z + \xi$ | $p_d + p_z + q_d$ | $p_d + p_z + q_d$ |
| All currencies | $p_c + p_d + p_z + q_c$ | $p_c + p_d + p_z + q_d$ | $p_c + p_d + p_z + (q_c + q_d)/2$ |

# Matched customer and merchant carry:

- Different sets of currencies that do not overlap
- Different sets of currencies with only ONE currency in common
- Different sets of currencies with MORE THAN ONE currency in common
- The same currency
- The same set of currencies

NO SALE TAKES PLACE

THAT CURRENCY IS USED

ONE OF THE COMMON CURRENCIES IS RANDOMLY SELECTED AND USED

# Outcome on the merchants' side

- $\pi_c$% of merchants accept only cash
- $\pi_d$% of merchants accept only cards
- $\pi_{cd}$% of merchants accept cash and cards; *etc*

$$\pi_c + \pi_d + \pi_{cd} \ldots = 100\%$$

A SIMILAR OUTCOME (WITH VALUES $x_c$, $x_d$, $x_{cd}$, *etc*) OCCURS ON THE CUSTOMERS' SIDE

- The vector $\omega = \{x_c, x_d, x_z, x_{cd}, x_{cz}, x_{dz}, x_{cdz}\}$ represents the customers' decisions

- The vector $\pi = \{\pi_c, \pi_d, \pi_z, \pi_{cd}, \pi_{cz}, \pi_{dz}, \pi_{cdz}\}$ represents the merchants' decisions

- Let $f(\pi)$ be the customers' best response to $\pi$ and let $g(\omega)$ be the merchants' best response to $\omega$

- In general $f(g(\omega)) \neq \omega$ and $g(f(\pi)) \neq \pi$

# Types of equilibria

- In some equilibria all agents use only one currency
- In others agents on one side use all currencies (or a subset) and agents on the other side use only one
- Other types of equilibria are also possible but are less frequently observed in numerical simulations

# Simulations

- Starting from an equilibrium in which two currencies are used, we simulate the effects of the introduction of a third currency on various scales (small: 1%; medium: 5%; large: 25%).

- Two launch modalities:

**“COMPLEMENT”**:
THE NEW CURRENCY IS ACCEPTED ALONGSIDE THE OTHER TWO

**“SUBSTITUTE”**:
THE NEW CURRENCY IS INTRODUCED AS AN ALTERNATIVE TO ONE OF THE OTHERS

# Key results

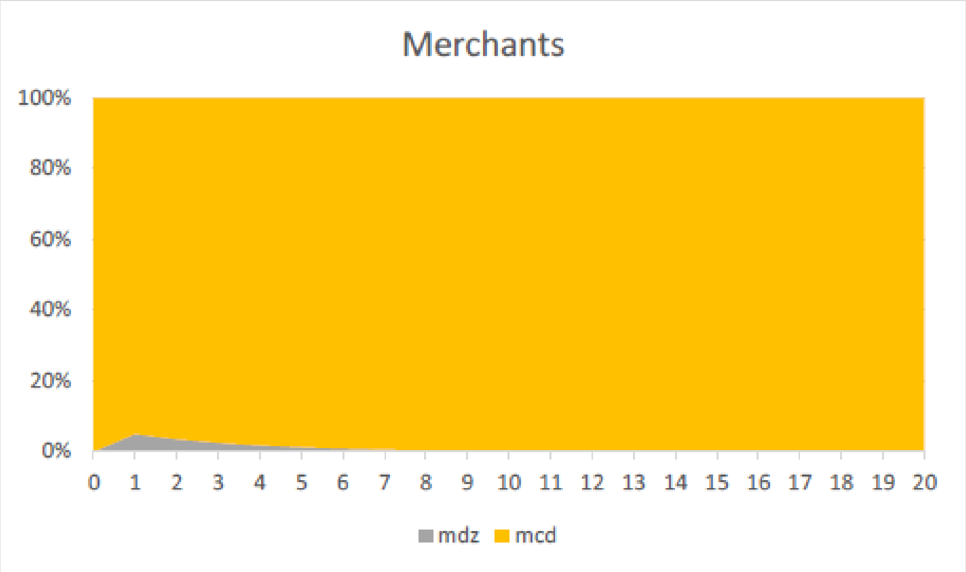
- A new currency is successful only if it is launched on a sufficiently large scale
- A new currency launched as a “complement” to existing currencies is not successful (this results deserves further investigation; in real situations success may depend, among other factors, on cross elasticities of substitution)
- A new currency can lead to the extinction of other currencies even when it is not successful

