Doctoral School of Economics

RÉSUMÉ OF THE PH.D. THESIS

Dániel HAVRAN

CORPORATE LIQUIDITY MANAGEMENT

Ph.D. dissertation

Supervisor:

Edina BERLINGER, Ph.D.
associate professor

Budapest, 2010.

Department of Finance

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Contents

1 Introduction

On one hand, *corporate liquidity* or financial slack means 'immediately solvency'. Keynes [1936] and also Hicks [1967] showed that economic actors hold low-yield assets such as cash because its special feature: the liquidity. Keeping the firm liquid entails holding liquid assets (*asset liquidity*, or *marketability*), and getting easy possibilities for funds (*funding liquidity*), as well. On the other hand, *corporate liquidity management* deals with short term assets and liabilities due to keep firm flexible. I principally use this last concept in my dissertation. Keeping liquidity is usually costly, but helps avoiding negative effects of unexpected cash-flow shocks.

The thesis has three parts. Chapter *Important questions of corporate liquidity* introduces general concepts of corporate liquidity and corporate liquidity management. It settles coprorate liquidity management into the framework of corporate financial decisions, such as capital structure, investment or dividend policies. It shows one explaination why liquidity management is valuable for firms, then it reviews a stylized process of corporate liquidity management. Two studies of my researches on corporate liquidity management follow the part of definitions. In chapter *Corporate liquidity management and credit risk* I connect firm's credit risk with the corporate liquidity in a theoretic, structured credit risk model. This model also relates to debt contracts and bargaining games. In chapter *Cash management in network industry* I show empirical evidences on cash circulating system of a given company working in network industry. I measure and model behaviours business units at micro level, and make predictions for aggregated liquidity position at macro level. This chapter contains my main results of the dissertation.

2 Results of chapter corporate liquidity and credit risk

2.1 Liquidity needs and debt contracts

While reasoning why liquidity management is important is simple task for banks, reasoning for keeping asset and funding liquidity is more complicated for corporate issues. When a bank fails to pay an obligation this reacts to ratings of credit riskiness. Then, higher cost of capital decreases profits and endangers running and solvency. A non-financial company does not attack on such a taut situation. If a non-financial firm is not able to pay obligations becomes due, for example does not pay to suppliers or workers, it can causes bad image and srikes of trade unions. When a firm cannot pay for longer time and defaults debt services, then it is threathen by liquidation forced by creditors. This is the real risk of lacking corporate liquidity. The complexity of debt contracts and debtor-lender relation often takes real consequences unpredictable.

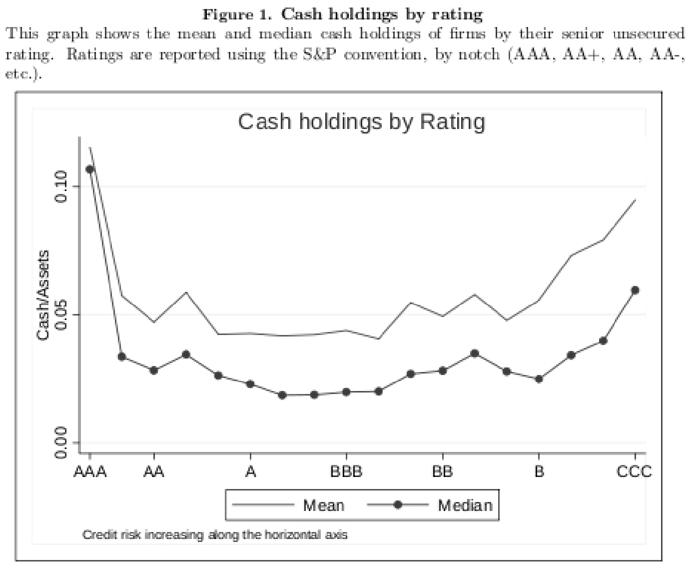
The research focuses on leveraged firms. Long term debt has two typical form: corporate bonds (mainly in US) and bankloans (mainly in Europe), which contains stricter covenants, and has usually shorter maturity. Debt contracts mightily determine corporate managers decision latitude, especially it is true for corporate liquidity management. The study supposes lender and owner-manager plays full information strategic game. However debt contracts differ from each other depend on maturity, seniority and so on, there are a few typical components, which characterise all of them. Seven components usually appear in debt contracts, such as the *loan*, *representation and warranties of borrower*, *affirmative covenants*, *negative covenants*, *condition of lending*, *events of default*, *remedies*. A liquidity shock caused by default means violating covenants. In this event, actions of the lender and the firm owner-manager are mainly deteremined by value of remedies, prospects of the firm, and some other of debt contract components. Liquidity shocks might causes to default obligations becoming due. There are several inducing factor of cash-flow shortages. Managers handle *seasonal* and *occasional* cash-flow shortages in a different manner. The first is predictable and liquidity manager plans funding seasonal effects, the second requires precautory cash holding or quick and flexible funding possibilities. Usually seasonal sales volatility induces seasonally negative cash-flows, and losses from business, financial or operational failure generates eventual cash-flow shortages. The studey concentrates on random, occasional cash-flow shortages. One can distinguishes three possibilities to avoid cash-flow shortages, *capital injection*, *group of short term financing* and *reorganisation process*. Firms rarely chooses issuing new capital to avoid liquidity shocks. Sometimes it would be preferred in case of large losses. Public firms cannot involve new capital by equity issues for only repairing liquidity shocks, because of dilution effects. Owners of closed firms are willing to reinvest, but it is not certain to posses enough capital from outside of the firm. Corporate liquidity manager can provide cash or cash equivalents from *cash reserves*, *firesales* – quick asset sales, *factoring* – pledging of accounts receivable , *commercial paper*, *trade credit* – stretching of accounts payable, *line of credit*. Under reorganization process, or *Chapter 11* (US) firm is dispensed from paying obligations. If cash-flow shortage cannot be avoided and firm violates debt covenant, lender steps. Lender decide on whether liquidiate the firm or renegiotate the contract. Creditor renegotiate debt contract to provide more value than from forced liquidation. Then it usually offers debt-restructuring or debt-for-equity swap. Under forced liquidation, or *Chapter 7* (US) the firm stops running and claimants aquire firm's assets.

