DANMARKS
NATIONALBANK

# STRESS TESTING KRONOS, THE DANISH RTGS-SYSTEM, IN A HISTORICAL PERSPECTIVE

16th Simulator Seminar, Bank of Finland, 30 August 2018

Thomas C. Nilsson, Economist, Payment Systems

DANMARKS
NATIONALBANK

# Agenda

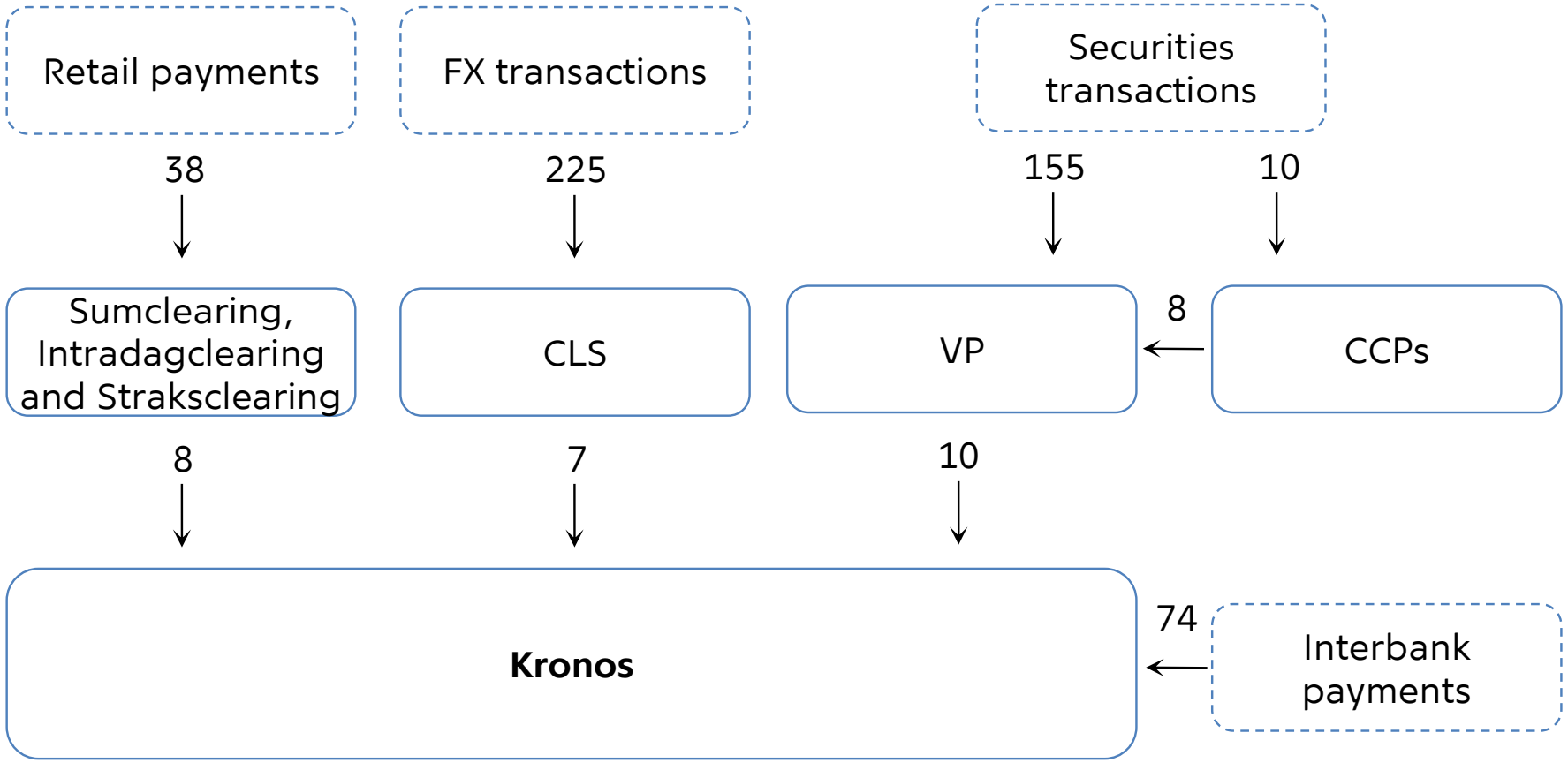
1. **Overview of Kronos** (3 min.)
2. **Research questions and results** (5 min.)
3. **Scenarios** (5 min.)
4. **Detailed results** (10 min.)
5. **Further research** (2 min.)

# Overview of Kronos

As of 2018 H1:

- 88 direct participants (1,800 correspondents in 2017).
- Average volume per business day: 5,779 transactions.
- Average value per business day: kr. 406 billion (€ 54 billion).
- Average value of each transaction: kr. 70 million (€ 9 million).
- High variance: The majority of transactions have a value of less than kr. 1 million.

# Payment flows between Kronos and ancillary systems



# Research questions and results

The primary purpose of our liquidity stress test is to answer "what if" questions:

a. What if a major participant is unable to send payments for a full day?

b. What if the unsecured money market freezes?

c. What if the value of collateral for intraday credit drops substantially?

We assess the resilience of the system, i.e. the effect on participants' liquidity, in each of the above scenarios (+ combined scenarios) for the years 2007-2017.

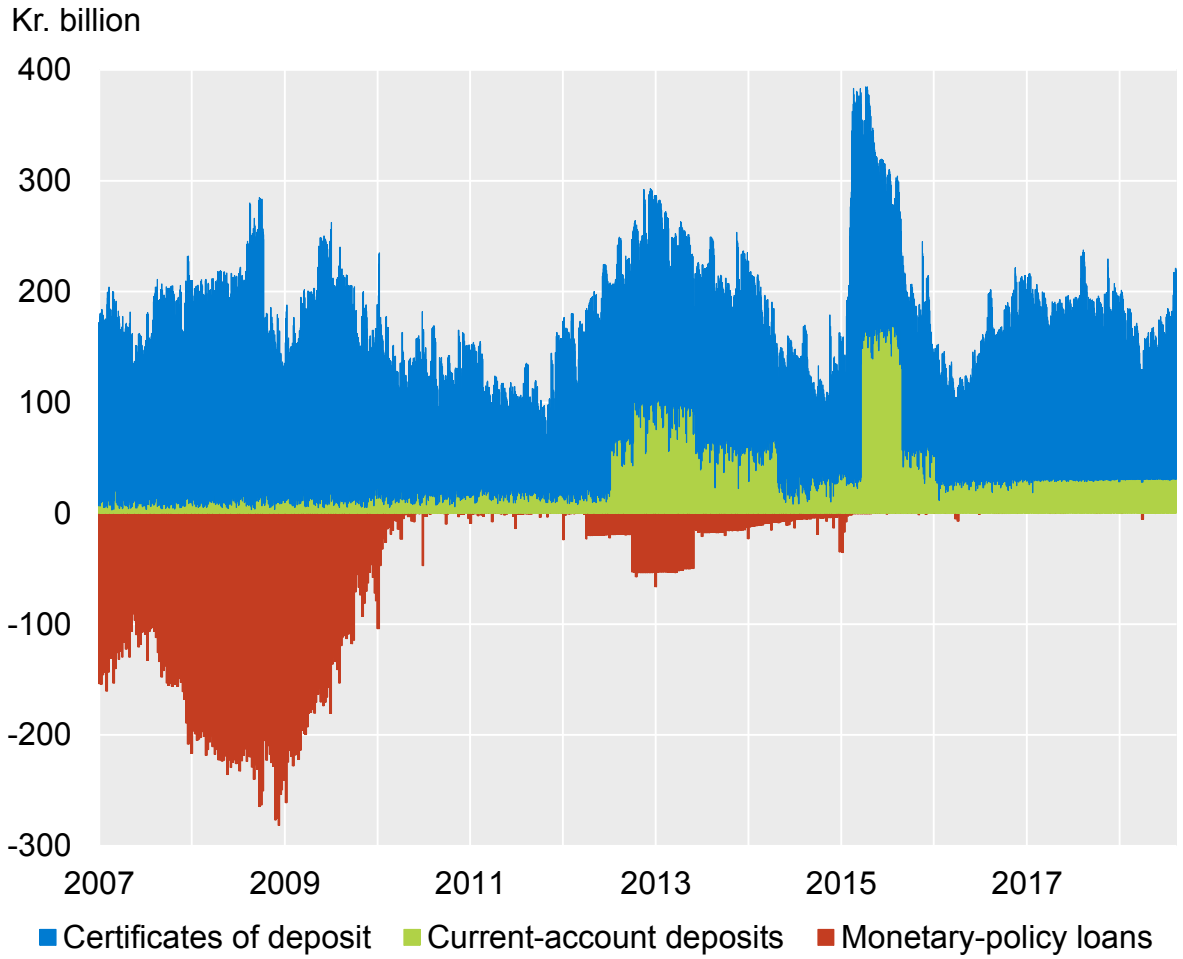
We find that even in the worst possible scenario, the average share of transactions that would have been settled (in value terms) is greater than **94% in crisis years** and greater than **98% in recent years**. The negative liquidity effect is limited and can be mitigated by means of Kronos' contingency procedures.

