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New approaches for identification of behavioral changes from LVPS data

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Presented views are those of the authors and do not necessarily reflect the view of Bank of Finland

Also

The views of the authors are subject to changes without prior notice… (i.e. work on progress)

Agenda

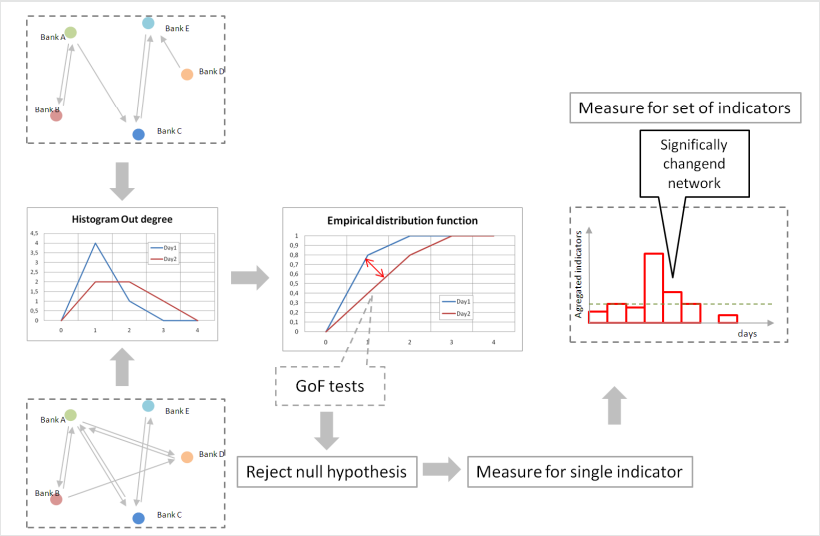
- Research questions
- Methodology
  - two indicator frameworks
- Simulation setup
  - Agent based model for testing the indicators
- Results
- Ideas for future
- Observations and conclusions

Research questions

- What has been the impact of recent turmoil on the behavior of banks in RTGS systems?
- How to identify possible changes in this behavior?
- What can be identified in the first place?

- Starting points:
  - Network topology studies of RTGS systems
  - RTGS data from BoF-RTGS and Finnish TARGET2 component

Overview of Analysis Framework mk. I



Analysis Framework mk. I

- Based on well known **network indicators** (e.g. degree, average path length, reciprocity…) and couple of **Goodness of Fit test** (GoF tests).
- The **distributions of network indicators** carry lot of information about the whole network and the process of how it was generated.

Network Indicators and What We Do With Them?

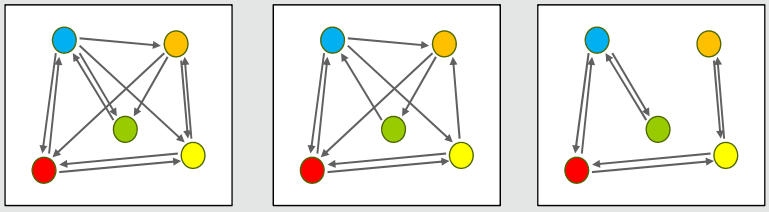
- A set of **network indicators** are computed for **each node** in the payment network.
  - The network can be constructed practically with transactions from any time period (e.g. day, week). We used networks composed from daily transactions.
- The distributions of those indicators are compared to the distribution of the same indicator in **comparison period**.
  - Comparison period can be from weeks to months.
- The **combined sample of indicator** in comparison period to represent **typical** or **normal** distribution of that indicator in that period.

Why Googness-of-Fit (GoF) tests?