Hypothesis Four market imperfections play role in value creating of corporate liquidity management. These are *liquidation costs*, *information asymmetry*, *transactional costs of capital injection*, *taxes*. Although taxes have role in corporate liquidity management, but it is not so relevant for this issue. Transacional cost of capital issuance modifies effects and mechanisms of corporate liquidity management, but it does not really induce needs of liquidity supply management. As it known from article of Holmström and Tirole [2000], value of corporate liquidity management can be explained with information assymetry. Can we explain value of liquidity management with assuming presence of liquidation costs and perfect information? The answer does not come trivially from earlier literature.

No capital injection is the only possibility for avoiding negative effects of temporary liquidity shocks. Liquidity would be provided by a third person, such as for example an other bank, the suppliers, or factoring institutes. In this case firm get liquidity by changing net working capital management. In practice of banking, bank orders lot of covenants prohibiting changes of net working capital allocation. I suppose here there is no such a covenants that forbits cooperation with existing business partners of the firm, to change structure of short term financing. I am intended to explain how this kind of net working management creates value for the firm.

Corporate debt value also depends on liquidity supplying. Does liquidity supplying create value also for firm's creditor? What happens, if a bad firm keep paying temporary but later cannot redempt creditors claims? How impacts on debt value and credit risk the corporate liquidity management?

Figure 1: Cash holdings by Rating



Source: Acharya, Davydenko and Strebulaev [2008], p. 44.

Davydenko [2009] and Acharya et al. [2008] studies relationships between cash holdings and credit risks. Their empirical findings were riskiness of US firms positively correlated with their level of cash and cash equivalents, especially for ratings B and below, see on Figure 1. They found high cash holdings at firms with very good ratings as well as firms with very bad ratings. This fact is counter-intuitive, one can supposes higher cash level helps avoiding liquidity shocks, and it means safe and flexible working. Theory of Myers and Rajan [1998] with assumption of information assymetry and agency costs might explain this relationship, but riskiness is not equal to transparency, and information assymetry. I examine how can this fact explain under perfect information and presence of bankruptcy costs.

The study aims to answer that under perfect information and presence of liquidation costs

- does really create value corporate liquidity management for owners,
- what is the mechanism of value creating,
- what are the impacts of corporate liquidity management for debt value,

- can be explained puzzle of cash and credit spread with mechainsms of corporate liquidity management?

2.2 Model

Model assumptions The study's setup is built on a standard framework of discrete structural credit models, with strategic interaction driven by the possibility of renegotiation of debt contract and the threat of liquidation.

Institutional assumptions. There is full infomation both for lender and firm owner-manager. There are bankrupcy (liquidation) costs. There are transaction costs of providing liquidity. There are no taxes, there are no problems with indivisibilities of assets. Trading in assets takes place continuously in time. The term structure is flat.

Dynamics of firm value. Unleveraged firm value V_t follows binomial motion such as model of Cox, Ross and Rubinstein [1979]. Firm produce free cash-flow in each period at β ratio of unleveraged firm value ($f_t = \beta V_t$). Free cash-flow to firm does not depend on capital structure and short term financing.

Conditions of debt contracts. In this model, lender is a bank, but one can associate as a bondholder, too. Firm has long term debt with P nominal value and T maturity. Debtor is obliged to meet interest paying with k fix rate. Capital redemption is in lump sum at maturity. Debt services (signed CS_t) has to be financed from f_t free cash-flow to firm. Owner-manager can partially or fully refuse paying debt service (paying only a smaller S_t amount), if firm is not threathen by forced liquidation. This might induce covenant violation. Lender chooses liquidation or debt contract renegotiation which seems to be better by future expectations of firm performance and liquidation value ($V_t - K$), where K is fix liquidation cost.

Dividend policy, investment policy. Investment policy is given. Free cash-flow to firm less effective debt service is paid to dividend, when it is greater than zero.

