A short-term theory of cash holding

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I develop a model of cash holding that focuses on short-term liquidity shocks due to uncertain net working capital. In the absence of uncertain cash flows, the model shows the trade-off between cash holding and investing in fixed assets, which reflects the transaction motive. Introducing uncertain cash flows reveals that cash holding reduces default risk, which enhances access to short-term bank finance. The model also assesses the role of trade credit as a substitute and complement of bank finance. I derive optimal levels of cash holding and explain the increase in cash holding of UK companies from 1988 to 2008.

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1. Introduction

Cash holding has attracted recent attention due to the considerable increase observed in the US (Bates et al., 2009). The question arises whether the increase can be explained using established theories of cash holding. The literature analyses the motives of cash holding, which determine the demand for cash: (1) transaction, (2) prevention,[1] (3) investment opportunities,[2] and (4) self-interest.[3] Recently, new theories emerged that link cash holding, capital structure, dividends and default (Gryglewicz, 2011), explore the trade-off between interest income taxation and cost of debt (Riddick and Whited, 2009), and highlight the relationship between cash flows and cash holding (Almeida et al., 2004). These theories re-interpret the precaution motive of cash holding. Yet they ignore the transaction motive, which seems to be the predominant motive based on empirical studies (Beltz and Frank, 1996; John, 1993; Deloof, 2001).[4] Moreover, Riddick and Whited (2009) contend that their model does not aim to explain the recent increase in cash holding.

My paper develops a short-term theory of cash holding based on which I derive optimal levels of cash holding using UK data from 1988 to 2008. My contribution is threefold: first, I model the short-term demand and supply of liquidity. Hence only decisions within the financial year are considered. Gryglewicz (2011), Riddick and Whited (2009), Almeida et al. (2004) and the motive-driven literature on cash holding overlook the short-term demand and supply of liquidity. I believe that firms decide about cash holding to meet short-term liquidity needs arising from

[1] Already Keynes (1936) mentions transactions and precaution as the motives for cash holding.
[2] Cash is needed to finance projects (i.e. R&D), as information asymmetry costs can be avoided related to external finance (Myers, 1977; Myers and Majluf, 1984).
[3] Self-interest of managers might drive stockpiling of cash, which Harford et al. (2008) names 'flexibility hypothesis'. According to Graham and Harvey (2001), flexibility allows mergers and acquisition in future, which might destroy value (Harford, 1999). Contrarily, the 'spending hypothesis' suggests that managers prefer spending cash now (Harford et al., 2008). The main idea goes back to Jensen's (1986) free cash flow hypothesis.
[4] Most empirical studies use proxies like sales as a measure for the transaction motive. My theory provides more robust proxies.

uncertain net working capital. My model also considers short-term supply of liquidity, namely trade credit granted by suppliers and bank finance. The latter point is important as an increase in cash holding can be either demand or supply driven. Second, the model introduces endogenous financial constraints, which deviates from Gryglewicz (2011) and Almeida et al. (2004). In particular, I argue that access to short-term bank finance is uncertain and depends on the firm's expected default risk. I show that default risk in turn depends on cash holding. Accordingly, firms can influence the likelihood of being financial constraint through their cash holding, which reflects the precaution motive. Moreover, the model investigates the impact of trade credit granted by suppliers as an additional source of short-term funding and as a positive signal to banks. Third, based on the theoretical model, I derive firm-specific time series of optimal cash holding. The empirical findings show that the recent increase in cash holding can be explained by my model. In line with previous finding, I confirm that the transaction motive is the predominant driver for cash holding. Yet the precaution motive is relevant for firms with difficult access to short-term finance.

To underline the contribution and highlight the theoretical differences, I compare and contrast my model to Gryglewicz (2011), Riddick and Whited (2009) and Almeida et al. (2004). From a theoretical perspective, Gryglewicz' (2011) dynamic model is the most sophisticated. Yet using a dynamic model has certain limitations: first expectations have to be formed for longer time periods; second deriving the optimal time path of cash holding requires more computational time; and third it assumes that firms have a long-term plan of corporate cash holding. Apart from the empirical challenges, my model setup makes a dynamic version difficult to derive – at least closed-form solutions do not exist. There are two main differences in my model setup: (1) access to short-term bank finance is uncertain, and (2) cash flow uncertainty is partially endogenous. Gryglewicz (2011) models financial constraints in a simple manner; constraint firms cannot raise additional capital after the initial stage. He points out that this ensures closed-form solutions. Almeida et al. (2004) uses a set of proxies to classify companies regarding their financial constraints. My model follows a different approach in that banks (debt holders) decide about providing short-term finance based on the expected default risk[5] and a set of firm-specific variables (i.e. interest coverage). Risk-neutral equity holders (or managers)[6] maximise their residual claim internalising the reaction of banks, which are risk-averse due to their payoff profile. Contrarily to the Brownian motion of cash flows suggested by Gryglewicz (2011), my model setup enables managers to influence the degree of cash flow uncertainty through cash holding. Therefore, cash holding – under certain conditions – can reduce the risk of default and enhance access to short-term bank finance. I interpret this function of cash holding as precaution motive.

Gryglewicz (2011), Riddick and Whited (2009) and Almeida et al. (2004) focus on the precaution motive of cash holding and ignore the transaction motive. In line with the literature on cash holding (i.e. Opler et al., 1999), they only consider the demand-side and do not explicitly model the supply of liquidity. Yet Bates et al. (2009) argue that there was no shift or structural break of the demand for cash that could explain the increase in cash holding. I believe to explain the recent increase in cash holding, the supply-side needs to be considered as well as the transaction motive. A very fundamental difference compared to Gryglewicz (2011) arises from his model setup: firms issue equity and debt to finance required investment and initial cash. My model has a different perspective in that I model the trade-off between holding cash and investing in fixed-assets. My belief is that firms do not issue more equity or debt

[5] To be more precise, in my model default risk refers to insolvency and not liquidity default as defined in Gryglewicz (2011).
[6] In my model, managers' do not have any self-interest.

if they want to hold more cash. If you follow Gryglewicz' (2011) view, then cost of debt can be regarded as the opportunity costs of cash holding. The traditional models of cash holding (Baumol, 1952; Tobin, 1956; Miller and Orr, 1966) share this perspective. Another interesting difference is that the traditional models argue that "transactions have to be foreseen and occur in a steady stream" Baumol (1952: 545) to ensure that the model separates the transaction motive and the precaution motive of cash holding. My interpretation of the transaction motive differs in two points: (1) the opportunity costs of cash holding are not only the cost of debt and (2) uncertain net working capital creates a transaction demand for cash. In fact, if net working capital were certain, firms would overcome the short-term liquidity need by changing equity and long-term debt. So there is no need for short-term finance. My model setup assumes that the firm decides first about long-term debt and equity, which determines the scale of the business (total assets). Then the firm decides whether to invest in fixed-assets, which generates cash flows, or hold cash. This difference is essential, as cash holding might increase because of higher interest rates or due to less attractive returns on fixed assets. In addition, the fixed-asset – cash trade-off also implies that cash holding can influence cash flow uncertainty by restricting the amount of fixed assets. In my model, cash flow uncertainty is partly driven by exogenous shocks due to the cost-income ratio of firms – but also influenced by cash holding. Changing cash affects fixed-assets which in turn affects cash flow uncertainty and default risk. Default risk influences the decision making of banks and thus the access to short-term bank finance.