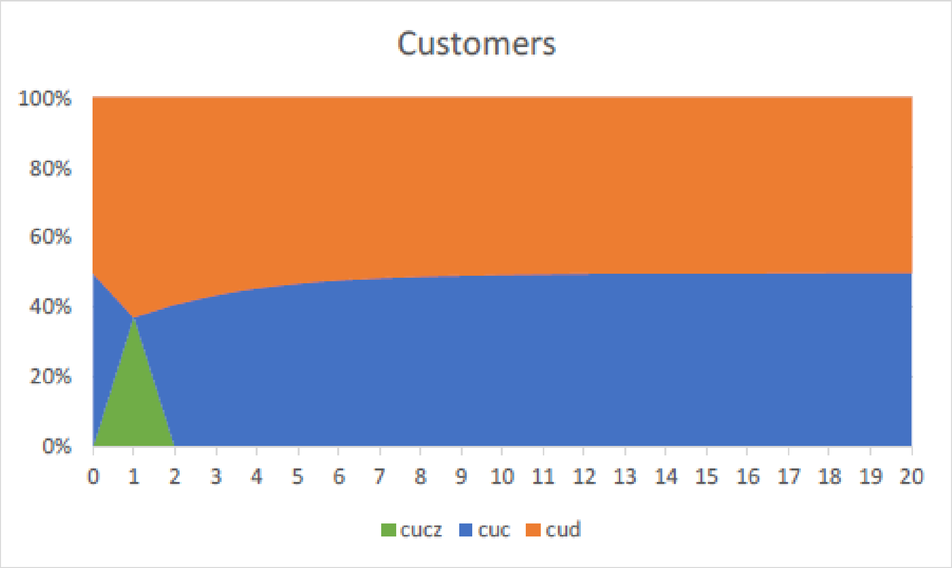
# Examples from the simulations

The following examples are all obtained simulating the **medium-scale** launch of a new currency as a **substitute** to one of the others

They highlight four qualitatively different outcomes

# Outcome 1: unsuccessful launch / unchanged equilibrium

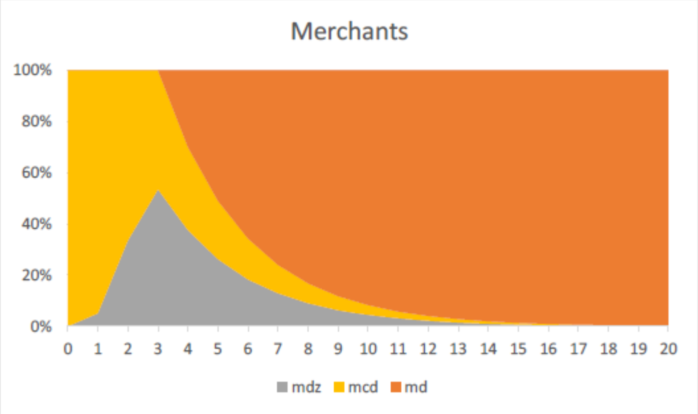


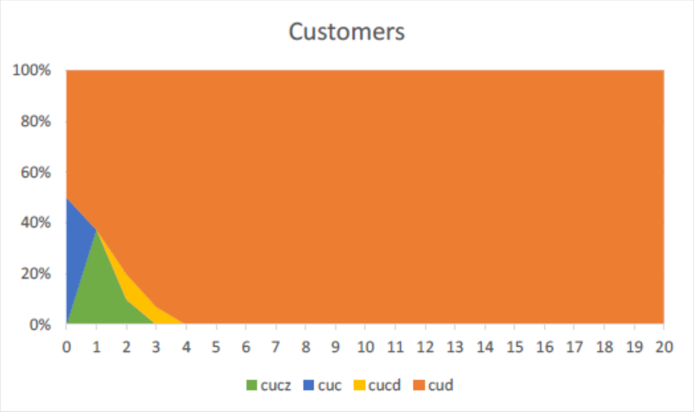



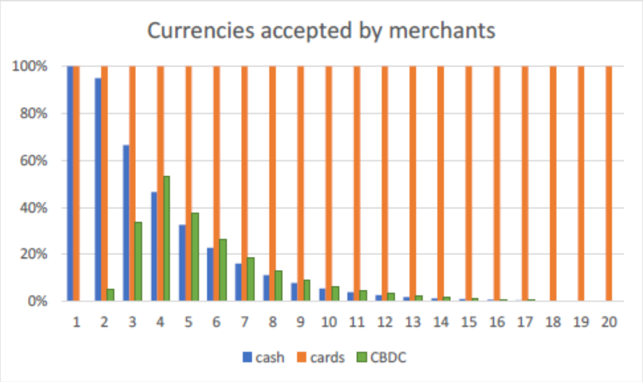

Source: Authors' simulations.

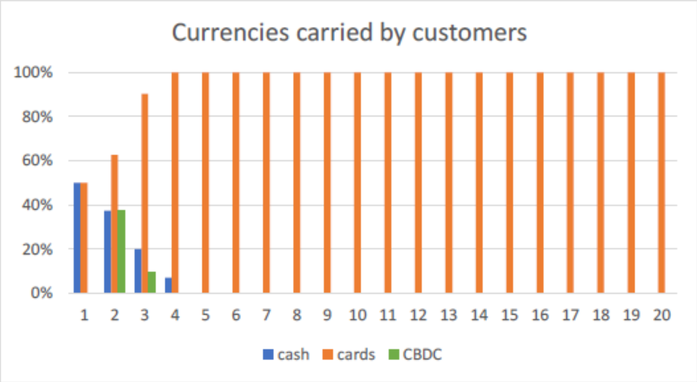
Note: Color code for line charts: blue = only cash; orange = only cards; red = only DC; yellow = cash and cards; green = cash and DC; gray = cards and DC. The horizontal axis shows periods from 0 to 20; the DC is launched in Period 1.