# Participants fill their current-accounts to their limit

Danmarks Nationalbank uses three monetary policy instruments:

1. Current-account deposits at 0.00%
2. Certificates of deposit at -0.65%
3. Monetary policy loans at 0.05%

In a low interest rate environment, monetary policy counterparties choose to place as much liquidity as possible in their current-account → liquidity in Kronos has been plentiful in recent years.



# Benchmark

- The payment flow in Benchmark closely resembles the actual flow in Kronos…
  - For each transaction:
    *Value* ≤ *Balance* + *Credit* → ✓ ,
    or the transaction is put in a bypass FIFO queue.
- … albeit with some exceptions:
  - We cannot observe queued transactions in our data, i.e. all payments in Benchmark are settled immediately.
  - Gridlock resolution is omitted.

| Time | From | To | Value | Balance | Credit | |
|---|---|---|---|---|---|---|
| 07:30 | Bank 1 | Bank 2 | 10 | 0 | 60 | ✓ |
| 08:17 | Bank 2 | Bank 1 | 20 | 40 | 0 | ✓ |
| 09:01 | Bank 1 | Bank 3 | 40 | 10 | 60 | ✓ |
| 09:37 | Bank 3 | Bank 2 | 20 | 40 | 32 | ✓ |
| 10:02 | Bank 2 | Bank 3 | 25 | 40 | 0 | ✓ |
| 11:04 | Bank 3 | Bank 1 | 50 | 45 | 32 | ✓ |
| 12:15 | Bank 3 | Bank 1 | 20 | -5 | 32 | ✓ |
| 13:53 | Bank 1 | Bank 2 | 50 | 40 | 60 | ✓ |
| 14:11 | Bank 1 | Bank 3 | 30 | -10 | 60 | ✓ |
| 15:27 | Bank 2 | Bank 3 | 30 | 65 | 0 | ✓ |

# Scenario *RPK*: Remove participant *K*

- A large participant is unable to submit payments for a full business day.
- The participant can still receive payments → liquidity sink effect.
- All other transactions are submitted as in benchmark → queues emerge, settlement is delayed or ultimately does not take place (unsettled).
- In the right example:
  Bank 1 (the largest participant) is removed → two unsettled payments.

| Time | From | To | Value | Balance | Credit | |
|---|---|---|---|---|---|---|
| 07:30 | Bank 1 | Bank 2 | ~~10~~ | 0 | 60 | |
| 08:17 | Bank 2 | Bank 1 | 20 | 30 | 0 | ✓ |
| 09:01 | Bank 1 | Bank 3 | ~~40~~ | 20 | 60 | |
| 09:37 | Bank 3 | Bank 2 | 20 | 0 | 32 | ✓ |
| 10:02 | Bank 2 | Bank 3 | 25 | 30 | 0 | ✓ |
| **11:04** | **Bank 3** | **Bank 1** | **50** | **5** | **32** | ✗ |
| 12:15 | Bank 3 | Bank 1 | 20 | 5 | 32 | ✓ |
| 13:53 | Bank 1 | Bank 2 | ~~50~~ | 40 | 60 | |
| 14:11 | Bank 1 | Bank 3 | ~~30~~ | 40 | 60 | |
| **15:27** | **Bank 2** | **Bank 3** | **30** | **5** | **0** | ✗ |

# Scenario *MML*: Remove money market loans

- We use the Furfine (1999) algorithm to identify money market loans:
  - Payment of $x$ on day $t$,
  - Repayment of $(1 + r)x$ on day $t + 1$.
- These transactions are removed to simulate a money market freeze.
- In the right example:
  Two MML transactions are removed
  → one unsettled payment.

| Time | From | To | Value | Balance | Credit | |
|---|---|---|---|---|---|---|
| 07:30 | Bank 1 | Bank 2 | ~~10~~ | 0 | 60 | |
| 08:17 | Bank 2 | Bank 1 | 20 | 30 | 0 | ✓ |
| 09:01 | Bank 1 | Bank 3 | 40 | 20 | 60 | ✓ |
| 09:37 | Bank 3 | Bank 2 | 20 | 40 | 32 | ✓ |
| 10:02 | Bank 2 | Bank 3 | ~~25~~ | 30 | 0 | |
| 11:04 | Bank 3 | Bank 1 | 50 | 20 | 32 | ✓ |
| **12:15** | **Bank 3** | **Bank 1** | **20** | **-30** | **32** | ✗ |
| 13:53 | Bank 1 | Bank 2 | 50 | 30 | 60 | ✓ |
| 14:11 | Bank 1 | Bank 3 | 30 | -20 | 60 | ✓ |
| 15:27 | Bank 2 | Bank 3 | 30 | 80 | 0 | ✓ |

# Scenario *C25*: Collateral value drops by 25%

- An extreme shock to the value of collateral leads to a decrease in participants' intraday credit lines.
- In the right example:
  A 25% drop in collateral value
  → two unsettled payments.

| Time | From | To | Value | Balance | Credit (-25%) | |
|---|---|---|---|---|---|---|
| 07:30 | Bank 1 | Bank 2 | 10 | 0 | 45 | ✓ |
| 08:17 | Bank 2 | Bank 1 | 20 | 40 | 0 | ✓ |
| 09:01 | Bank 1 | Bank 3 | 40 | 10 | 45 | ✓ |
| 09:37 | Bank 3 | Bank 2 | 20 | 40 | 24 | ✓ |
| 10:02 | Bank 2 | Bank 3 | 25 | 40 | 0 | ✓ |
| 11:04 | Bank 3 | Bank 1 | 50 | 45 | 24 | ✓ |
| **12:15** | **Bank 3** | **Bank 1** | **20** | **-5** | **24** | ✗ |
| 13:53 | Bank 1 | Bank 2 | 50 | 20 | 45 | ✓ |
| **14:11** | **Bank 1** | **Bank 3** | **30** | **-30** | **45** | ✗ |
| 15:27 | Bank 2 | Bank 3 | 30 | 65 | 0 | ✓ |

# Sources of error

*We overestimate the negative effect, because*

- The participants are *passive* → No reaction to e.g. the lack of incoming payments from another participant (÷ ABM, ÷ stop sending rule).
- The participants *cannot* pledge additional collateral intraday through auto-col. or by any other means.
- Payments *cannot* be submitted by means of contingency procedures.

*We underestimate the negative effect, because*

- Ancillary systems are *static* and are modelled as passive participants → Mutual dependencies and spillover effects are unaccounted for.
- The duration of all scenarios is limited to one business day (÷ interday balance transfers and other effects).

# Indicators

I. Direct effect:

$$\frac{\textit{unsubmitted payments in the scenario}}{\textit{submitted payments in benchmark}}$$

II. Indirect effect:

$$\frac{\textit{unsettled payments in scenario}}{\textit{submitted payments in scenario}}$$

III. Multiplier effect:

$$\frac{\textit{unsettled payments in scenario}}{\textit{unsubmitted payments in scenario}}$$

IV. Liquidity usage indicator:
"To what extent do participants use their available liquidity (balance on current-account + intraday-credit line) to settle payments?"