Another difference is related to how I define short-term liquidity risk and default. Gryglewicz (2011) uses a different definition of liquidity shock, which he labels liquidity default; firms that cannot serve coupon payments using cash flows and cash holding experience a short-term liquidity shock. In my model, short-term liquidity shocks arise from uncertain working capital requirements. For instance, if customers do not pay on time, accounts receivable arise that need to be financed. There are three main differences: (1) my model allows short-term bank finance – but access to bank finance is uncertain; (2) trade credit is considered; (3) the short-term liquidity shocks arise during the financial year and cannot be financed by cash flows. From my perspective, the liquidity default described by Gryglewicz (2011) is of course a serious issue for debt holders – but as long as the firm has access to short-term finance and is financially viable (i.e. low financial leverage) it should not lead to default. In my model, such short-term liquidity concerns are implicitly considered when modelling the access to short-term bank finance. Firms that exhibit high liquidity risk measured by interest coverage and the cash conversion cycle find it harder to get access to short-term bank finance. Gryglewicz (2011) uses the term insolvency and refers to a case where the firm's entity value falls below the total amount of debt. In my model, I describe this case as default or default risk, which affects access to short-term finance. Putting it differently, a firm – in my model – can survive a short-term liquidity shock triggered by uncertain net working capital if the bank is willing to provide short-term bank finance or suppliers grant trade credit.

The paper is structured as follows: section two develops the theoretical model followed by a description of the dataset and variables. Section four proposes an econometric approach that leads to a testable model, based on which I obtain empirical findings that highlight the explanatory power of the short-term theory of cash holding. Finally, the conclusion stresses the limitations of the approach and points to future research opportunities.

2. A short-term theory of cash holding

2.1 Short-term liquidity need: The transaction motive

The model structure follows Holmström and Tirole (1998, 2000) in that I use two points in time as well as an interim point. In contrast to theoretical papers that focus on project financing (i.e. Baumol, 1952), my model is based on the firm level and accounting data and hence it can be tested directly. In the start-up period (t = 0), a new firm is set-up with total assets A_0 financed by equity (E_0) and long-term debt (D_0). Shareholders (managers)[7] need to decide whether to invest in fixed assets (FA_0) that yield cash flows (CF_2) in the second period or cash holding (C_0). Cash holding does not generate any returns in terms of cash flows, and fixed assets will depreciate (l) over time. Fixed assets produce revenues (REV_2) according to a capital turnover ($T = REV_2 / FA_0$). The relation between revenues and costs ($COGS_2$) is determined by the cost-income ratio ($k = COGS_2 / REV_2$). As the company starts trading in t=0, there is no initial net working capital ($WC_0=0$) and hence no initial liquidity need. In the interim period (t=1), a short-term need for liquidity arises due to customers delaying payments, which results in accounts receivable ($REV_2= REV_1+ AR_1$). However, payments to suppliers could be postponed, which leads to accounts payable ($COGS_2= COGS_1+ AP_1$). The resulting net working capital ($WC_1= AR_1- AP_1$) is drawn from a cumulative distribution function $F_{WC}(WC_1)$, which reflects its uncertain nature. Net working capital needs to be financed using cash holding (C_0) and short-term debt (S_1). Firms have to pay interest (r) on short-term debt.[8] The final period (t=2) describes the liquidation period; hence, the short-term model of cash holding does not capture dividend policies and changes to the capital structure, as the company is liquidated

[7] Note that there are no agency costs, so managers and shareholders make the same decisions that maximise shareholder value.

[8] As a simplification, I ignore fixed costs (SGA) and inventory. Adding both components does not affect the model predictions. The empirical model accounts for both components.

and shareholders receive their residual claim. Full revenues and costs are realized so that working capital is equal to zero (WC_2=0). There is no moral hazard, and thus shareholders receive the total amount of initial cash holding in t=2.

Without loss of generality, equity and debt holders are risk-neutral.[9] Equity holders get the residual claim of the cash flow in t=2 and the liquidation value. To reflect the possibility that a continuation of operations is not beneficial, I define a critical level of working capital WC_1^*. If the firm exceeds the critical level in t=1, a continuation does not make sense, as the costs of short-term finance outweigh the cash flows in t=2.[10] Accordingly, the resulting expected utility of shareholders $U_E(WC_1^*)$ can be determined as follows.

$$U_E(WC_1^*) = F_{WC}(WC_1^*) \cdot FA_0 \cdot T(1-k) - D_0(1+i) - r \cdot \left(\int_{C_0}^{WC_1^*} (WC_1 - C_0) f_{WC}(WC_1)\, dWC_1 \right) + FA_0(1-l) + C_0 \qquad (1)$$

Equation 1 describes shareholders' expected residual claim. They receive the expected cash flow ($FA_0 \cdot T \cdot (1-k)$) if the project continues, which implies that net working capital does not exceed the critical level WC_1^* ($F_{WC}(WC_1^*)$). They have to pay back long-term debt and interest ($D_0 \cdot (1+i)$) and cover the expected interest payment of short-term debt. Note that short-term debt can be repaid, as net working capital is equal to zero in t = 2.[11] The liquidation also provides fixed assets after deprecation and the initial cash holding.[12] Applying the Leibniz rule, I can derive the optimal level of cash holding. The second derivative is negative, which confirms a global maximum (see appendix A2).

[9] Debt holders behave like risk averse agents due to their asymmetric payoff structure.

[10] The appendix provides a detailed calculation of WC_1^* and highlights the interrelation with cash holding.

[11] Thus, there is no risk that some customers cannot pay. This assumption can be modified.

[12] Note that cash used to fund net working capital will be repaid in t=2.