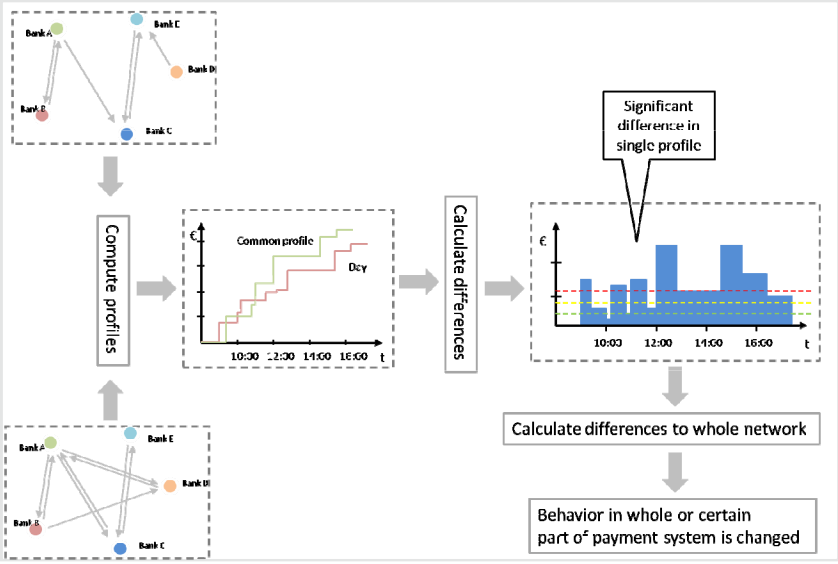
- The **exact analytic form** of distribution of certain network indicators not known. **Empirical distributions** used in analysis.
- GoF tests are generic and **non-parametric** test to test if to samples are generated from **the same distribution**.
  - No assumptions about distributions
  - Not as powerful as test with defined distributions to detect small differences, but able to distinguish big differences.
- Three different GoF tests in use Kolmogorov-Smirnov two-sample test, Anderson-Darling two-sample and Crámer-von Mises test.
  - Tests are efficient to detect little bit different aspects of distributions. (e.g. Anderson-Darling efficient to detect changes in tail distributions)

Aggregating Results of Single Indicator Distributions

- The combination of results of single indicator comparisons is based on idea that if **multiple** indicators indicate that if the distributions of those indicators have been changed then it is more likely to observe bigger change in network than in situation in which a single indicator has been changed.



Overview of Analysis Framwork mk.II

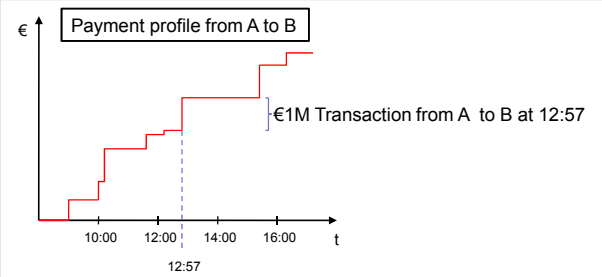


Analysis Framework mk.II

- Based on **pairwise comparison** of **payment profiles**.
- Framework is easily to implemented to operational use.
- Framework mk. II is a supplement for framework mk.I

What is Payment Profile?

- Defined between to a **pair** participants.
  - e.g. Bank A's profile to Bank B is the **sum** of A's **payments** at **function** of **time.**
- Profile describes three main charasteristics of banks's payment behaviour: **timing**, **value** and **volume**.

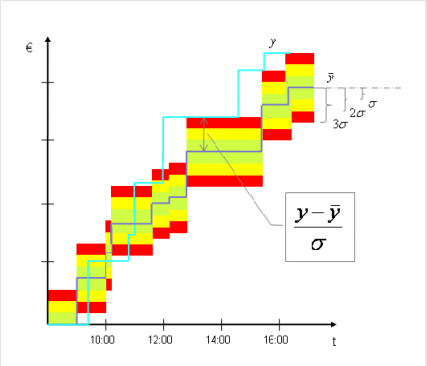


Typical Behaviour i.e. The Common Profile

- **Common payment profile** is defined for some time period.
  - e.g. ranging from days to months.
- The common profile do implement the **normal** and **typical** behavior for that time period.
- Construction of comparison is data highly relevant
  - Derivation as a minimization problem (see bonus slides)
  - In presented results we used unconstrained minimization which reduces to average.