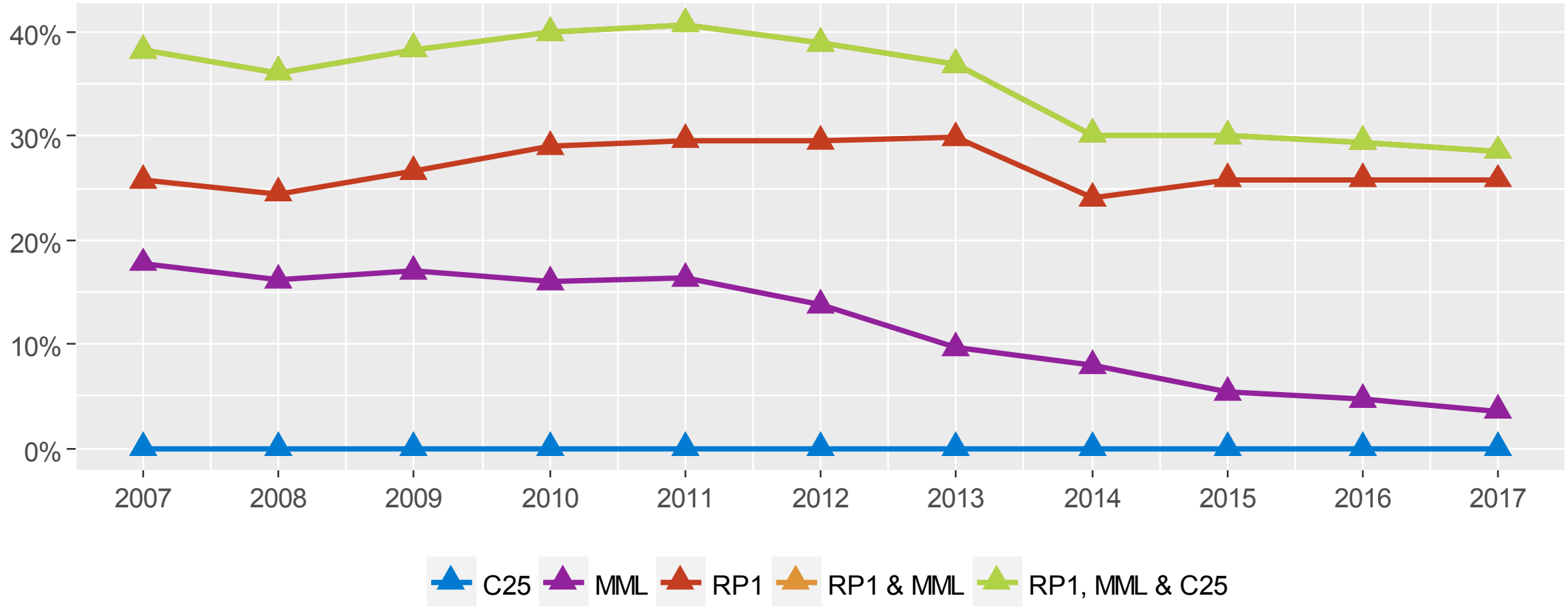
V. Settlement delay indicator: "The rate of payments in queue, a time- and value-weighted average:
Earlier submission; higher value
→ higher weight".

(Details in Appendix)

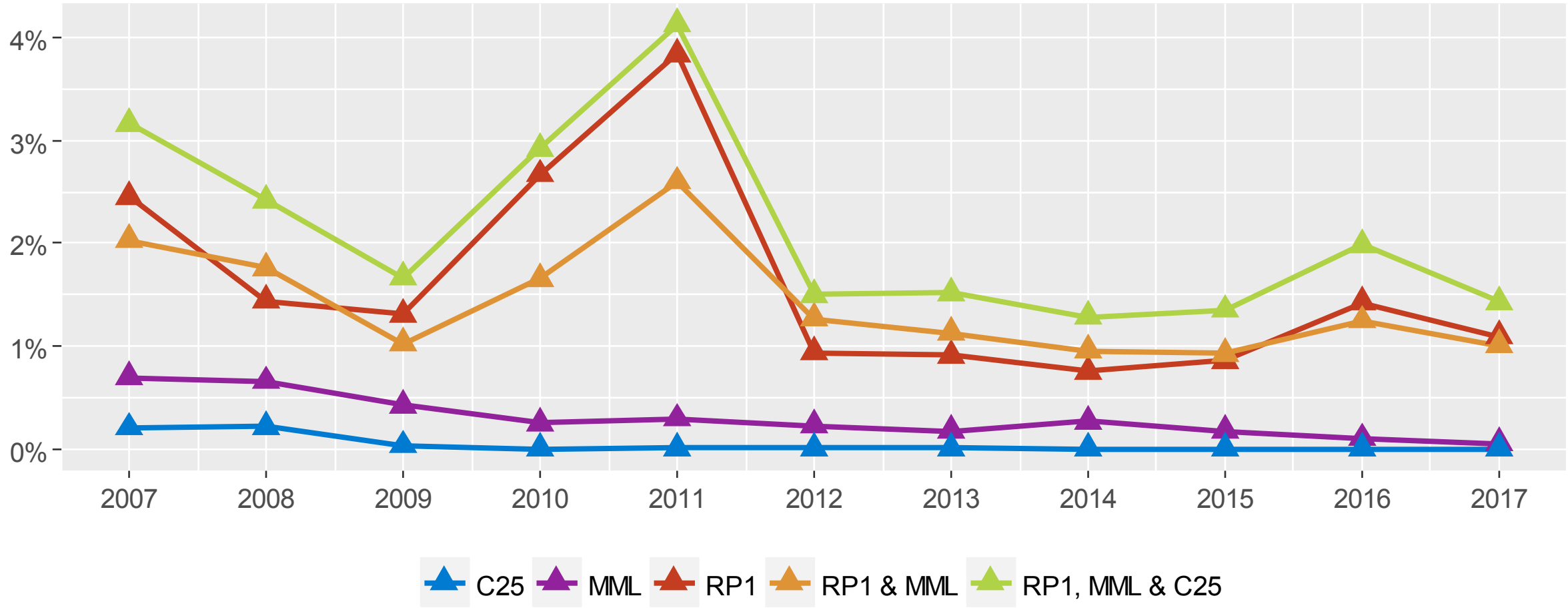
# Simulated scenarios and periods

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BEN** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP1** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP2 | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP3 | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP4 | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP5 | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **MML** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **C25** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP1 & MML** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP2 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP3 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP4 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP5 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP1, MML & C25** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP2, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP3, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP4, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP5, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