Pricing. Firm value V after paying effective debt service and dividend is $(1-\beta)\,V_t$. Because firm value V is not traded, I use techniques of martingal prices for non traded assets. With martingal probability p firm expected value at next period is

$$\mathbb{E}\left[V_{t+1}\right] \doteq puV_t + (1-p)\,dV_t = (1+r)\,(1-\beta)\,V_t$$

where r is sum of risk free rate and market price of risk.

Model I discuss on two forms of liquidity supplying mechanism: capital issuance and short term financing in two excluding models. I show at first the general form of debt service game, after develope linkage liquidity mechanisms and credit pricing.

Game of debt service. Game of debt service is built on the fundamental ideas of Anderson and Sundaresan's model. They implicitly assumed that only the shareholders have bargaining power, debtholders does not. Owner-manager decides on whether pay the total amount of debt service CS_t, or pay less. Firm cannot pay more than actual f_t free cash-flow to firm, but choose lower level of payment than nominal CS_t debt service. Effective cash-flow payment after decision is $S_t \in [0, f_t]$. If firm pays CS_t, it means continuation. When firm default this payment, the lender might accept this reduces debt service, or reject it. Accepting the lower amount means continuation, rejecting induces liquidation or renegotiation. Consider the equilibrium at the last period. When the firm pays less than CS_T, lender's best reply

$$\text{Lender's best reply} = \begin{cases} \text{accept and continuation} & : \; S_T \geq \max\left(V_T - K, 0\right) \\ \text{reject and liquidate} & : \; \text{otherwise.} \end{cases}$$

Owner-manager chooses level of S_T in the function of creditors best reply

$$\text{Owner-manager's best reply} = \begin{cases} S_T = CS_T & : \; V_T - K > CS_T \\ S_T = \max\left(V_T - K, 0\right) & : \; \text{otherwise.} \end{cases}$$

So, owner-manager sets S_t minimal debt service in such way, to be indifferent accepting or rejecting the debt contract for the lender.

$$S\left(V_T\right) = \min\left(CS_T, \max\left(V_T - K, 0\right)\right)$$

Thus, debt value at maturity and value for equity holders

$$D\left(V_T\right) = S\left(V_T\right)$$

$$E\left(V_T\right) = V_T - D\left(V_T\right)$$

Debt valuation, when equity issuance is possible. Let extend the case above with the periods before maturity. Two new notations are introduced for simplicity

$$D_+\left(V_t\right) \doteq \frac{pD\left(uV_t\right) + (1-p)\,D\left(dV_t\right)}{1+r}$$

$$E_+\left(V_t\right) \doteq \frac{pE\left(uV_t\right) + (1-p)\,E\left(dV_t\right)}{1+r}$$

where $D_+\left(V_t\right)$ is the expected value of the $t+1$th period debt at t, and $E_+\left(V_t\right)$ is the expected value value of the $t+1$th period equity at t. Owner-manager also sets S_t minimal debt service to the indifference level of the lender. Creditor chooses continuation when expected value of debt and the incoming cash at now is higher than the benefits from liquidation.

$$S(V_t) = \min\left(CS_t, \max\left(0, \max\left(V_t - K, 0\right) - D_+\left(V_t\right)\right)\right)$$

The level of f_t free cash flow to firm determines whether it can pay S_t amount of cash, or it has got liquidity problem in the first meaning. When $f_t \geq S_t$, then the firm pays, and continue. Hence, debt and and equity values at time t

$$D(V_t) = S(V_t) + D_+(V_t)$$

$$E(V_t) = f_t - S(V_t) + E_+(V_t)$$

When cash-flow shortage occurs ($f_t < S_t$), then the owner-managers have to choose from the two alternatives: 1. firm does not inject capital and declares bankruptcy, 2. firm gets needed cash from equity issuance. In the first case, debt value at bankruptcy and value of equity follows

$$D^{nic}(V_t) = \max\left(0, \min\left(V_t - K, CS_t + P\right)\right)$$

$$E^{nic}(V_t) = V_t - K - D^{nic}(V_t)$$

In the second case, calculating with continuation the debt and equity value is

$$D^{ic}(V_t) = S(V_t) + D_+(V_t)$$

$$E^{ic}(V_t) = E_+(V_t) - (1 + \mu)\,\Delta E_t$$

where the firm issue $\Delta E_t = S(V_t) - f_t$ level new equity, and equity issuance cost is μ. Owner-manager chooses equity issuance, and the firm continues working if and only if $E^{ic}(V_t) \geq E^{nic}(V_t)$. Capital raising is not worthy for new shareholders, the new capital is provided by the present owners, assuming at this point they are able to raise capital. Thus, equity value and debt values

$$E(V_t) = \max\left[E^{nic}(V_t), E^{ic}(V_t)\right]$$

$$D(V_t) = \begin{cases} D^{nic}(V_t) & : \quad E^{nic}(V_t) \geq E^{ic}(V_t) \\ D^{ic}(V_t) & : \quad \text{otherwise.} \end{cases}$$

The valuation goes step by step backward from maturity to the first period. One can conclude that the criteria of liquidation are depend on the unleveraged value, the cash flow, the long term loan interest rate and the bankruptcy costs.