Measuring the Difference in Behaviours

- Measure for difference is a **standardised difference** between profiles.
- Standardisation allows us the define ranges in which variation is still regarded as normal.

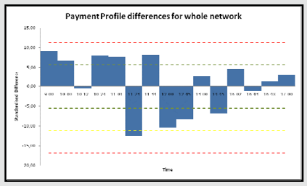


Possibilities to aggregation of Pairwise Comaparisons

- Many suitable aggregation levels.
  - We used aggregation on participant and over the whole system level.
- The used level of aggregation will define the normalness of behaviour at aggregation level.
  - The network may seem normal in the viewpoint of the whole network even there is a few participants which behaviour is changed totally.

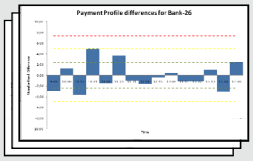
Aggregated Results –What We See?

System



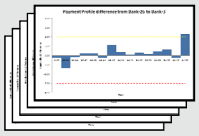
$\sim_a N(0,N)$

Participant



$\sim_a N(0,n_i)$

Pairwise



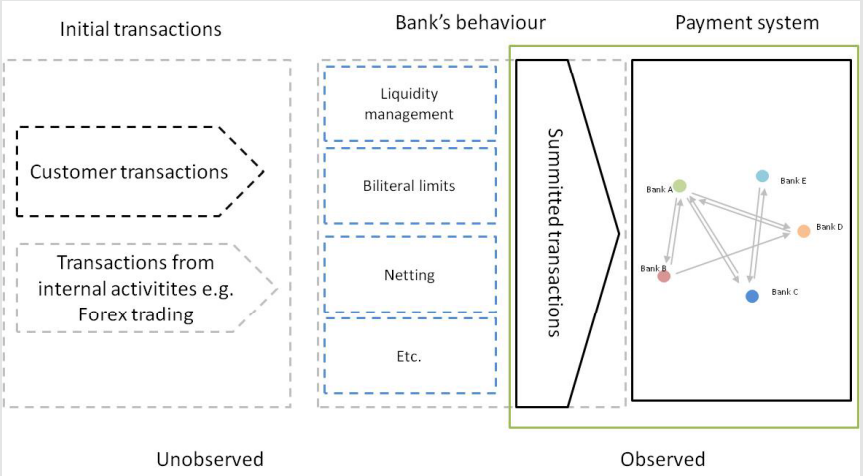
$\sim_a N(0,1)$

N=Number links in the system
n_i= Number of links of the participant i

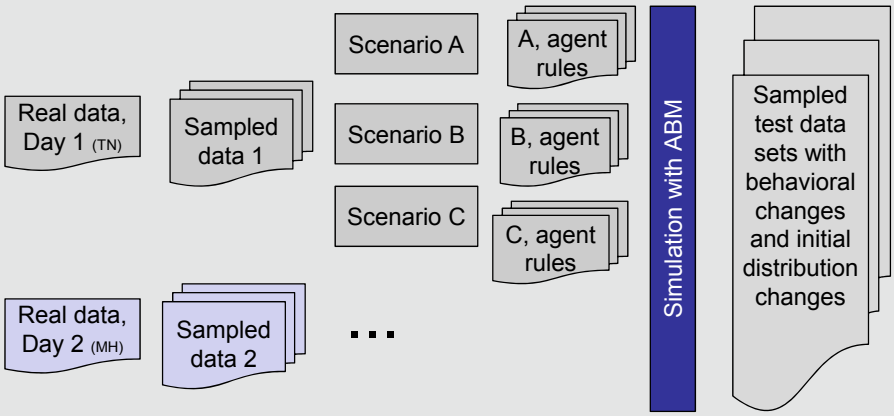
Aggregated Results –What We See? (explained)

- The differences of payment profiles follow approximately standardised normal distribution (**N(0,1)**)
- The sum N of such random variables follows the distribution of **N(0,N)**. (Assumed **i.i.d.**)
- This explains the fact that in aggregated everything may seem normal even if in the participant or in pairwise level there might be observed differences compared to normal behaviour at that level.