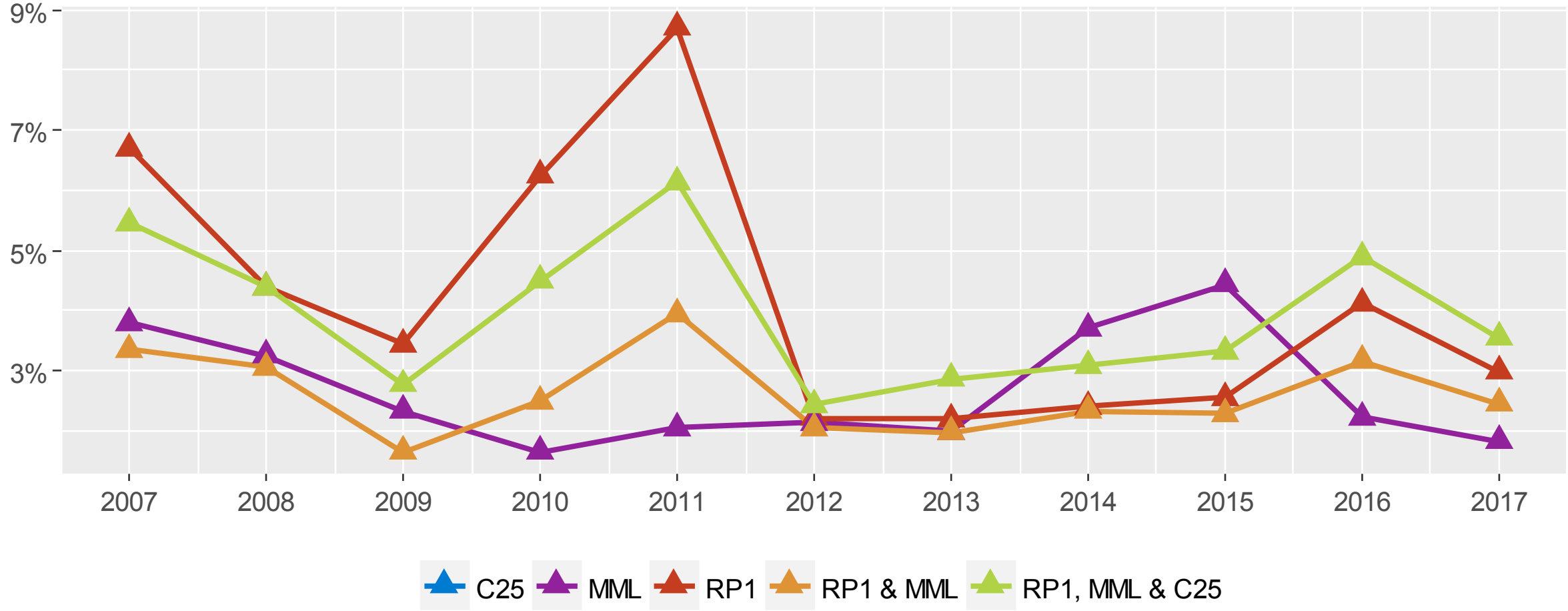
# Direct effect



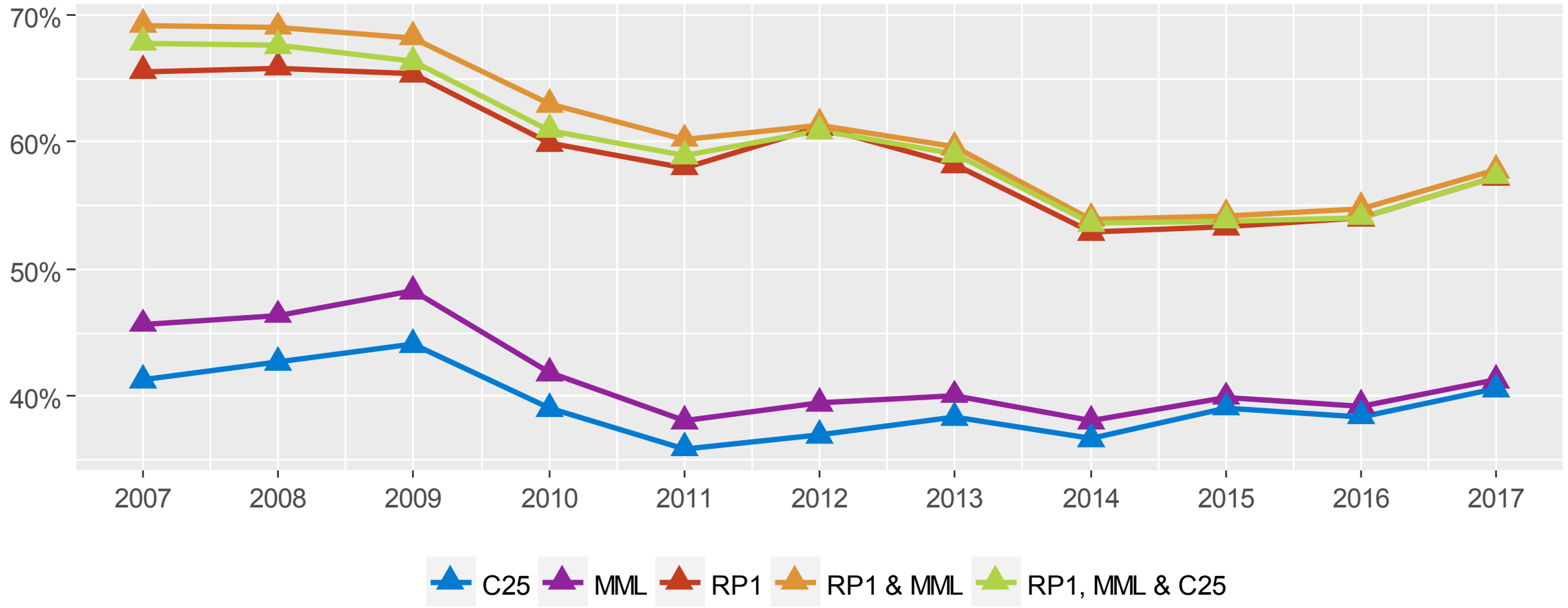
# Indirect effect



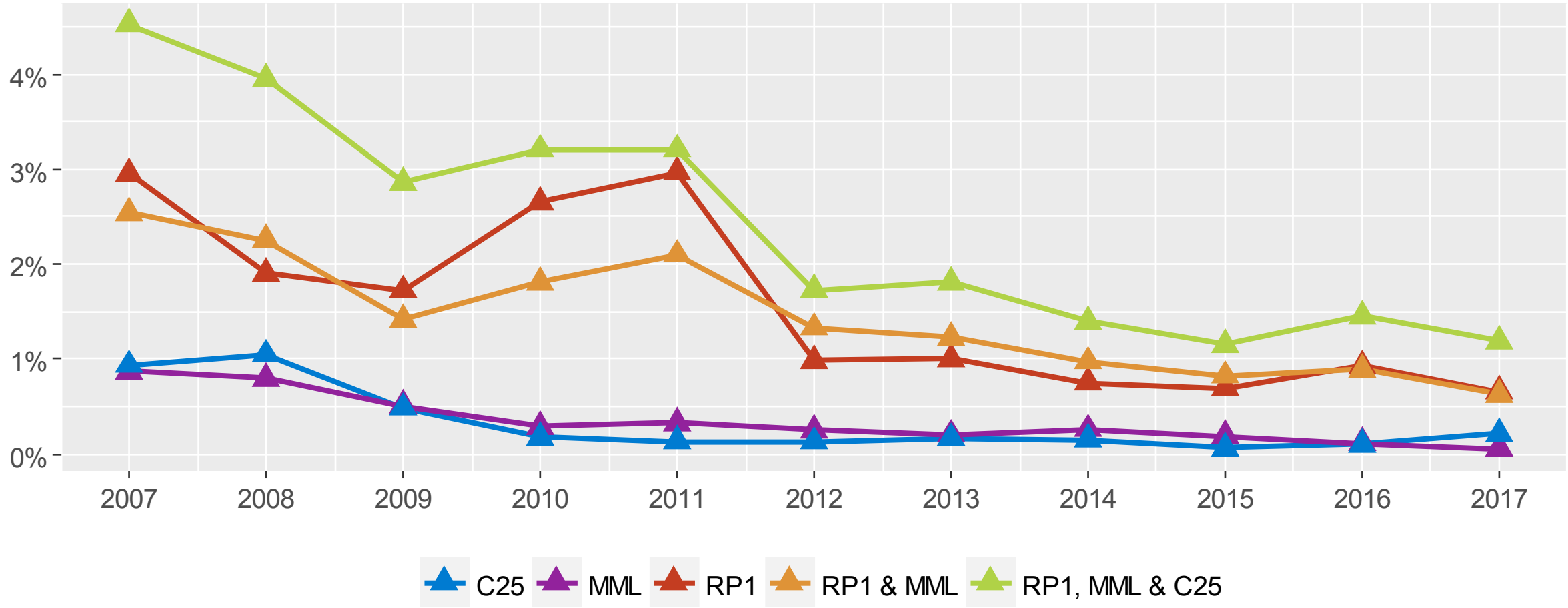
# Multiplier effect



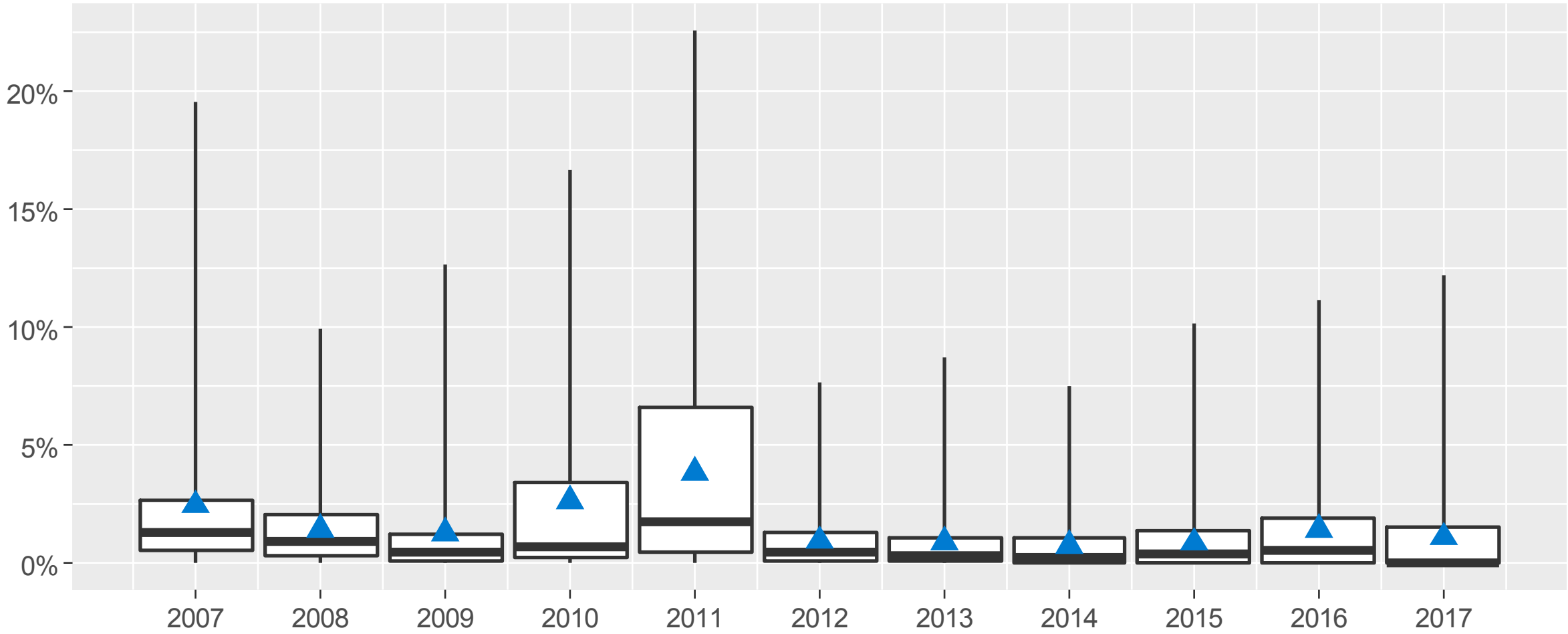
# Liquidity usage (consumed liquidity)



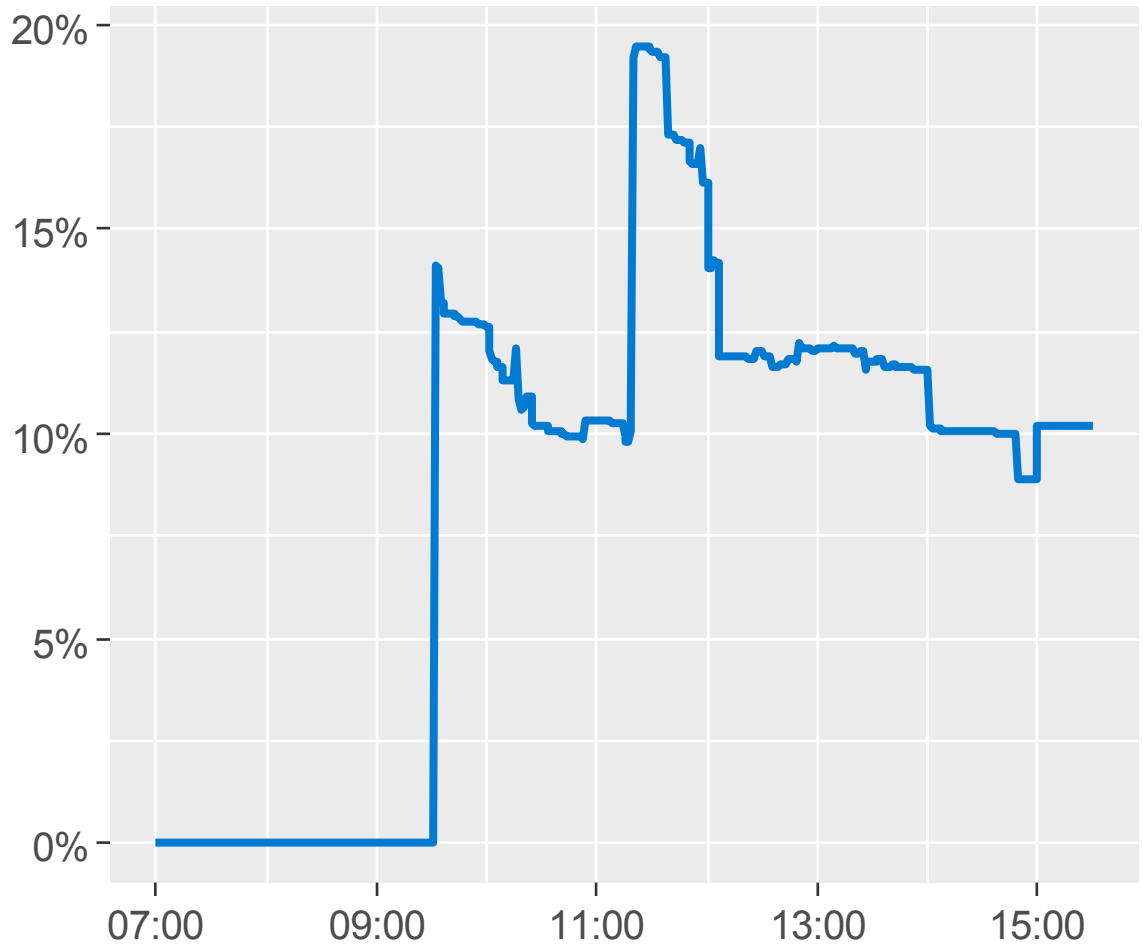
# Settlement delay



# Distribution of the indirect effect (RP1)



# Value in queue / Cumulative transaction value on a particularly critical day in 2017 (RP1)




- On a critical day: Significant value in queue over the course of the day
  → Further analysis needed.
- However, on these critical days:
  - The number of unsubmitted payments that lead to queues is limited.
  - A maximum of 5 participants have payments in queue.

→ Kronos' contingency procedures!

# Further research

- A closer look at critical dates, times, and participants [Fall 2018].
- Adapting to the data structure of Kronos2 (K2) [Spring 2019].
- Inter-day considerations [2019].
- The effect of gridlock resolution or other liquidity savings mechanism's in Kronos2 [2019].
- Other suggestions?

# That's all folks!

Thank you.

# Appendix A: Indicators I & II, direct & indirect effect

- Direct effect:

$$\frac{\textit{unsubmitted payments in the scenario}}{\textit{submitted payments in benchmark}} = \frac{35}{295} = 11.9\%$$

- Indirect effect:

$$\frac{\textit{unsettled payments in scenario}}{\textit{submitted payments in scenario}} = \frac{20}{260} = 7.7\%$$

| Time | From | To | Subm. bench. | Subm. scena. | Un-subm. | Un-settled | |
|---|---|---|---|---|---|---|---|
| 07:30 | Bank 1 | Bank 2 | 10 | ~~10~~ | 10 | | |
| 08:17 | Bank 2 | Bank 1 | 20 | 20 | | | ✓ |
| 09:01 | Bank 1 | Bank 3 | 40 | 40 | | | ✓ |