Debt valuation, when short term financing is available. Let us assume that the firm is able to get short term liquidity with one-period maturity loan. The only case, when owner-manager uses short term financing, if the shareholders' value grows with this action. Suppose furthermore that there is no covenant that would prohibit the short term financing in this manner. In the model, I consider a general short term financing form, it can be all of the listed forms before. Suppose that short term liquidity supplier differs from long term creditor, and it has comparative advantage in financing. Comparative advantage means the ability of controlling free cash flow to firms, which is pledged to the short term financier by the firm. It receives the future cash-flows, whatever happens, there is no debt service game. The owner-manager can only pledge the λ rate of its future expected cash-flow. Since, the fee or interest rate of short term financing is h, upper bound of liquidity supply at time t is

$$H_t \leq \lambda \frac{\mathbb{E}\left[f_{t+1}\right]}{1+h}$$

The short term lender bear the risk of future cash-flows, no more cash will get later if it is insufficient to cover the whole lent amount. Because the short term lender controls future cash flow, we also have to define controlled cash-flow to firm:

$$f_t' \doteq f_t - H_{t-1}\left(1+h\right)$$

The S_t minimal long term debt service is determined the same way as before. Now, we can examine instances of liquidity problems. When $f_t' \geq S_t$, then there is no liquidity demand, $H_t = 0$. Thus, calculating debt value and shareholders' values

$$D\left(V_t\right) = S\left(V_t\right) + D_+\left(V_t\right)$$

$$E\left(V_t\right) = f_t' - S\left(V_t\right) + E_+\left(V_t\right)$$

The firm keeps running. In the case of cash-flow shortage ($f_t' < S_t$), the owner-managers might use short term liquidity supply. The short term lender is willing to finance, only if the needed cash is below the upper bound:

$$S_t - f_t' \leq \lambda \frac{\mathbb{E}\left[f_{t+1}\right]}{1+h} \equiv \lambda \frac{f_t}{1+h}$$

this bound is the function of next year period expected cash-flow. The owner-manager demands money, if equity value will be higher with liquidity supplying then in the bankruptcy case:

$$E^L(V_t) > E^N(V_t)$$

When liquidity is supplied, the value of equities becomes

$$E^L(V_t) = f_t'' - S(V_t) + E_+(V_t)$$

where:

$$f_t'' \doteq f_t - H_{t-1}(1+h) + H_t$$

The provided cash amount is

$$H_t = S(V_t) - f_t'(V_t)$$

and hence the value of debts is

$$D^L(V_t) = S(V_t) + D_+(V_t)$$

and operating continues. When liquidity is not provided by short term financing, debt and equity values

$$D^N(V_t) = \max[0; \min(V_t - K; CS_t + P)]$$

$$E^N(V_t) = V_t - K - D^N(V_t)$$

in this case $H_t = 0$. The firm stops running. Summarizing upper parts, in period t, resulting equity and debt values

$$E(V_t) = \begin{cases} E^L(V_t) & : \; E^L(V_t) \geq E^N(V_t) \text{ and } S_t - f_t' \leq \lambda \frac{f_t}{1+h} \\ E^N(V_t) & : \; \text{otherwise.} \end{cases}$$

$$D(V_t) = \begin{cases} D^L(V_t) & : \; E^L(V_t) \geq E^N(V_t) \text{ and } S_t - f_t' \leq \lambda \frac{f_t}{1+h} \\ D^N(V_t) & : \; \text{otherwise.} \end{cases}$$

One might calculate $t = 0$ values with backward induction, but the solution is get with iteration, because last period depends on the first, and vice versa. It could be modelled with not-recombining binomial trees. Here, it is needed to rethink the bargaining game at the maturity. Because of the short term loan, it has to be extended with the controls of short term lenders. The S_T minimal debt service changes to

$$S(V_T) = \min\left[CS_T, \max\left(V_T - K - \min\left\{f_T, (1+h) H_{T-1}\right\}, 0\right)\right]$$

thus debt value and shareholders' value also change to

$$D(V_T) = S(V_T)$$

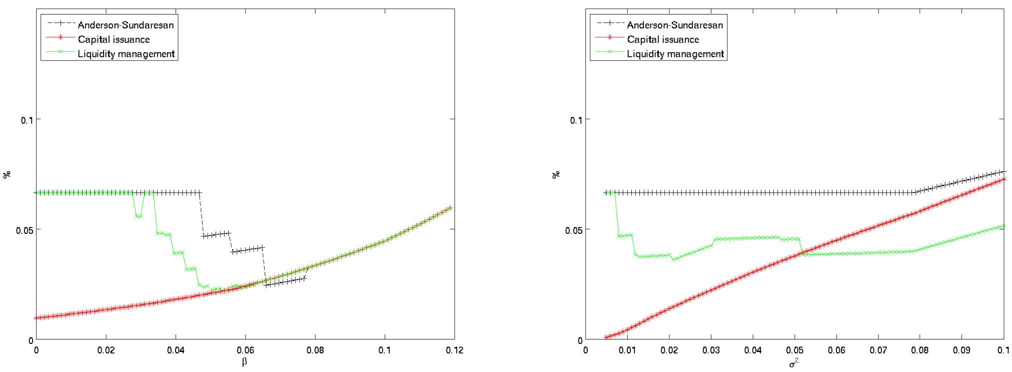
$$E(V_T) = V_T - D(V_T) - \min\left\{f_T, (1+h) H_{T-1}\right\}$$

One would ask whether this form is really create shareholders' value, because at maturity firm has to pay rolled short term loans. The answer is certainly yes, because the shareholder always decide the best solution to get higher equity value. The impact of the liquidity management on debt value is not so obvious.