PROPOSITION 1:

$$\frac{dU_E(WC_1^*)}{dC_0} = -F_{WC}(WC_1^*) \cdot T(1-k) + l + r\big(F_{WC}(WC_1^*) - F_{WC}(C_0)\big) \quad (2)$$

In the absence of moral hazard and uncertain cash flows, proposition 1 describes the trade-off between investing in fixed assets and cash holding and reflects the transaction motive. Cash holding reduces the expected cost of short-term borrowing, and higher interest rates (r) increase the optimal level of cash holding. Holding cash reduces the level of fixed assets and hence leads to a loss of net returns on fixed assets, which depends on the capital turnover (T), the cost-income ratio (k) and depreciation (l). The model makes some strong assumptions, which can be relaxed: (1) the cash flow is certain; hence, debt can be repaid without risk, which excludes the precaution motive. As a consequence, there is no default risk and thus no financial constraints. (2) The model does not account for trade credit and associated costs. (3) Shareholders get the initial level of cash holding (C_0) at liquidation; hence, there is no moral hazard. (4) There are no taxes. The latter assumption can be removed easily, and one can show that taxes do not affect the optimal level of cash holding, for taxes reduce the cost of debt but also reduce the net return on fixed assets. This finding illustrates the main difference compared to other models: I model the trade-off between cash holding and fixed assets. In Gryglewicz' (2011) model, there is no trade-off between cash holding and fixed assets, as debt and equity are selected so that the firm reaches the desired level of cash holding and investment. Riddick and Whited (2009) argue that there is a trade-off between the tax payments on interest income from cash holding and the reduction of future financing costs. In my model, cash does not earn interest – but it could be introduced, and as long as short-term debt is more expensive than the interest on deposits the model predictions do not change.

2.2 Uncertain cash flows: The precaution motive

There are two different types of risk: (1) cash flow uncertainty driven by uncertain capital turnover (T) and/or uncertain cost-income ratio (k); (2) uncertain net working capital in t=2, as customers might not be able to pay. The second type might be disruptive but does not pose a serious threat, for accounts receivable are relatively small compared to the entity value. Hence in line with the literature on the precaution motive, the model introduces uncertain cash flows. The cost-income ratio k is drawn from $F_k(k)$, which is exogenous and has no interrelationship with other random variables. As shareholders are risk-neutral, only the expected value of k affects their decision making but not the volatility of k.[13] But the volatility of the cost-income ratio affects default risk, and thus debt holders alter their lending behaviour. At liquidation in t=2, the entity value has to be sufficient to pay debt holders; thus, I can define a critical cost-income ratio k*.

$$k^* = 1 - \frac{{}^{D_0}\!/_{A_0}(1+i) + {}^{r}\!/_{A_0}\left(\int_{C_0}^{WC_1^*}(WC_1 - C_0)f(WC_1)\,dWC_1\right) - {}^{C_0}\!/_{A_0}\,l - 1 + l}{F(WC_1^*)\cdot\left(1 - {}^{C_0}\!/_{A_0}\right)\cdot T} \quad (3)$$

Differentiating equation 3 with respect to cash holding reveals the impact of cash holding on the critical cost-income ratio, which in turn drives the default risk.[14]

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[13] We assume that capital turnover (T) remains unchanged, which simplifies the analysis without loss of generality. In addition, a low capital turnover would not induce a loss and would only reduce profitability, which does not affect default risk.

[14] In fact, default risk is equal to $Prob(Default) = 1 - \int_0^{k^*} f_k(k)dk$.

$$\frac{\partial k^*}{\partial C_0}|_{L\leq\bar{L}} = -\left[F_{WC}(WC_1^*)\cdot\left(1-{}^{C_0}/_{A_0}\right)\cdot T\right]^{-2} \tag{4}$$

$$\cdot\Bigg\{\left[F_{WC}(WC_1^*)\cdot\left(1-{}^{C_0}/_{A_0}\right)\cdot T\right]$$

$$\cdot\left[-{}^{r}/_{A_0}\left(F_{WC}(WC_1^*)-F_{WC}(C_0)\right)-{}^{l}/_{A_0}\right]$$

$$-\left[L(1+i)+{}^{r}/_{A_0}\left(\int_{C_0}^{WC_1^*}(WC_1-C_0)f_{WC}(WC_1)\,dWC_1\right)-{}^{C_0}/_{A_0}\,l\right.$$

$$\left.-1+l\right]\left[-F_{WC}(WC_1^*)\cdot{}^{T}/_{A_0}\right]\Bigg\}>0$$

Cash holding can reduce the critical cost-income ratio k*; however, the partial impact depends on the firm's financial leverage L (≡D_0/ A_0). The higher the financial leverage the smaller the partial impact of cash holding on reducing default risk.[15] Consequently, the precaution motive exists even in the short-term model if firms are below the critical level of financial leverage. Firms with high financial leverage and high cash holdings do not obtain a reduced level of default risk. In worst case, cash holding can even aggravate the default risk in highly leveraged firms. Accordingly, highly leveraged firms should use excess cash holding to reduce long-term debt.

Putting it differently, uncertain cash flows do not have a direct impact on shareholders' decision making; for they only consider the expected value of the cost-income ratio when deciding about the cash versus fixed asset trade-off (see Proposition 1). However, debt holders are risk-averse due to their payoff profile; thus, they consider the potential default risk. Consequently, the access to short-term debt is uncertain and depends on default risk, which can be influenced by cash holding (see equation 4). The utility of shareholders needs to reflect the uncertain access to short-term finance. Accordingly, the probability of continuing operations does depend on whether the project should be continued, which implies that the net working capital is

[15] See appendix A.3 for details.

below the critical level WC_1^*, and whether short-term finance S_1 is sufficient. Short-term finance has to exceed WC_1^* - C_0 to ensure that the firm continues its operations if it makes economic sense to do so.[16]

At this stage, I assume that access to short-term finance S_1 and net working capital WC_1 are independent random variables, which implies that the joint probability density function $f_{S,WC}(S_1, WC_1)$ is equal to the product of the marginal probability density function f_S (S_1) and $f_{WC}(WC_1)$. The utility of shareholders contains the modified probability of continuation, and shareholders form expectations about the cost-income ratio.

$$U_E(WC_1^*, S_1, k) \tag{5}$$

$$= \left(1 - \int_0^{WC_1^* - C_0} f_S\,(S_1|\Omega) dS_1\right) \cdot F_{WC}(WC_1^*) \cdot FA_0$$

$$\cdot T\big(1 - E(k|\Omega)\big) - D_0(1+i) - r$$

$$\cdot \left(\int_{C_0}^{WC_1^*} (WC_1 - C_0) f_{WC}(WC_1)\, dWC_1\right)$$

$$\cdot \left(1 - \int_0^{WC_1^* - C_0} f_S\,(S_1|\Omega) dS_1\right) + FA_0(1-l) + C_0$$

$$\text{with } \Omega \equiv \{C_0, L, \boldsymbol{z}, \hat{\beta}_C, \hat{\boldsymbol{\gamma}}\}$$