| 09:37 | Bank 3 | Bank 2 | 20 | 20 | | | ✓ |
| 10:02 | Bank 2 | Bank 3 | 25 | ~~25~~ | 25 | | |
| 11:04 | Bank 3 | Bank 1 | 50 | 50 | | | ✓ |
| **12:15** | **Bank 3** | **Bank 1** | **20** | **20** | | **20** | ✗ |
| 13:53 | Bank 1 | Bank 2 | 50 | 50 | | | ✓ |
| 14:11 | Bank 1 | Bank 3 | 30 | 30 | | | ✓ |
| 15:27 | Bank 2 | Bank 3 | 30 | 30 | | | ✓ |
| | | | **295** | **260** | **35** | **20** | |

# Appendix A: Indicator III, multiplier effect

- Multiplier effect:

$$\frac{\textit{unsettled payments in scenario}}{\textit{unsubmitted payments in scenario}} = \frac{20}{35} = 57.1\%$$

| Time | From | To | Subm. bench. | Subm. scena. | Un-subm. | Un-settled | |
|---|---|---|---|---|---|---|---|
| 07:30 | Bank 1 | Bank 2 | 10 | ~~10~~ | 10 | | |
| 08:17 | Bank 2 | Bank 1 | 20 | 20 | | | ✓ |
| 09:01 | Bank 1 | Bank 3 | 40 | 40 | | | ✓ |
| 09:37 | Bank 3 | Bank 2 | 20 | 20 | | | ✓ |
| 10:02 | Bank 2 | Bank 3 | 25 | ~~25~~ | 25 | | |
| 11:04 | Bank 3 | Bank 1 | 50 | 50 | | | ✓ |
| **12:15** | **Bank 3** | **Bank 1** | **20** | **20** | | **20** | ✗ |
| 13:53 | Bank 1 | Bank 2 | 50 | 50 | | | ✓ |
| 14:11 | Bank 1 | Bank 3 | 30 | 30 | | | ✓ |
| 15:27 | Bank 2 | Bank 3 | 30 | 30 | | | ✓ |
| | | | **295** | **260** | **35** | **20** | |

# Appendix A: Indicator IV, liquidity usage

- Liquidity usage indicator: "To what extent do participants use their available liquidity (balance on current-account + intraday-credit line) to settle payments?"

$$liqusagc = \frac{\sum_{i=1}^{N} -L_i}{\sum_{i=1}^{N} \sum_{j=1}^{M_i} a_{i,j}} \in [0;1],$$

where $L_i$ is the minimum of the cumulative sum of payments sent and received over the business day for participant $i$, and

$a_{i,j}$ is the value of payment $j$ of participant $i$.