2.3 Main results

Comparatic statics prove variety of evidences of liquidity supplying mechanisms in dynamic debt contract. Debts with different principal amounts, interest rates, and maturities are compared. I also examine effects of β coefficient, liquidation cost, and unleveraged firm's value volatility. Calculated credit risk spreads are compared in three cases. First is the base model of Anderson and Sundaresan [1996], second is the model of equity issuance, and third is the model of short term financing. Liquidity supplying mechanism effectively impacts on debt value, the correspondence is nonlinear and depends on model environment.

Figure 2: Credit risk premia in function of β and σ



(a) Cash-flow payout ratios and risk **(b)** The volatility threshold effect

Volatility dependencies Effects of liquidity supplying possibility to debt value highly depends on volatility of unleveraged firm value. (Figure 2 b.) There is a volatility threshold value separates effects of liquidity providing into a useful and a harmful case. Under this threshold both capital injection and short term financing create value for lenders as well as for shareholders.

Resolving cash and credit spread empirical puzzle This model explains Acharya et al. [2008] emipirical findings on positive correlation between cash holding and credit riskiness. The keyword the volatility, again. Mechanism of non-operative cash hoardings is similar to capital injection. Holding cash raising credit spreads in case of risky firms with high volatility. Cash reserves at safe (less volatile) firms make their riskiness lower.

Real performance versus valuation anomalies Market valuation of equities and real firm performances often divorce to each other. Outcome of liquidity problems arriving from real economic issues highly depends on market valuation of firm and equities. Liquidity shortage and high market value of equities may predicts continuation and renegotiation, because leners's beleifs on debt value are positive. Liquidity shortage by random shock and high market value of equities may predicts liquidation, while firm's real performance may good. When liquidity shock and valuation panic simultaneously occur, forced liquidation does not have real economic background. Reorganisation process may help, although bad future expectations of owner-manager indicate turning to liquidation acquiring assets from claimants. Liquidation costs make harder to levy claims.

Relevancy of liquidation costs Growing liquidation costs highly emerge credit risk spreads. The results emphasise the significant role of liquidation costs on decisions and thus pricing.

3 Results of chapter cash management in network industry

3.1 Description of the cash-management system

For firms in network industries, cash management is typically depends on the structure of the network and behaviours of firm units. For corporate liquidity problems, there are several relating models especially for cash handling. Classical cash-management models, as Baumol [1952] and Miller-Orr [1966] are showed the trade off between cost of delivery and alternative cost of cash holdings. Eppen and Fama [1968] or Stone [1972] suggested to solve corporate cash management problem with mathematical programming. Very often the common cost function of the delivery and cash holding is very flat, and there are lot of solution near to optimal. In this case, optimization is usually needless – warns Daellenbach [1974]. Others, such as Pogue and Bussard [1972] or Kusy and Ziemba [1986] use stochastic programming to solve a wider problem: the (corporate or bank) liquidity planning. This is very close to cash management, because working cash is the part of working capital. Later, Castro [2007] used stochastic programming for bank ATM's cash-management. The complexity of the modeling cash circulation in network is from mapping and aggregating heterogeneous individual acts. Tesfatsion [2001] and Forster [2004] suggests agent-based modeling for such cases.

I formalize and show the firm's cash-handling system through a stylized model. The model is based on the inner account system of the firm. There are four type of actors: clients, branches, cash-management center, central bank. The branches open with S amount of cash stock, and they had ordered from the cash management center an I amount of cash (coins and banknotes) which arrives immediately after the opening. They accepts cash from some revenues (R), and they deliver payments (P). At the end of the day, the next days' cash-movements are planned. Furthermore, they send extra cash outflow (O) to the cash center, and they make decision on the next day's ordering. Formally, the equation of branches forms

$$S_t^i + I_t^i + R_t^i = S_{t+1}^i + O_t^i + P_t^i$$

The cash-management center collects outflows from this units, and distribute the demand for next day.

$$Z_t + JNTI_t = Z_{t+1} + JNTO_t$$

Where JNTI and JNTO are the inflows and outflows of cash management center, thus the sums of cash amounts for branches, plus the volume of transfered cash amounts with central bank

$$JNTI_t = \sum_i^N O_t^i + MNBO_t^i$$

$$JNTO_t = \sum_i^N I_{t+1}^i + MNBI_t^i$$

where N is the number of the units. Note that cash amounts at day t from cash center arrives to the branches at day $t+1$: it is carried at night. Transfers between central bank and cash-handling center is always in the daytime. To close up the system, equation of aggregate volume forms

$$(MNBO_t - MNBI_t) - (Z_{t+1} - Z_t) = \sum_i^N I_{t+1}^i - \sum_i^N O_t^i$$

where MNBI is the inflow to the central bank, and MNBO is the outflow. Clients generate demand for P and supply of R, and cash-management center handles the aggregate amounts. Cash-management center plans in the following manner: it estimates the ordered amounts for next day and decides how much to send to or order from the central bank. These transactions are in the daytime. Later, usually in the evenings exact information on cash demands are arrived. The center distributes the cash packages to each business units. If cash management center has adequate estimation, then liquidity position will be near to zero at this time. Usually, noise appears in estimations. I call this difference as 'planning error'.