To simplify the notation, I define the information set Ω; hence, debt holders can observe firm characteristics including cash holding, financial leverage and other control variables (z) in t=0 and can condition their offer of short-term funding on these variables. Shareholders have also access to the same information; thus, they can condition their expectations based on the information set Ω. The conditional expected value of short-term finance is modelled using a log-linear model with predetermined

[16] One could argue that short-term debt has to exceed WC_1-C_0 and not WC_1^*-C_0. The issue is that WC_1 is unknown in t=0, whereas shareholders can form expectations about WC_1^*, which depends on known variables and the expected cost-income ratio.

firm-specific variables that include cash holding in t=0. The effect of cash holding is twofold: (1) cash holding reduces the need for short-term bank finance and hence is a substitute, which is reflected in the upper boundary $WC_1^*-C_0$; (2) cash holding reduces the default risk depending on the financial leverage of the firm, as it increases the critical level of the cost-income ratio.

$$E(S_1|\Omega) = \hat{\beta}_C C_0 + \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z} \tag{6}$$

To derive the first-order condition, I need to impose assumptions concerning the distributions of the random variables. The model assumes that random variables follow a log-normal distribution.[17]

PROPOSITION 2

$$\begin{aligned}\frac{dU_E(WC_1^*, S_1, k)}{dC_0} &= \left(1 - F_S(WC_1^* - C_0|\Omega)\right) \\ &\cdot \left[\left(-F_{WC}(WC_1^*) \cdot T(1-k)\right) + r\left(F_{WC}(WC_1^*) - F_{WC}(C_0)\right)\right] + l \\ &+ \left(f_S(WC_1^* - C_0|\Omega) - \sigma_S{}^{-2} \cdot \hat{\beta}_C C_0^{-1}\right. \\ &\cdot \left. F_S(WC_1^* - C_0|\Omega)\left[\ln(S_1) - ln(WC_1^* - C_0) - \hat{\beta}_C \ln C_0 - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z}\right]\right) \\ &\cdot \left[F_{WC}(WC_1^*) \cdot (A_0 - C_0) \cdot T(1 - E(k)) - r \cdot E_{C_0}^{WC_1^*}(WC_1 - C_0)\right]\end{aligned} \tag{7}$$

Proposition 2 describes the optimal level of cash holding if access to short-term finance is uncertain due to uncertain cash flows. The first part of proposition 2 refers to the same trade-off (between cash holding and fixed-assets) as in proposition 1; however, it weighs this trade-off with the probability that short-term finance is sufficient to continue operations. The second part captures the impact of cash holding on the probability that short-term finance is sufficient to continue operations. This

[17] The probability density function of the cost-income ratio drawn in t=2 is unknown, so the model does not consider a joint probability density function based on S_1, WC_1 and k. Banks, however, observe cash holding and financial leverage in t=0 and they know that these firm-specific variables affect the cost-income ratio in t=2, which in turn drives the default risk.

term is weighed by the additional benefit – in terms of the expected utility for shareholders – if the project can continue. Putting it differently, the impact of cash holding on access to short-term finance becomes more relevant if 'the pot of gold at the end of the rainbow is large'. Based on proposition 2, I can derive optimal levels of cash holding.[18]

2.3 The role of trade credit

Thus far, the model has not differentiated between net working capital as a whole and trade credit, or put differently the model ignored the costs and benefits of trade credit granted by suppliers (TC_1). The next step is to introduce trade credit as additional source of short-term finance. Net working capital WC_1 can be decomposed into accounts receivable AR_1, inventory (which I add to AR_1 to simplify notation) and trade credit TC_1 (=AP_1).[19] One could argue that accounts receivable resemble trade credit provided by the firm to customers and hence the analysis of the role of trade credit has to focus on balancing both, giving and receiving trade credit. The issue is that modelling both sides makes the analysis far more complex, as costs might differ and the default risk of customers needs to be considered. Moreover, it has been shown that trade credit provided to customers is interlinked with sales and pricing (Nadiri, 1969). To maintain sales, firms need to provide trade credit to customers, which also reflects the negotiation power. As the model focuses on liquidity needs and sources of short-term finance, I focus on trade credit granted by suppliers.

Apart from the amount of trade credit, the model considers the costs of trade credit r_{TC}. It is an ongoing debate whether trade credit is more expensive and why

[18] Due to assuming log-normal distributions, I need to make the assumption that $S_1 > 1$ to avoid an improper integral.

[19] In the theoretical model, we simplify the notation by assuming that $AP_1 = TC_1$, which is not exactly accurate, as we defined AP_1 as all current liabilities (excluding short-term debt) so it contains more items than trade credit.

firms rely on it: (1) the availability of trade credit might be a signal concerning the quality of the buyer; (2) suppliers might have an informational advantage compared to banks due to their relationship with the buyer, (3) the collateral (input) might have a different value for the supplier than for a bank (Biais and Gollier, 1997; Burkart and Ellingsen, 2004).

The effect of trade credit on cash holding and access to short-term finance is threefold: (1) the assumption that access to short-term finance S_1 and net working capital WC_1 (=AR_1-TC_1) are independent random variables has to be reconsidered; (2) trade credit reduces the need to finance working capital, which reduces the costs of short-term debt finance; (3) trade credit increases the cost-income ratio k due to the costs of trade credit r_{TC}, which makes it more likely that the cost-income ratio exceeds the critical level k* increasing the default risk. Based on these three effects, I modify the expected utility of shareholders.

$$U_E(WC_1^*, S_1, k, TC_1) \tag{8}$$
$$= \left(1 - \int_0^{WC_1^* - C_0} f_{S|WC}\,(S_1|\Omega) dS_1\right) \cdot F_{WC}(WC_1^*) \cdot FA_0$$
$$\cdot T(1 - E(k_0|\Omega) - E(r_{TC}|\Omega)E(TC_1|\Omega)) - D_0(1+i) - r$$
$$\cdot \left(\int_{C_0}^{WC_1^*} (WC_1 - C_0) f_{WC}(WC_1)\, dWC_1\right)$$
$$\cdot \left(1 - \int_0^{WC_1^* - C_0} f_{S|WC}\,(S_1|\Omega) dS_1\right) + FA_0(1-l) + C_0$$

The model accounts for the conditional and not the marginal distribution of access to short-term finance with the associated conditional moments; this reflects that short-term finance and net working capital, which includes trade credit, can be correlated. The expected value of the cost-income ratio k based on information available at t=0 changes due to the expected value of trade credit and expected costs of trade credit. So the expected value of k could be written as $E(k_2)=E(k_0)+r_{TC}E(TC_1)$ before introducing costs for trade credit cost-income ratios were the same in both periods ($E(k_2)=E(k_0)$). Moreover, the costs of short-term finance are influenced by trade credit, as only the net working capital needs to be financed; however, this was already incorporated in proposition 1 and 2. The difference is that the costs of trade credit are not made explicit in proposition 1 and 2. Finally, the expected trade credit (at t=0) might influence the conditional expectation of access to short-term finance S_1, which would be another element of z and can be incorporated into the log-linear model (see equation 6). If trade credit increased the conditional mean of access to short-term finance, it would confirm the signalling theory of trade credit (Biais and Gollier, 1997; Burkart and Ellingsen, 2004).