Why We Need Controlled Environment



Process of preparing controlled test data sets



2 x | 60x | 3x | 10 | = | 3600

Preparation steps

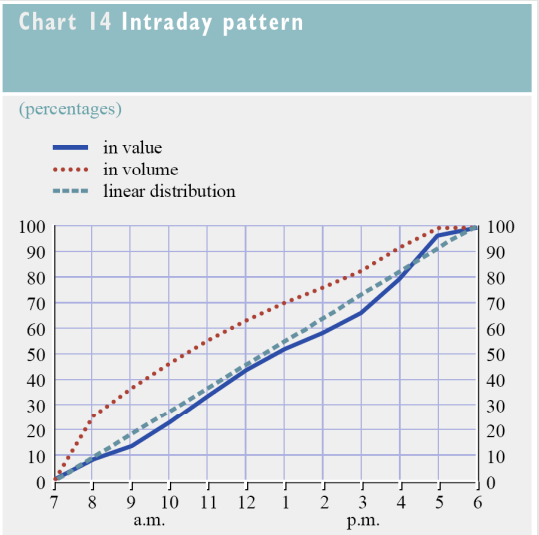
1. Data from the birthdays of the authors from BoF-RTGS or Finnish TARGET2 component
2. Two months of sampled days with **Poisson-lognormal model** based on the days of step 1
3. Three scenarios where **one participant changes its behavior** (implement internal bilateral sending limits)
   A. Largest sender in step1 data
   B. Largest net sender
   C. Largest net sender among counterpartiers of monetary policy
4. Ten levels for behavior (internal bilateral limits)
   – linear range starting from nonrestricting limit to full free riding (payments only settled with money received from counterparties)
   – Symmetric vis-a-vis all counterparties
5. Simulation with BoF-PSS2
   1. Liquidity restrictions
   2. Contagious impacts of the behaviour through systems settlement rules

Data generation

- Transaction values from lognormal distribution
- Number of transactions from poisson, intervals from exponential distribution
  - Parameters estimated for each bank against each counterparty independently
  - No feedbacks

⇒Sampled data has no intraday patterns

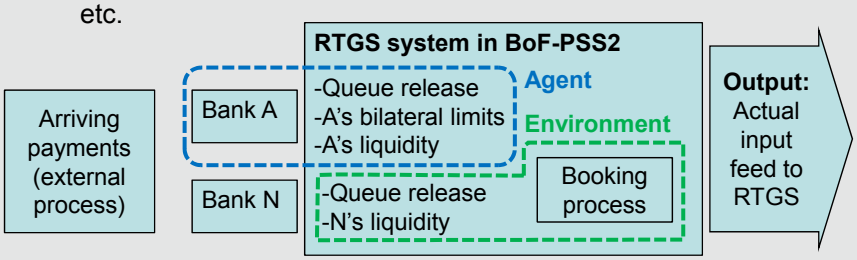
… would they be needed?



The average intraday pattern of TARGET2.
Source: ECB, TARGET2 annual report 2008

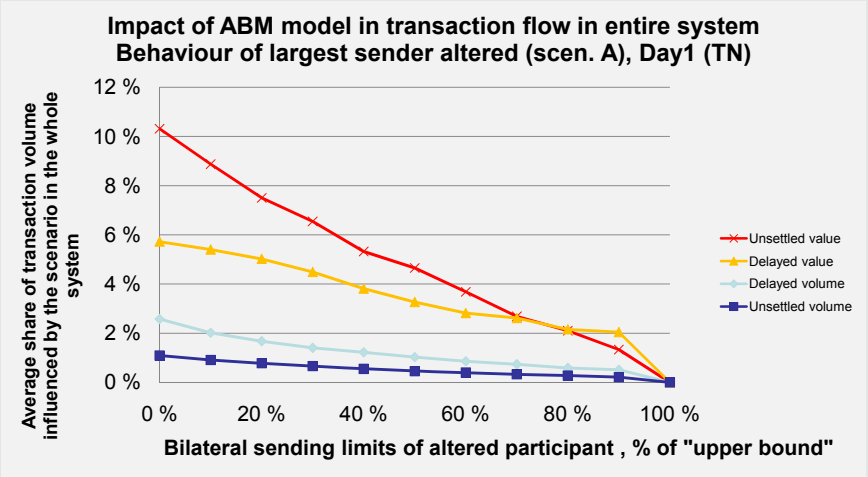
How to do ABM in BoF-PSS2?