$$\text{Planning error} = Z_t + (MNBO_t - MNBI_t) - \sum_i^N I_{t+1}^i$$

Closing level of the cash in the center is the planning error added the incoming extra cash from the units.

$$Z_{t+1} = \text{Planning error} + \sum_i^N O_t^i$$

One can also summarize the aggregate amount of cash holdings, which is the closing level of the branches, the cash-management center and the cash just under delivery demanded by business units.

$$G_{t+1} = \sum_i^N S_{t+1}^i + Z_{t+1} + \sum_i^N I_{t+1}^i$$

Where G inventory is working cash, part of working capital.

Characters of cash circulation system The study uses the time series of the firms accounting system from 01-01-2001 to 05-31-2006. Database contains about 2500 actors' acts on approximately 1600 days. I put relevant empirical facts from the year 2005. Aggregated opening stock level fluctuated between HUF 5 and 15 billion day by day, ordered cash amount was in range between HUF 0 and 10 billion. Aggregated inflows from clients were around between HUF 5 and 15 billion day by day, (approx. HUF 3100 billion per year) aggregated outflows of branches near HUF 5 billion and 25 billion, (approx. HUF 2700 billion per year). Size of flows from branches to centre were close to HUF 5 billion. There is a very specific *monthly seasonality* in the time series. Dominantly inflows appear at first part of the month, and outflows are higher in the last two week of the month. These kind of waving origins from the special schedule of wages, invoices and social transfer payments in Hungary. Although, yearly sum of cash inflows are higher then cash outflows, cross-financing techniquies for branches could not work, almost all of branches need hoarding some daily reserves, because of the strong seasonality in months. Aggregated cash inventory (G) is much more higher in the first part of the month, liquidity position with central bank is positive at the first week of the month, and negative at the last one. Planning error were between the range of zero and HUF 1,5 billion. During the five year period of 2001-2006 there were a nominal growth on the value of transferred coins and banknotes. The volume decreased between branches and cash centers, in parallel, cash stock level at the branches increased.

3.2 Micro-level analysis

Apart from coin and banknote denomination differencies analysis on cash management of local business units focuses to cash tansfers and inventories.

Optimal cash management program Local units aim to reserve enough cash on low costs for transfers induced by clients. Costs are composed of transportational costs and alternative costs of cash holdings. Costs of transportation depend on the carried amount of cash, alternative cost of cash holdings comes from the interest losses of reserves at local units. Cash reserve is measured by opening level $(S+I)$ of units. Each branch optimizes on $[0,T]$ finite time horizon.

Daily decisions. At the decision time of the day, business unit knows level of U for now, and foresee next day level of P outflows. Unit has to meet two rules in decision of amount to transfer for center and amount to demand next day. According to my hypothesis, flows of P and R are stochastic. Cash holdings generate interest losses. Transfer is costly, monoton in volume.

Constraints. The leader of business unit has to meet two rules specified by the headquarters. *Precautory rule* assess to be enough cash for next day outflow planned. *Inventory limit rule* give an upper constraint for daily stockpiling at the time of closing. Amount of daily transfer has an upper boundary for physical and security reasons. Negative stock level, demand or supply are excluded.

Program of cost optimization forms

$$\min_{\{O_t, I_{t+1}\}_{t=0}^{T}} \mathbb{E}\left[\sum_{t=0}^{T} \beta^t \left(c\left(O_t\right) + c\left(I_{t+1}\right) + \left(U_t - O_t + I_{t+1}\right)\right)\right]$$

with following constraints

$$U_{t+1} = U_t + I_{t+1} + R_{t+1} - P_{t+1} - O_t \tag{1}$$

$$U_{t+1} + I_{t+1} - O_t \geq \text{kvant}\left(P_{t+1}; \alpha\right) \tag{2}$$

$$U_t - O_t \leq k \tag{3}$$

$$I_{t+1} \geq 0 \tag{4}$$

$$O_t \geq 0 \tag{5}$$

$$I_{t+1} \leq I_{max} \tag{6}$$

$$O_t \leq O_{max} \tag{7}$$

$$S_{t+1} = U_t - O_t \geq 0 \tag{8}$$

Where $\beta = 1/(1+r)$ is the discount factor, $c()$ is carrying cost, and r is interest rate (daily). In the model, R, P are exogenous, S is endogenous, and I, O are decision variables. A kvant(x, α) function is quantile function. The problem can be solved by numeric algorithms, applying the Bellman-theorem.

Empirical findings on cash stockpilings I test the program above for some characteristic branches. Delivery costs are constructed as a step function. Banknote and coin transfers between units and cash handling center are carried by one or more trucks with determined upper loading limit. I use constant daily interest rate for count alternative costs. Assuming that manager's time-preference function is a discount factor calculated with the interest rate, one can count present values of costs.