- *liqusagc* = 0: Submitted payments are funded exclusively by received payments (only possible on participant level; *liqusagc* > 0 on system level).
- *liqusagc* = 1: Submitted payments are funded exclusively by available liquidity.

# Appendix A: Indicator V, settlement delay

Settlement delay indicator: "The rate of payments in queue, a time- and value-weighted average: Earlier submission; higher value → higher weight".

$$setdelay = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M_i}(t_{i,j} - s_{i,j})a_{i,j}}{\sum_{i=1}^{N}\sum_{j=1}^{M_i}(T - s_{i,j})a_{i,j}},$$

where $a_{i,j}$ is the value of payment $j$ of participant $i$,

$s_{i,j}$ is the submission time of payment $j$ of participant $i$,

$t_{i,j}$ is the settlement time of payment $j$ of participant $i$, and

$T$ is the closing time of Kronos (15:30).

- *setdelay* = 0: No payments are queued.
- *setdelay* = 1: All payments are queued from submission time to closing time.

# Appendix A: Indicators VI & VII, liquidity bounds

- Upper bound of liquidity:

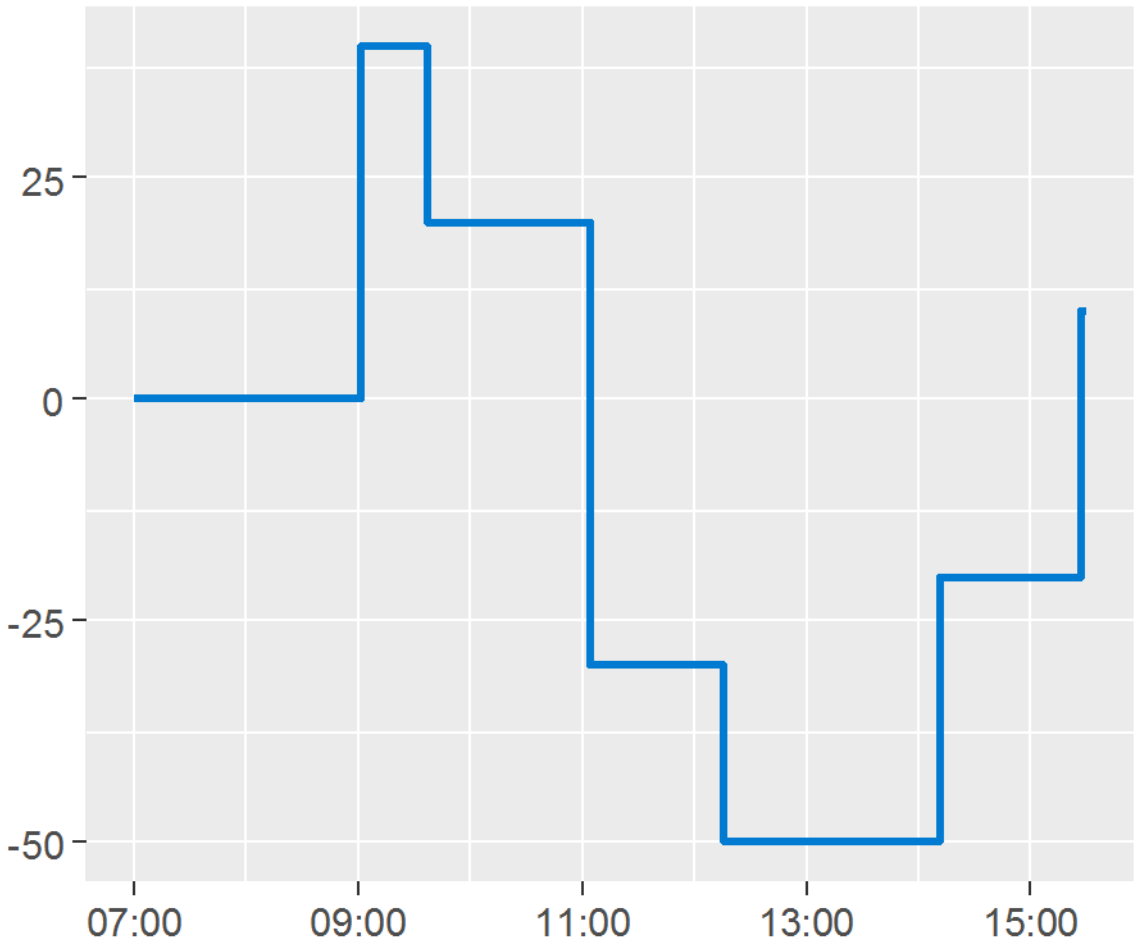
$$\max(L, 0) = 50,$$

where $L$ is the minimum of the cumulative sum of payments sent and received over the business day: "Sufficient liquidity for all payments to be settled in their original order".

- Lower bound of liquidity:

$$\max(\textit{value received} - \textit{value sent}, 0) = 0$$

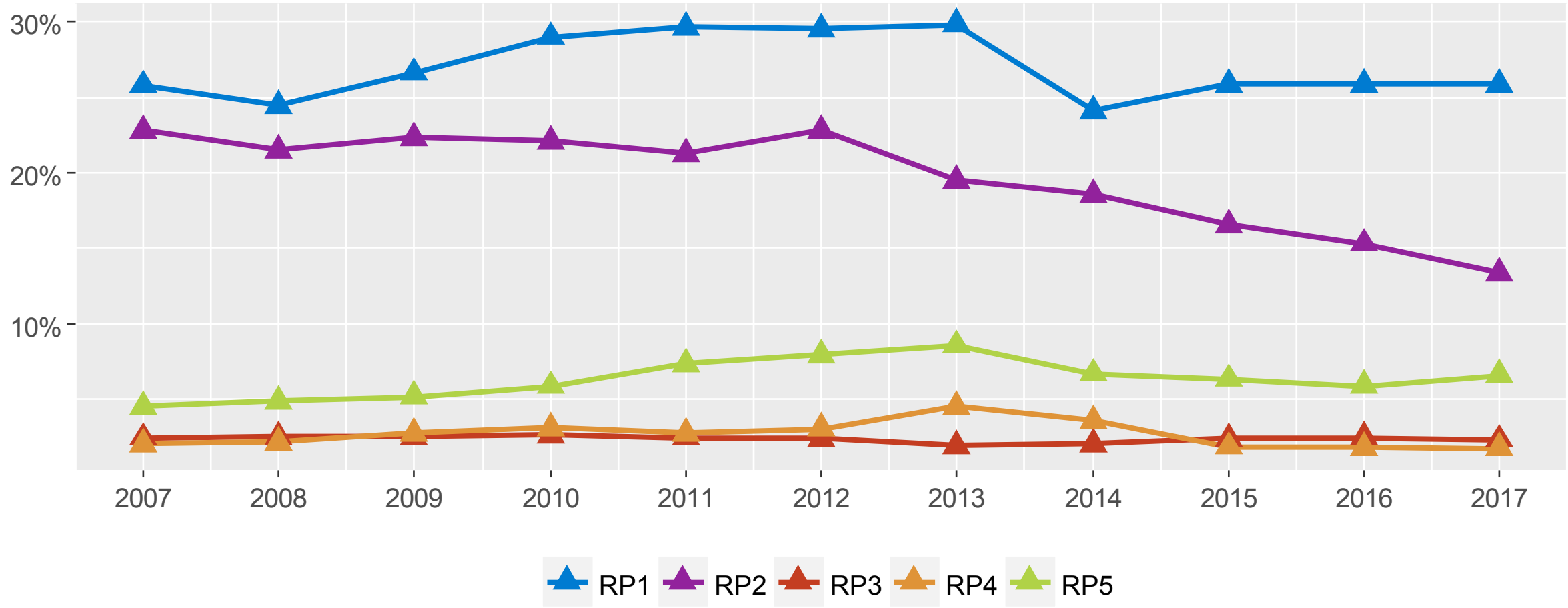
"Sufficient liquidity for all payments to be settled through multilateral netting".