- Easy way: Use participant level features to model participant's internal functions
  - Liquidity positions, **bilateral sending limits**, multilateral sending limits, receipt reactive queue logic, all other queue release logics etc.



- Versatile way: Build or link your ABM into BoF-PSS2 submission algorithm

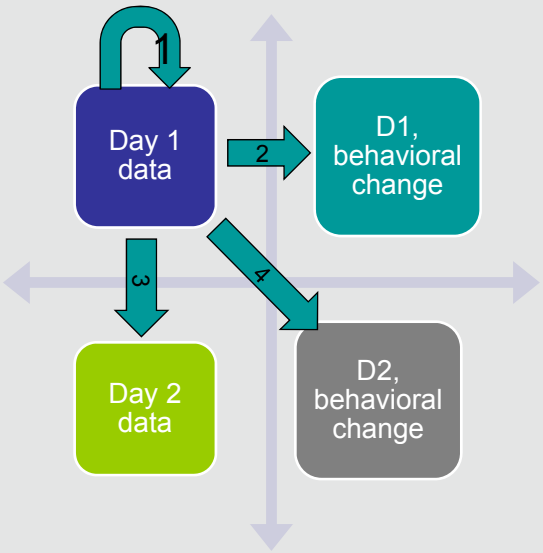
Example of output of the ABM



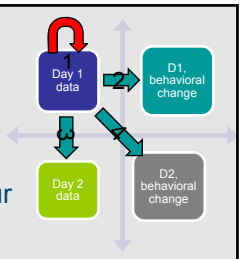
Source: BoF

Test setups

1. Internal variation of generated days
2. Change in behavior (variable strength)
3. Change in underlying arrival process i.e. original sampled day
4. Change in both arrival process and behaviour

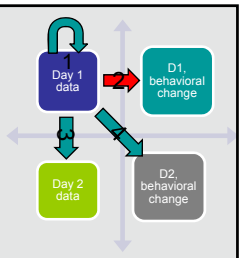


Selected results, test 1 with mk. II



- Days from same sample without changes in behaviour
- Differences between the days normally distributed
- Rate of (sensitive) false alarms 45%
  (EOD difference on network level is more than one std deviation different from sample mean)
- Noisy basic data set with current data generation

Selected results, test 2 with mk. II



- Scenario A applied: behavior of largest sender altered
- Bilateral limits 0%, 50% and 90% of non-restricting value tested

Increase in accuracy when…

- Change in behavior is larger
- Observations in more disaggregated level

(Small number due to nonautomated procedure…)

Test	Blim 0%	Blim 50%	Blim 90%
Nr of cases	10	10	10
Network level			
Observed	20%		60%
Missed alarm	80%		40%
Participant level (altered participant)			
Observed	90%	70%	30%
Missed (no alarm)	10%	30%	70%
Pairvice level (altered vis-a-vis one counterparty)			
Observed	90%		50%
Missed (no alarm)	10%		50%

Selected results, test 3

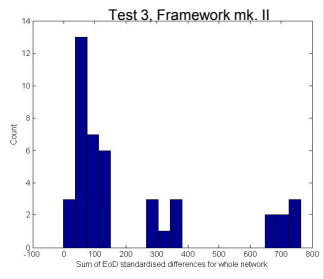
Framework Mk. I:

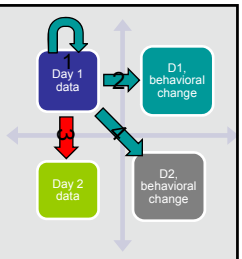
- Most indicators don't alarm in test 3 of Mk I
  - Day level networks – intraday features disappear
  - Expected result since samples are from same original distributions
- Results more informative with real data

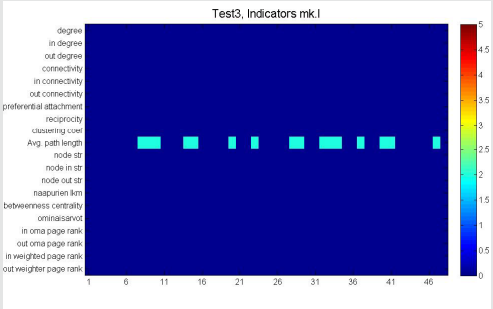
Framework Mk. II:

- Clear difference between day1 & 2 (volume, value, …)
- Mk. II catches changes in both
  - Timing of payments i.e. intraday pattern
  - Value of payments, i.e. level of activity

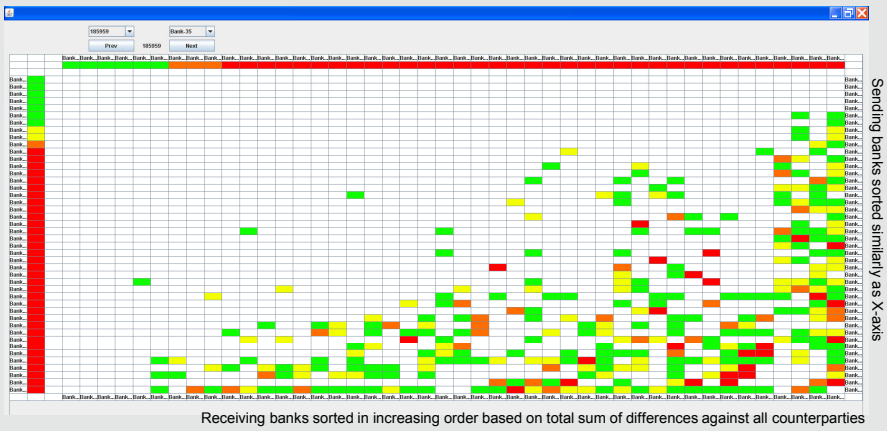
=> (too) clear identification in test 3







Visualisations of the results



Receiving banks sorted in increasing order based on total sum of differences against all counterparties

Analysis software shows animated status matrix of bilateral differences. Displays the problem banks and contagion structure of the network.

Ideas for future

- More iterations with the TestLab2084 would be beneficial to improve the indicators
  - Own test setup for Framework mk. I is needed
  - After iterations applying methods to real data
- The definition of common profile could be more elaborate.
- The definition of difference measure could be more elaborated. (not linear measure.)
- The aggregation of pairwise comparisons need futher research to find practical way to do it.

Limitations of the Frameworks

- The results of the both frameworks are greatly dependent of chose of comparison period and the time period in which network is constructed.
- The choise of network indicators in framework mk. I affects the frameworks ability to detect changes.
- Efficient in detail level rather than aggregated network level.(mk. II)

Observations and (preliminary) conclusions

- Aggregation period and level are critical for what can be observed with the indicators
- Filtering of raw data (value bands) has large impact on network indicators
- Time lag from real world incidents to network indicators is ambiguous
- Stochastic data generation in the test setup has its challenges… (Signal/noise ratio)
- **Difference of change in behavior vs. change in ”world” is not structurally identifiable (?)**