At the business unit 'No. 1000' there are cash incomes, which is transported to the cash center. The simulated and the observed acts are very close to each other. At the branch 'No. 2014' one can easily note strongly seasonality. The town is situated at the bank of Lake Balaton, summer is highly frequent. The branch does not pay significant outflows, it gets dominantly extra cash amounts. Unit 'No. 2079' is stated in a small village and therefore it has very volatile cash-flows, there is not real periodicity in the time series. This unit is also allowed to retain higher stocks, the real closing cash levels above the counted one, but there is no characteristic over-ordering or over-sending. This kind of units would rather retain than transfer from/to cash handling center, but it has often to do. At the largest branches, like 'No. 3850', outcomes are determining part of cash-flows. It has to be covered with extra cash. The unit closing stocks are above the optimal level. This kind of actor usually has inflows from clients in the first part of months, and outflows on the second half. Real activities sometimes overreacted unexpected changes: in case of ordering in November, the theoretical decision is below the fact. In the case of 'No. 6817' branch, simulation results are not very similar to the observed activities. Usually, this unit order and hold much more cash, than the optimal program suggests, and in parallel it sends less money to the center.

There are some critics of optimization. Although generated and observed paths are seemingly very close to each other, but very difficult to measure formally this distance. The cost function is so flat, it cannot show real differences between simulated and real trajectories. There are critics from practice, too. Managers of branches are not perceived directly by cash holding's interest losses. So, in practice business units rather choose sub-optimal solutions, with distortion following from their own fashions.

Measuring with a two-coefficients approach I describe a method that measures the fashions of the units' cash-handling. It can be supposed that each branch plan for only the next day. They have to meet the precautionary rule and the cash holding limit. The payments are foreseen for next day, the incomes remain unknown. They do not take into consideration carrying and cash holding costs in short term planning. Therefore, their decision area is a convex two-dimension set constrained by the two rules. Branches have to choose the level of ordering for next day and the level of sending.

The decision set could be a triangle, a quadrangle or a pentagon. Figure 3 shows an example of the decision set. Line AD symbolizes the precautionary rule, line

AB constrains cash holding limit for this day. Amounts of ordering and sending are limited by EFGC rectangle, so the unit must choose ordering-sending strategy within ABCD quadrangle. The shape of decision set changes day by day.

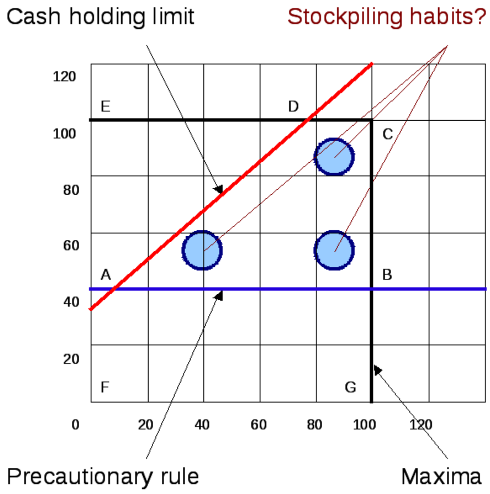


Figure 3: Example of decision set

I suppose that each branch follows own behavior: they prefer to make decisions on one part of the decision set. For example they use to choose on the "North-West part", and so on. Habits can be easily describe with two factors. Considering that I' and I'' is the minimum and maximum allowed ordering-level, furthermore O' and O'' is the lower and upper limit of sendig-level, the two coefficients are:

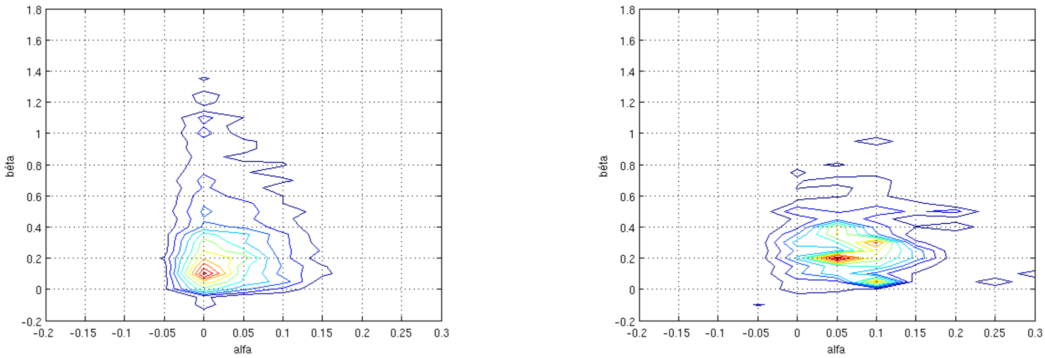
$$\alpha_t = (I_t - I_t') \,/\, (I_t'' - I_t') \tag{9}$$

$$\beta_t = (O_t - O_t') \,/\, (O_t'' - O_t') \tag{10}$$

This two coefficients are independent from decision sets, they are scaled between 0 and 1. Although there were large dispersion of (alpha, beta) coordinates for each day for each branches, supposing a relatively stable coefficients are acceptable. Interviews with management of cash handling centers confirm that lots of units have very stable habits in cash handling. In practice, cash holding limits are not effective constrains for all branches, it causes that (alpha, beta) values are often beyond the $[0, 1]$ interval.