3. The method of sampling and construction of variables

The sample is based on XXX et al. (2011), which contains annual data of all listed companies on the London Stock Exchange (Main Market) from 1988 to 2008. Pooling cross-section and time-series observations, the sample contains 14073 observations of cash holding. To mitigate the impact of outliers, a winsorisation is applied to extreme observations.[20] The following endogenous variables are constructed: cash holding defined as cash and cash equivalents relative (cash) and short-term bank finance (S). Based on the theoretical model, the following exogenous variables are included: pre-tax cost of debt (r and i), the cost-income ratio defined as operating costs relative to operating income (k) and capital turnover defined as sales relative to total operating assets (T). The theoretical model also considers deprecations; however, obtaining unbiased figures is difficult based on a database download, for tax regimes allow

[20] Based on the 95 and 5-percentile, extreme observations are replaced by their closest percentile.

different approaches to depreciation. Operating working capital (WC), defined as accounts receivable plus stock minus accounts payable, has to be financed through cash holding, trade credit granted by suppliers (tc) and short-term access to bank finance. As shown in the theoretical model, there might be an interrelation between the effectiveness of cash holding in reducing default risk and financial leverage. Therefore, I include financial leverage defined as total debt relative to total assets (L). The empirical analysis shows the variables relative to total assets, which is different from the theoretical model.

In line with prior research on corporate cash holding and to explore heterogeneity across firms, the study includes firm size defined as the natural logarithm of total assets (size) and interest coverage defined as earning before interest and taxes relative to interest expenses (cover). Some studies include the ratio of bank finance and total debt (bank) as a proxy for good relationships with banks and the monitoring role of banks, which is also common in the trade credit literature (Gama et al., 2008). To account for profitability, I use the return on adjusted total assets (ROA), which reflects EBIT relative to operating assets defined as net property, plant and equipment and net operating working capital. The theoretical model uses uncertain cost-income ratios to introduce cash flow volatility. I also include an empirical proxy for the uncertainty of cash flows defined as the variation coefficient of EBIT in a three-year window (risk). The definition of cash flow risk differs from Bates et al. (2009) in that they refer to the mean of the standard deviation of cash flows in an industry based on 2-digit SIC codes. Their measure captures the industry-specific cash flow uncertainty but does not reflect firm-specific risk. Moreover, standard deviations are not robust, whereas variation coefficients account for differences in means. To assess the firm's ability to manage its working capital, I include the cash conversion cycle (CCC) as suggested by Deloof (2001) and Gitman (1974). The CCC refers to accounts payable relative to revenues and inventory relative to cost of goods sold. It deducts accounts payable relative to cost of goods sold and thus combines balance sheet and income statement measures, which makes it a dynamic measure.

4. Deriving an econometric model

4.1 Determining the optimal level of cash holding

Assuming log-normal distributions of the random variables enables to determine the optimal level of cash holding under proposition 1 (transaction motive) and proposition 2 (precaution motive). As the explanatory variables are pre-determined in the log-linear model that explains the conditional expectation of short-term finance (equation 6), the model can be estimated using OLS. When calculating the optimal level of cash holding in line with the theoretical model, expectations need to be formed. In particular, to account for uncertain cash flows, firms need to form expectations about the cost-income ratio. To determine conditional expectations, I use dynamic panel models and apply the Arellano and Bond (1991) GMM estimator. These dynamic models account for lagged dependent variables and a set of lagged control variables including firm size, financial leverage, ROA, interest coverage, bank loans relative to total loans, revenue growth and the cash conversion cycle (CCC).

In the case of some firms, corner solutions are possible. For instance, if the firm expects a high cost-income ratio, the model predicts that cash holding should be equal to one. This is an optimal solution in the short-term world that starts in $t = 0$ and ends in $t = 2$ – but it does not reflect the reality of firms that survive for more than one period and cumulate cash over time. Hence, I modify the model predictions for a multi-period setting that repeats the short-term model n times.

4.2 The accumulation of cash

Without incurring additional costs (i.e. liquidation of assets), the maximum change in cash holding in period t+1 is limited by the cash flow in t+1 diminished by interest payments to long and short-term debt holders and depreciation to replace worn-out capital.[21] As my short-term model does not incorporate dividend policies and decisions about capital structure, the maximum change of cash does not consider dividends or a change in capital structure explicitly. Following the theoretical model, free cash flows in t+1 depend on decisions taken in t. A change in total assets (i.e. financed by an equity issue) or dividend payments affect total assets in t+1. The new capital structure after debt/equity issues and dividends in t+1 is the basis for the next short-term model of cash holding. Accordingly, it is a repeated static model with an accumulation rule of cash holding, but not a dynamic model. The following equation illustrates the accumulation of cash.[22]

$$C_{it+1} = \begin{cases} C_{it} + min(FA_{it}T_{it}(1-k_{it}) - iD_{it} - rS_{it} - lFA_{it}, C_{it}^{*} - C_{it}); C_{it}^{*} > C_{it} \\ C_{it}; C_{it}^{*} = C_{it} \\ C_{it}^{*}; C_{it}^{*} < C_{it} \end{cases} \quad (9)$$

Following proposition 1 and 2 and applying the restrictions concerning the maximum increase in cash holding based on equation 9, I generate time series of optimal levels of cash holding for every firm.

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[21] I assumed that firms want to maintain the capital stock; hence, worn-out capital is replaced.

[22] The theoretical model does not account for taxes – but empirically taxes need to be considered when determining the maximum change in cash holding. After-tax cash flows are calculated using a marginal tax rate of 35%.