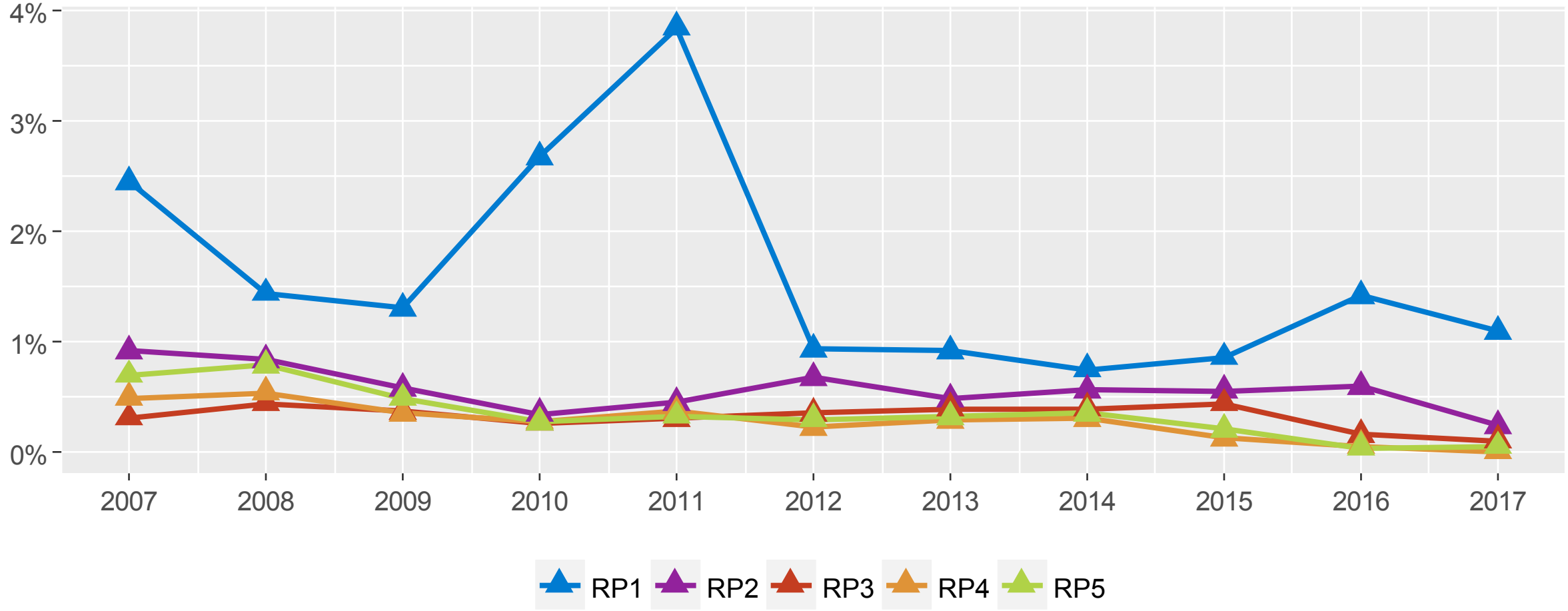
# Appendix B: Additional results across the RP-scenarios

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BEN** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP1** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP2** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP3** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP4** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **RP5** | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| MML | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| C25 | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP1 & MML | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP2 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP3 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP4 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP5 & MML | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP1, MML & C25 | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP2, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP3, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP4, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RP5, MML & C25 | - | - | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