# Outcome 2: unsuccessful launch / extinction of one currency



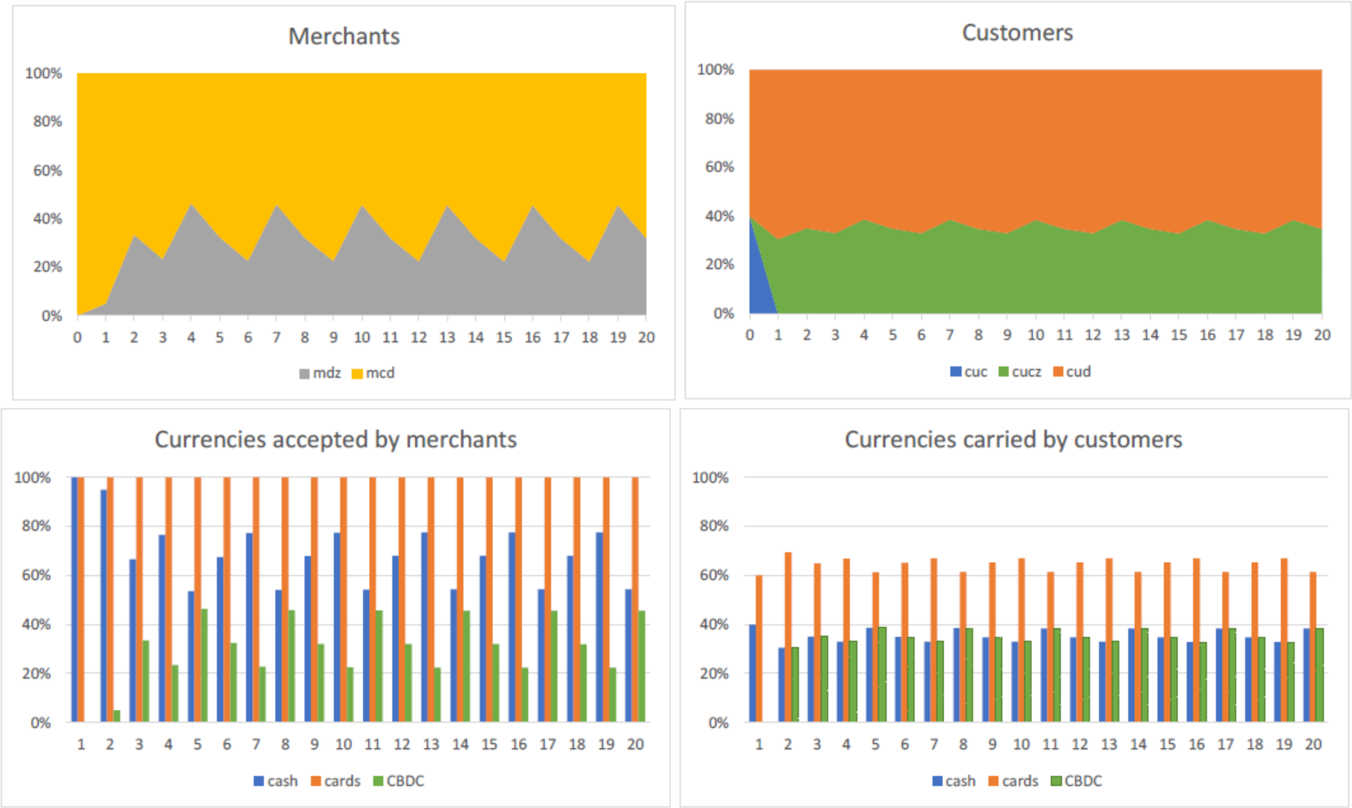




Source: Authors' simulations.
Note: Color code for line charts: blue = only cash; orange = only cards; red = only DC; yellow = cash and cards; green = cash and DC; gray = cards and DC. Color code for bar charts: blue = cash; orange = cards; green = DC. The horizontal axis shows periods from 0 to 20; the DC is launched in Period 1.

# Outcome 3: successful launch / new multi-currency equilibrium




Source: Authors' simulations.

# Outcome 4: successful launch / extinction of all other currencies


Source: Authors' simulations

# In conclusion

- Could a new currency replace one/more/all other currencies?

  → **YES**

- Could a new currency coexist in equilibrium with the others?

  → **YES**

- Could a new currency lead to the extinction of one of the others even if it fails to be accepted in the system?

  → **YES**

# Some final considerations

*A priori* it may be difficult to predict the outcome.

Entities planning the launch of a new currency
should beware of these (and similar) unintended effects.