5. Empirical findings

5.1 Descriptive findings

Table 1 refers to all variables in percent of total assets and shows the annual median. Cash holding increased from 6.2% to 10.1% since 1988 and reached its peak in 2006. Short-term bank finance (S) declined from 25% to 19% as well as trade credit granted by suppliers (tc) which dropped by 49%. Yet net working capital (wc) also reduced, which was mainly driven by an improvement in inventory management. Although the median of net working capital declined, the standard deviation of net working capital increased making the liquidity need more challenging to predict. Focusing on the variables in proposition 1, one can argue that the pre-tax costs of debt declined until 2002 but rebounded thereafter. Capital turnover defined as revenue relative to fixed operating assets (T) exhibited a pronounced downward trend. In combination with a higher cost-income ratio (k), the attractiveness of investing in fixed assets deteriorated. At a first glance, it is unclear whether the lower costs of debt or the lower return on fixed assets have the predominant impact on optimal cash holding. Based on the implications of proposition 2, one can argue that the decline in short-term bank finance could point to a more restricted access to bank finance. Financial leverage (L) remained unchanged, whereas interest coverage (cover) showed a downward movement, which might indicate that banks are less willing to lend. Other control variables underline the deterioration of profitability (ROA) and higher cash flow risk (risk). Firm size (size) did not change on the aggregated level. Considering long and short-term bank loans, the total importance of bank finance compared to total debt declined (bank). Using the cash conversion cycle (CCC), a dynamic measure of liquidity, stresses that liquidity needs hardly changed.

(Insert Table 1)

5.2 The transaction motive

Following proposition 1, I generate optimal levels of cash holding C_{it}^{T} given expected values of capital turnover (T), cost-income ratio (k) and cost of debt (r). Expectations are formed on the firm-level based on observed firm-specific variables. The resulting dynamic panel models are estimated using Arellano and Bond's (1991) GMM estimator. The increase in optimal cash holding is restricted by the free cash flow (equation 19). The critical level of net working capital WC_{it}^{*} and the cumulative density function $F_{WC}(.)$ need to be determined. As shown in the appendix (A1), critical net working capital WC_{it}^{*} is calculated, and as expected most firms almost certainly should continue their operations with a median of 0.80 and a mean of 1.18. Therefore for the median firm net working capital has to exceed 80% of total assets to make a continuation value-destroying. This is highly unlikely, as actual net working capital is on average 0.23, and the maximum reaches 0.47. To parameterise the cumulative density function $F_{WC}(.)$, I assume that net working capital follows a log-normal distribution.[23] The moments of net working capital can change over time, which reflects the decline of net working capital due to improved management (reducing of inventory). Figure 1 plots the average actual cash holding and the average optimal level of cash.

(Insert Figure 1)

On the aggregated level, the correlation between both time series is 0.87 until 1997 – but thereafter falls to 0.57. On the disaggregated level, using rolling regressions based on three-year windows, one can observe that the partial impact declines from 0.831 (1988-1990) to 0.773 (1994-1996) – but then recovers to 0.850

[23] Based on Kolmogorov-Smirnov tests and Shapiro-Wilk tests, the null hypothesis that net working capital follows a log-normal distribution cannot be rejected for any year.

(2006-2008).[24] Accordingly, the pure transaction motive has a high relevance in explaining cash holding; however, it only explains an average increase by 3.8 percentage points compared to an actual change of 6.4 percentage points. The transaction motive suggests an increase in cash holding – in spite of a decline in net working capital. The main reason for higher optimal cash holding is the expected increase in the cost-income ratio and higher costs of debt. Both effects make cash holding more attractive, as the expected net return of fixed assets lowers, whereas costs of external funding increases.

To explore the heterogeneity across firms, Table 2 splits the sample into deciles based on firm size, financial leverage, actual cash holding and interest coverage. Proposition 1 does not incorporate any size effect or financial constraints directly; thus, the cross-sectional differences observed are due to differences in cost of debt, turnover, and the cost-income ratio. In line with the literature, smaller firms hold more cash – but there seems to be an optimal size range close to the median where cash holding reaches its minimum. Very large companies cumulate more cash, which reflects arguments in the literature.[25] Interestingly, the model predictions (C^T) for different size deciles are in line with actual cash holding. There is a clear size advantage concerning the cost-income ratio and cost of debt, whereas capital turnover exhibits a size disadvantage. Firms with the lowest leverage and almost no debt have the highest level of cash holding. With increasing leverage, cash holding declines in line with model predictions. The main drivers for this finding are high interest rates and cost-income ratios in the case of firms with low debt. Analysing cash holding deciles illustrates that the model forecasts are in line with different levels of cash holding. The average forecast – affected by outliers – is above the average actual cash

[24] The partial impact is in all time period significantly different from zero.

[25] Yet in the UK, most of these large corporations are not R&D intense, which does not support the argument of Bates et al. (2009).

holding for most of the deciles. Differentiating firms based on their interest coverage underlines that firms with low coverage and hence high risk of default hold more cash, which again is reflected in the model predictions. With increasing coverage, cash holding declines; however, firms with very high interest coverage tend to cumulate more cash revealing a u-shaped relationship. Accordingly, the model predicts levels of cash holding in line with actual figures for different types of firms in spite of the fact that firm size and financial leverage are not included directly.

(Insert Table 2)

5.3 The precaution motive

The first step is to estimate the conditional mean of short-term debt based on equation 7. The model makes predictions concerning the impact of cash holding and financial leverage on the critical cost-income ratio (see appendix A3), which in turn affect the default risk and access to short-term bank finance. Cash holding should have a positive impact on short-term finance if the firm is below a certain level of leverage. This suggest a quadratic interaction term between cash holding and leverage, which mimics the changing impact of cash holding for different levels of leverage. Accordingly, the access to short-term finance, which follows a log-normal distribution, can be explained by cash holding, leverage and a quadratic interaction term as well as a set of control variables. Table 3 shows different model specifications concerning the interaction effect. Model D also considers random-effects to capture cross-sectional differences and allows first-order autocorrelation of residuals. I use GLS to estimate model D, whereas panel OLS is applied to the first three specifications. All explanatory variables are lagged by one time period to ensure weak exogeneity.

$$\ln(S_{it}) = \alpha + \beta_C \ln(C_{it-1}) + \beta_L L_{it-1} + \beta_{CL} \ln(C_{it-1}) L_{it-1} + \beta_{CL^2} (\ln(C_{it-1}) L_{it-1})^2 + \boldsymbol{\gamma}^{\boldsymbol{T}} \boldsymbol{z} + \upsilon_i + \varepsilon_{it} \quad (10)$$

(Insert Table 3)

To illustrate the complex non-linear relationship between cash holding and leverage, Figure 2 depicts the combined impact on short-term bank finance for different deciles of cash holding and leverage. As predicted by the theoretical model, cash holding has only a positive impact on short-term finance if the firm is below a certain level of leverage. Empirically, the turning point is around the 80-percentile of financial leverage. This statement holds for most firms – except in the case of cash poor firms in the 20-percentile.