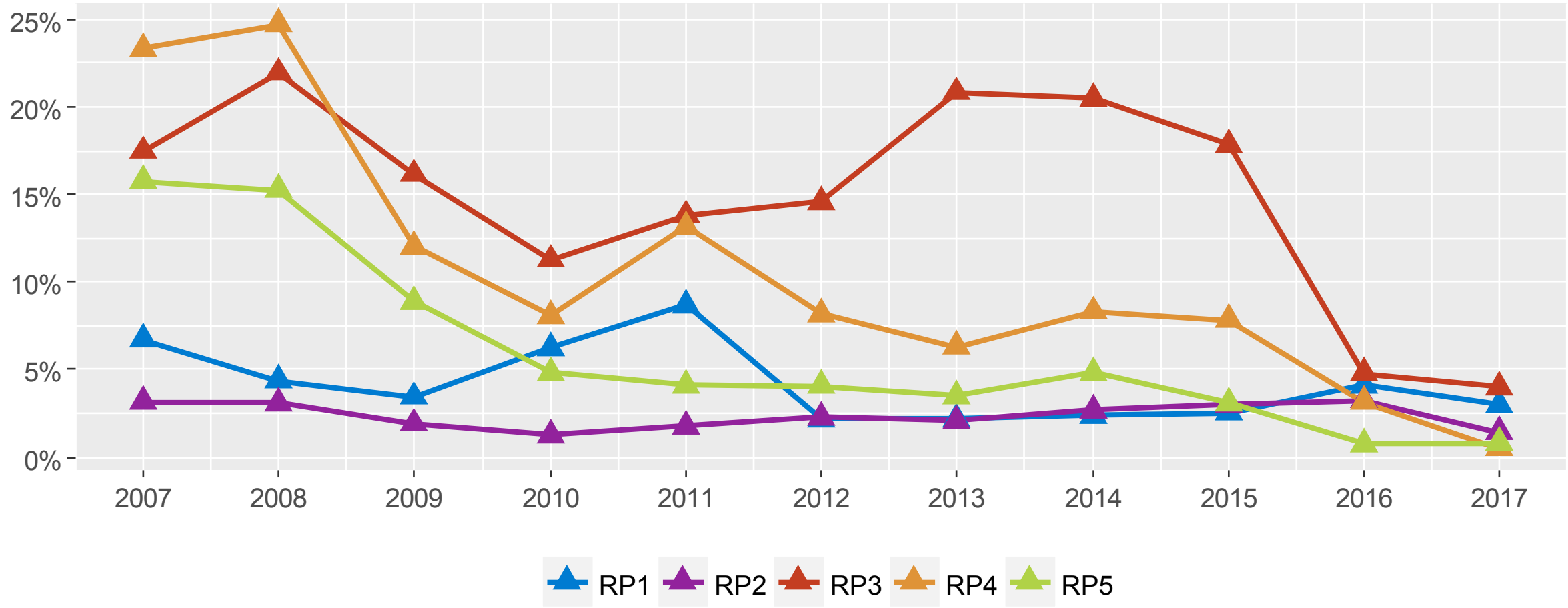
# Appendix B: Direct effect



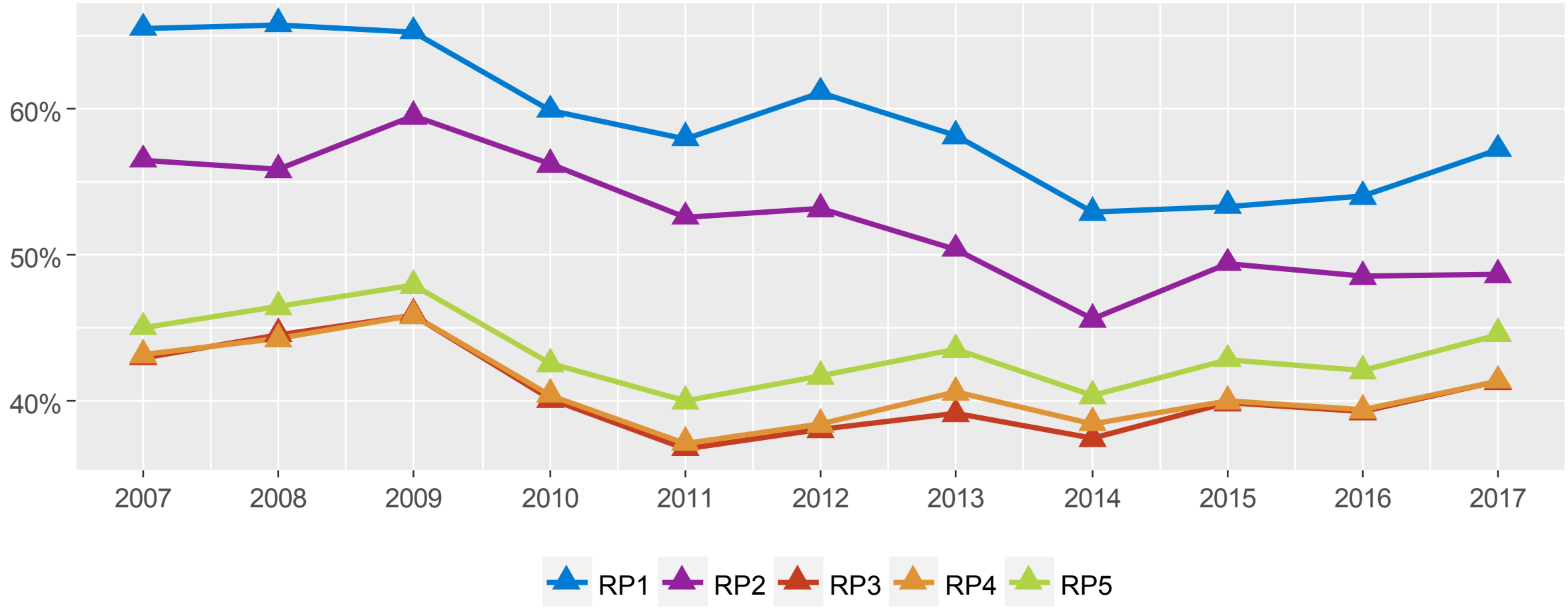
# Appendix B: Indirect effect



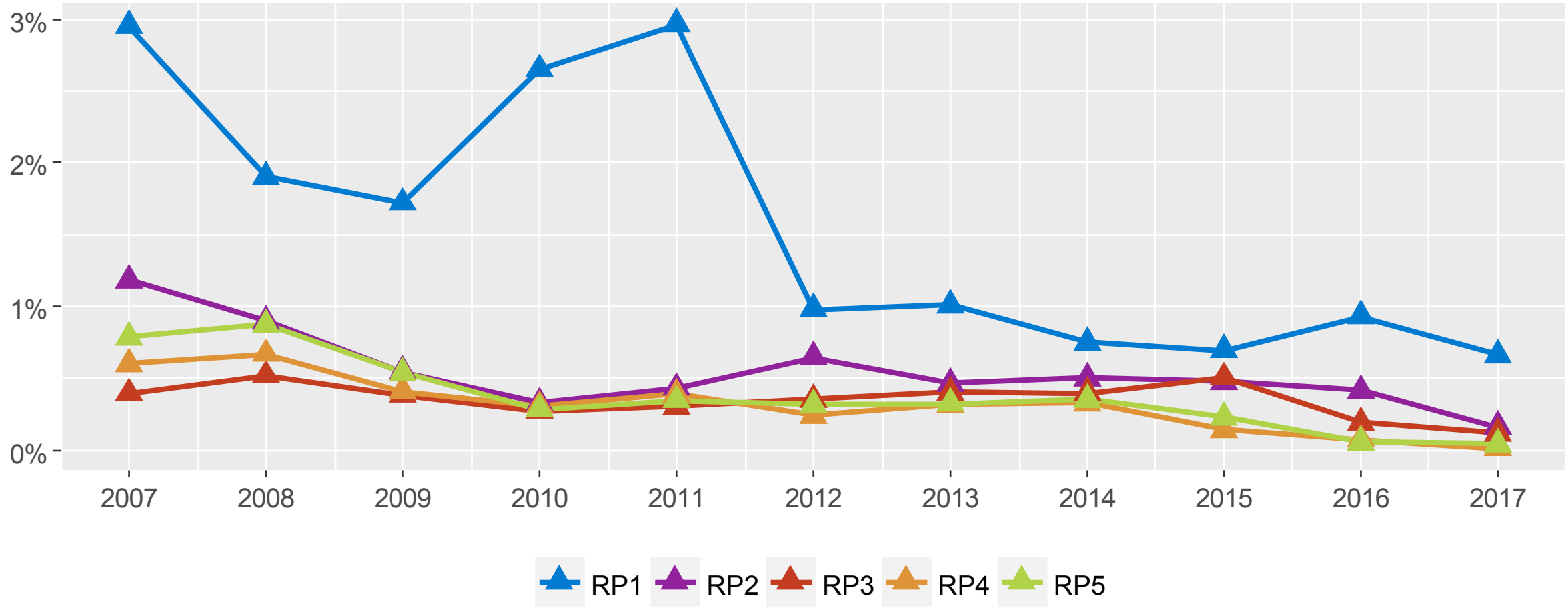
# Appendix B: Multiplier effect



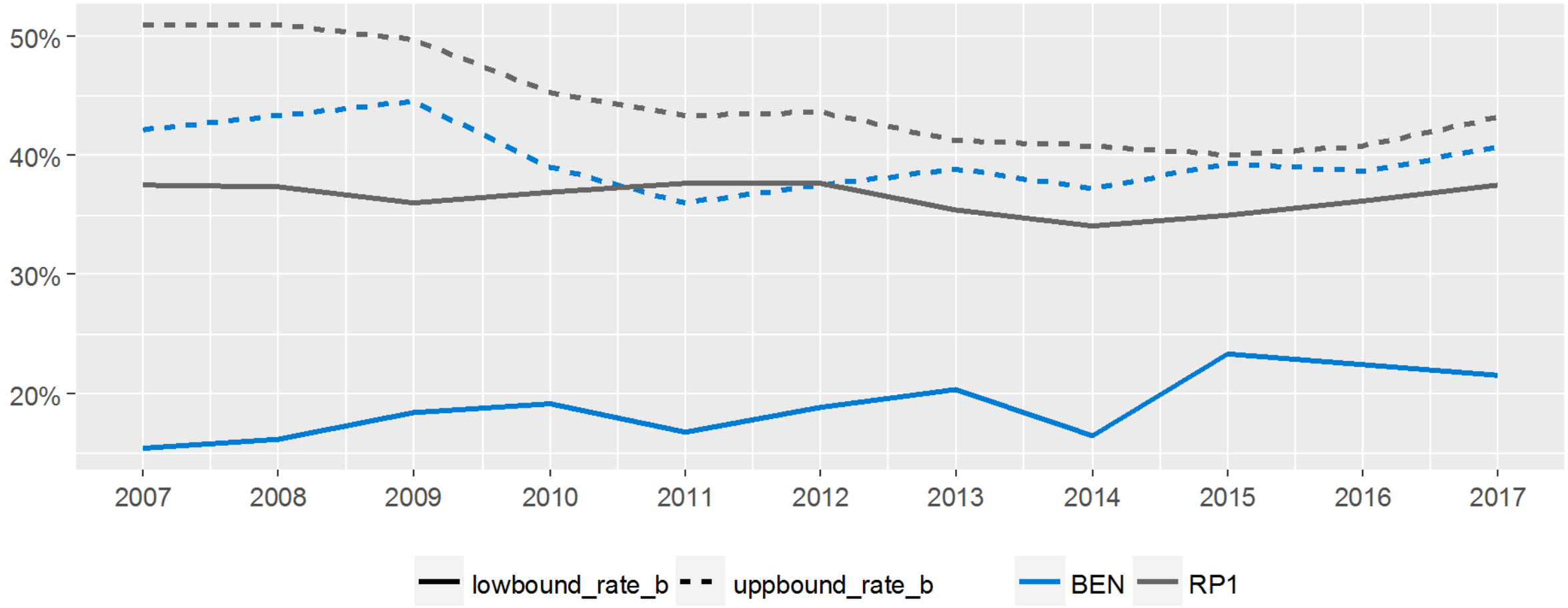
# Appendix B: Liquidity usage (consumed liquidity)



# Appendix B: Settlement delay



# Appendix B: Liquidity bounds, BEN & RP1



# Appendix B: Liquidity bounds, BEN & RP5