THANK YOU

BONUS MATERIAL

Further Details to Analysis Framework mk. II

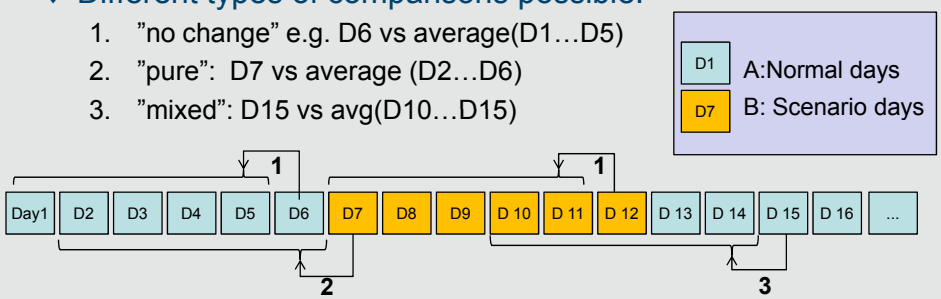
- The definition of common profile as unconstrained minimization problem could be altered to constrained minimization problem
  - Would catch the typical behavior more accurately in situation where variation of profiles is large.
- The aggregation of differences could be done in basis of e.g.
  - Clustering
  - Network indicator < or > given X
- The aggregation could be more detailed e.g. weighting could be used.

More Details to Analysis Framework mk. II

- The aggregation level i.e. Do we look the whole network or just one participant defines how much variation from normal behaviour is accepted and it can be suprising amount in pairwise comparisons.
- The variation in normal behaviour i.e. Noise can be high compared to the effects from the change of behaviour of single participant. (Noise/Information ratio)
- The upper level i.e. network level analysis might not capture the details of participant level or in a pairwise behaviour.

Construction of the tested comparisons in the TestLab2084

- Sampled days into one long row from two sources A & B
  - n+1 selected randomly from same source in terms
- Indicators computed for the artificial row of days with length of period n (n=5 was used)
- Different types of comparisons possible:
  1. ”no change” e.g. D6 vs average(D1…D5)
  2. ”pure”: D7 vs average (D2…D6)
  3. ”mixed”: D15 vs avg(D10…D15)



Construction of the common profile in framework mk. II

- The common profile is defined as the profile which **minimizes** the **squared error** at every time point.
- Profile is defined as the **point set** and then the minimizing can be done separately at each time point.

A Bit of Algebra (common profile continued)

$$\min_{y'} \sum_{i=1}^{N} \left(y_i - y'\right)^2$$

$$= \min_{y'} \sum_{i=1}^{N} \left(y_i^2 - 2y_i y' + y'^2\right)$$

$$= \min_{y'} \left(\sum_{i=1}^{N} y_i^2 - \sum_{i=1}^{N} 2y_i y' + \sum_{i=1}^{N} y'^2 \right)$$

$$\frac{\partial f}{\partial y'} = 0$$

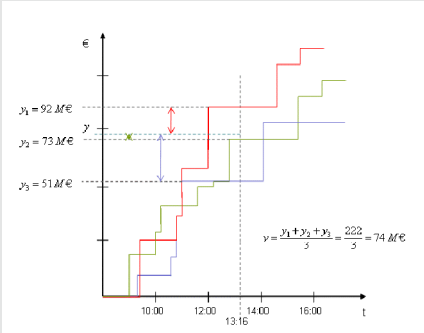
$$\frac{\partial}{\partial y'} \left(\sum_{i=1}^{N} y_i^2 - \sum_{i=1}^{N} 2y_i y' + \sum_{i=1}^{N} y'^2 \right) =$$

$$= \sum_{i=1}^{N} \frac{\partial}{\partial y'} y_i^2 - \sum_{i=1}^{N} \frac{\partial}{\partial y'} 2y_i y' + \sum_{i=1}^{N} \frac{\partial}{\partial y'} y'^2$$

$$= -2\sum_{i=1}^{N} y_i + 2\sum_{i=1}^{N} y' = -2\sum_{i=1}^{N} y_i + 2Ny'$$

$$-2\sum_{i=1}^{N} y_i + 2Ny' = 0$$

$$y' = \frac{\sum_{i=1}^{N} y_i}{N} = \bar{y}$$



Presented minimum fulfills KKT conditions