(Insert Figure 2)

The difference between proposition 1 and 2 is due to the uncertain access to short-term bank finance as captured in the first term in equation 8, namely the probability that short-term finance is sufficient to finance good firms. A good firm has net working capital below the critical value. To illustrate whether the optimal level of cash holding C_{it}^{T} based on proposition 1 is sufficient if access to short-term finance is uncertain, Figure 3 plots the probability of a liquidity shortage based on transaction cash (C_{it}^{T}) and actual cash holding. A liquidity shortage occurs if short-term bank finance is not sufficient to fund a good firm. I determine the probability of a liquidity shortage following equation 8.

$$Prob(\text{liquidity shortage}) \equiv \int_0^{WC_1^* - C_0} f_S\,(S_1|\Omega) dS_1 \quad (11)$$

It is evident that firms holding only the transaction cash exhibit a higher probability of liquidity shortages compared to actual cash holding. Interestingly, since 1997 the figure illustrates that even based on actual cash holdings the average likelihood of a liquidity shortage increases.

(Insert Figure 3)

Analysing the heterogeneity across firms, I determine the probability of liquidity shortages for different deciles. Only in the case of financial leverage deciles a systematic pattern emerges. Whether firms hold only the transaction cash recommended (C_{it}^{T}) or actual cash levels does not make a difference in terms of the probability of liquidity shortages if the firms is not in the 80-percentile of financial leverage. Highly leveraged firms need to hold more cash compared to the transaction motive to reduce their liquidity risk. Actual cash holdings of these firms mitigate the liquidity risk by 43% for firms in the 80-percentile) and 83% for firms in the 90-percentile.

Based on proposition 2, I derive optimal levels of cash holding if cash flows and access to short-term bank finance are uncertain. Table 4 shows the mean and median of actual cash holding and optimal levels of cash holding based on the transaction (C_{it}^{T}) and precaution (C_{it}^{P}) motive. In particular based on the medians, the theoretical model has a high explanatory power.

(Insert Table 4)

5.4 The role of trade credit

From an empirical perspective, the impact of trade credit is more challenging to establish, for the actual costs of trade credit cannot be estimated based on public information. Chludek (2010) contends that the actual cost of trade credit depends on whether trade credit has been extended on two-part terms and whether the discount has been taken. In addition, the average discount and discount period have to be determined. The problem is that I can only observe changes in the trade credit period determined by accounts payable divided by cost of goods sold. The other variables cannot be observed directly as they are not reported. Prior research relies on survey methods to determine the value of these variables but only for a very limited number of firms and not for panel data. Accordingly, I test the following model implications: (1) trade credit should increase the cost-income ratio, and (2) trade credit can be used as a signal for banks concerning the quality of a buyer, which refers to the signalling theory of trade credit (Biais and Gollier, 1997; Burkart and Ellingsen, 2004). Using a random-effects regression model, the first implication cannot be confirmed as the coefficient of lagged trade credit is negative and insignificant (-0.020 with a p-value of 0.610) even after including firm-specific control variables (-0.086 with a p-value of 0.152). Yet the second implication is true, as lagged trade credit has a positive effect with a coefficient of 1.567 on the conditional mean of short-term bank finance (equation 10). The coefficient is significant on the 99.9% level of confidence. Including trade credit does not alter the results for the other explanatory variables. Accordingly, I conclude that the pronounced decline of trade credit reduced the conditional mean of short-term bank finance, which contributed to the importance of the precaution motive. Cash holding becomes more important to replace trade credit and bank finance and to ensure better access to external finance.

6. Conclusion

Recent theories on corporate cash holding focus on the long-term decisions of a firm related to dividend policy and capital structure (Gryglewicz, 2011; Riddick and

Whited, 2009; Almeida et al., 2004). My model develops a short-term view of cash holding and its substitutes, short-term bank finance and trade credit granted by suppliers. The model reinterprets the transaction motive by modelling the short-term liquidity need due to working capital requirements that arise during the financial year. The first proposition derives a trade-off between holding cash, which reduces the expected costs of short-term bank finance, and investing in fixed assets, which provides future cash flows. In contrast to prior research (e.g. Opler et al., 1999), I argue that not only interest rates reflect the opportunity costs of cash holding but also the expected return on invested capital. Empirically, I derive the optimal level of cash holding based on the static model and apply a rule for changes of cash holding. Accordingly, the approach is to optimise cash holding in each period and to adjust cash holding without selling assets, which would incur significant transaction costs. Already based on the transaction motive, the constructed time path of optimal cash holding explains the increase of actual cash holding to a large extent.

Considering uncertain cash flows and the resulting default risk suggests that the access to short-term bank finance is not guaranteed. The second proposition derives the optimal level of cash holding under these circumstances, which reflects the precaution motive. Empirically, I show that firms hold more cash compared to the transaction motive to ensure better access to short-term bank finance. The theoretical model also predicts an interaction effect between the impact of cash holding on default risk and the firm's financial leverage. These effects can be confirmed in my panel regression model. The model also shows that trade credit has a positive impact on short-term bank finance, which supports the signalling theory of trade credit (Biais and Gollier, 1997; Burkart and Ellingsen, 2004). Combining the optimal level of cash holding based on the transaction and precaution motive provides a solid explanation for the increase in cash holding. Moreover, due to the rapid decline in trade credit granted by suppliers, bank finance is more restricted, as positive signals – the firm gets more trade credit – are rare.

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Table 1: Annual medians of variables