Categorizing branches by behaviours Using data from 2003 to 2005, I distinguished the units by stockpiling behaviours. The contour map shows the frequency of (alpha, beta) strategies of 2500 observed branches. There are two contour maps

Figure 4: Countour maps of business units by behaviours, on (α, β)



(a) For the number of branches

(b) For volume weighted data

on Figure 4. On the left side, I collect plain quantity data, on the right side, data are weighted by the volume. By weighted contour map, I identified six larger group of strategies. These are:

1. Large branches: they are usually delivery social transfers, and accept remittances (0.05; 0.2)
2. "Delivery" units (0.1;0.3)
3. "Accumulator" branches (0.1; 0)
4. "Cash mover" branches (0.05; 0.85)
5. "Anchorite" branches (0;0)
6. "Shopping center" units: they are located in large shopping centers and do not delivery social transfers (0;1)

These categories are confirmed by an earlier empirical research, where units were examined by outer features with cluster analysis.

Characters of the most often behaviours I describe the most important stockpiling and transfer strategies in the next examples. Behaviours of 'Anchorite' branches are the most simple strategy: they move as few cash as possible. They are practically independent from the cash management center: they financing themselves to pay outflows. 'Shopping center' units' strategy is an other simple one. They order always the minimum, and they send always the possible maximum amounts. This pattern is very similar to the 'Cash mover' branches' strategy. Third typical strategies are the patterns of large units. They usually have inflows and outflows, but not in the same time. Therefore they accumulate some cash (do not send back) for next days. The cash stock level is higher than the other types of strategies. 'Delivery' and 'Accumulator' branches make similar stockpiling.

3.3 Macro-level analysis

Effects of the changing behaviours on the cash management system The system works with 2500 branches, and stockpiling habits affects aggregate patterns of liquidity positions. How would change the aggregated liquidity position if the habits of the business units change? Does it cause dramatic, or slight changes for the system liquidity planning? Does the working cash amount change with varying habits? In this section I expose two agent-based simulations to answer this questions. The first scenario ('Scenario 2005') examines the direct effects of the changes of individual stockpiling. In 'experiment 1', I suppose that behaviors turn to more transfering and lower cash holdings. In 'experiment 2' behaviours change to that reserving character will be stronger. The second ('Scenario 2011') is a really scenario analysis, where I assume decreasing trend of incomes. In this situation, altered cash-flows have impact on branches stockpiling habits, thus whole aggregated liquidity position varies too. I use the introduced two-coefficients approach for modeling behavior-changes. The simulation uses six representative agent, with the six type of habits shown above. The representative agents behave as the typical units in the group. There are different cash-flows patterns for each group. I aggregated this cash-flows within the groups. I also model and compare the originally observed data with the initial agent-based simulation where I used the revealed habits above.

Results for 'Scenario 2005' In the first analysis, I used the data of year 2005. Over the observed habits, two other hypothetic stockpiling habits are modeled. In the first hypothetic case (this is 'experiment 1') the motive of sending becomes stronger, in the second one ('experiment 2') this motive becomes more week. Results with the original parameters return the size of waving as well as the patterns. The forecasted transfer with central bank is similar to observed cash-flows, too. The differences arise only in the extraordinary periods. The minimal aggregated cash level was around HUF 15 billion, the maximum was about HUF 28 billion. On the second week the jumping level comes from the accumulating motive, it does not visible in the second simulation ('experiment 2'). In the case of 'experiment 1' the aggregated stock reserve was higher with HUF 5 million for each day, in the case of 'experiment 2', the reserve decreased with around the same amount. The transfers with the central bank are not significantly impacted by stockpiling-changes. Main conclusion is while habits affect aggregate cash levels, there is no important influence on transfers of central banks.

Results for 'Scenario 2011' This scenario models forecasted trends for year 2011. Because the forecasted year is 2011, I corrected the base time series from 2005 with the most probably trends. The payments via cash decreases to the 45% of the base year. The volume of incomes drops to the 74% of the volume of year 2005. These changes affects every branches, at the same way. I used the coefficients of the base, 'experiment 1' and also 'experiment 2' he changes have significant impacts on the system. If the habits remain unchanged, the volume of cash level drops with HUF 5 billion, and the transactions with central bank also varying dramatically. This new pattern has more moderate waving, than the 2005-year observation. Taking into consideration the varying habits for 2011, it modifies the forecast at least HUF 0.5 billion. The most possible alternative signs heavy drops in the level of working cash. The alternating fashions do not change the central bank transactions considerably.

3.4 Conclusion

The stockpiling habits of branches are measurable with two coefficients. Working of their cash management can be also modeled by this way. The empirical research found six type of branches in the stockpiling point of view. An agent based model with six representative business unit is adequate to analyze the system effects of the habit changing. At making forecasts, one must take into account the changes of cash-flow generated by clients as well as changes of business units cash management habits. This model could be useful also in the risk management.

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