year	cash	S	tc	wc	k	T	i	L	ROA	size	risk	bank	cover	CCC
1988	0.062	0.250	0.150	0.334	0.881	2.723	0.100	0.126	0.156	10.728	0.222	0.270	10.099	0.173
1989	0.058	0.244	0.143	0.347	0.893	2.591	0.111	0.149	0.154	10.777	0.244	0.060	7.092	0.170
1990	0.058	0.237	0.137	0.320	0.900	2.465	0.134	0.168	0.143	10.862	0.274	0.111	4.958	0.167
1991	0.061	0.232	0.127	0.308	0.917	2.391	0.131	0.169	0.120	10.807	0.265	0.109	4.326	0.168
1992	0.070	0.230	0.124	0.303	0.922	2.297	0.120	0.172	0.107	10.773	0.287	0.100	4.212	0.164
1993	0.081	0.225	0.122	0.290	0.922	2.255	0.104	0.154	0.108	10.895	0.324	0.090	5.066	0.149
1994	0.104	0.213	0.133	0.306	0.919	2.307	0.089	0.142	0.111	10.998	0.307	0.061	6.875	0.142
1995	0.089	0.220	0.138	0.289	0.915	2.417	0.088	0.145	0.126	11.122	0.278	0.056	7.324	0.142
1996	0.088	0.230	0.139	0.286	0.914	2.502	0.089	0.141	0.124	10.738	0.350	0.049	6.882	0.133
1997	0.103	0.239	0.130	0.282	0.920	2.480	0.085	0.129	0.130	10.692	0.336	0.078	7.033	0.134
1998	0.090	0.235	0.121	0.268	0.923	2.300	0.084	0.145	0.115	10.755	0.428	0.051	6.649	0.139
1999	0.087	0.216	0.107	0.246	0.924	2.017	0.080	0.141	0.099	10.742	0.469	0.086	5.603	0.145
2000	0.097	0.193	0.091	0.218	0.940	1.705	0.076	0.123	0.072	10.739	0.612	0.059	4.627	0.168
2001	0.085	0.198	0.091	0.206	0.961	1.670	0.078	0.117	0.044	10.652	0.582	0.067	2.860	0.159
2002	0.099	0.199	0.090	0.196	0.970	1.655	0.069	0.139	0.031	10.287	0.571	0.055	2.375	0.158
2003	0.104	0.217	0.098	0.200	0.965	1.672	0.068	0.131	0.040	10.112	0.534	0.061	2.966	0.133
2004	0.124	0.210	0.094	0.195	0.958	1.738	0.066	0.107	0.050	10.102	0.538	0.061	3.606	0.141
2005	0.132	0.188	0.083	0.180	0.952	1.567	0.070	0.091	0.053	10.107	0.502	0.066	4.143	0.153
2006	0.136	0.182	0.078	0.172	0.949	1.426	0.068	0.094	0.054	10.287	0.529	0.074	3.932	0.158
2007	0.121	0.181	0.076	0.161	0.944	1.263	0.073	0.105	0.060	10.475	0.531	0.084	4.197	0.170
2008	0.106	0.191	0.077	0.163	0.951	1.269	0.072	0.126	0.052	10.638	0.531	0.075	3.169	0.176
Total	0.101	0.209	0.101	0.223	0.938	1.852	0.081	0.129	0.077	10.554	0.452	0.070	4.659	0.154
Obs	14073	13801	13803	12189	13704	13490	12116	14622	13977	14631	14509	6518	12776	13104

Table 2: Heterogeneity across firms

	Firm-size deciles						Leverage deciles					
Deciles	cash	C^T	i	T	k	size	cash	C^T	i	T	k	L
1	0.155	0.140	0.152	2.535	1.019	8.342	0.204	0.227	0.234	2.355	0.992	0.002
2	0.120	0.121	0.143	2.113	0.964	9.263	0.170	0.194	0.201	2.211	0.969	0.017
3	0.105	0.123	0.145	1.883	0.949	9.933	0.113	0.139	0.170	2.250	0.949	0.049
4	0.087	0.107	0.150	1.941	0.940	10.440	0.104	0.126	0.142	2.022	0.935	0.083
5	0.082	0.103	0.127	1.916	0.944	10.901	0.096	0.114	0.123	1.795	0.935	0.122
6	0.097	0.113	0.145	1.966	0.935	11.464	0.084	0.097	0.117	1.816	0.937	0.162
7	0.115	0.119	0.136	1.826	0.929	12.056	0.071	0.082	0.100	1.893	0.946	0.209
8	0.116	0.138	0.144	1.841	0.926	12.834	0.068	0.077	0.092	1.594	0.934	0.271
9	0.108	0.135	0.126	1.668	0.920	13.652	0.077	0.071	0.095	1.467	0.922	0.352
10	0.088	0.109	0.100	1.018	0.896	14.028	0.077	0.069	0.085	1.050	0.893	0.417
	Cash holding deciles						Interest coverage deciles					
Deciles	cash	C^T	i	T	k	cash	cash	C^T	i	T	k	cover
1	0.006	0.026	0.120	2.010	0.934	0.006	0.201	0.150	0.144	1.740	1.101	-5.848
2	0.009	0.029	0.116	1.584	0.922	0.009	0.071	0.065	0.111	1.989	0.965	0.727
3	0.020	0.039	0.116	1.578	0.926	0.020	0.066	0.073	0.105	1.756	0.940	1.320
4	0.036	0.053	0.122	1.651	0.929	0.036	0.068	0.083	0.105	1.633	0.929	1.833
5	0.055	0.074	0.132	1.800	0.929	0.055	0.075	0.091	0.109	1.670	0.922	2.408
6	0.080	0.100	0.133	1.778	0.931	0.080	0.088	0.106	0.126	1.727	0.914	3.260
7	0.108	0.133	0.140	1.795	0.923	0.108	0.081	0.110	0.133	1.797	0.913	4.454
8	0.147	0.173	0.146	2.089	0.933	0.147	0.100	0.135	0.146	1.961	0.915	6.714
9	0.215	0.241	0.152	2.248	0.942	0.215	0.140	0.153	0.180	2.076	0.903	12.722
10	0.389	0.330	0.179	1.744	1.038	0.389	0.171	0.229	0.202	2.123	0.908	42.129

Table 3: Modelling the conditional mean of short-term finance

Variable	A	B	C	D
$\ln(cash_{it-1})$	0.242***	0.283***	0.301***	0.038***
L_{it-1}	0.753***	2.224***	3.232***	0.956***
$\ln(cash_{it-1})\ L_{it-1}$	-	-0.169***	-0.416***	-0.141**
$(\ln(cash_{it-1})\ L_{it-1})^2$	-	-	0.029***	-0.002
$size_{it-1}$	0.790***	0.787***	0.794***	0.816***
ROA_{it-1}	0.801***	0.867***	0.951***	0.149**
$risk_{it-1}$	-0.034**	-0.038***	-0.038***	0.003
$bank_{it-1}$	-0.261***	-0.264***	-0.263***	0.025
$cover_{it-1}$	-0.001	-0.002**	-0.003***	0.000
$Liquidity_{it-1}$	-0.000***	-0.000***	-0.000***	0.000
Constant	-1.108***	-1.419***	-1.555***	0.632***
Observations	5560	5560	5560	4684
F-test	0.000	0.000	0.000	0.000
Adjusted R-squared	0.882	0.883	0.883	0.852
F-test random effects	-	-	-	0.000

Table 4: Annual sample means and medians of actual cash holding and optimal cash holding based on the transaction and precaution motive

	Mean			Median		
year	cash	C^T	C^P	cash	C^T	C^P
1988	0.106	0.114	0.118	0.062	0.073	0.105
1989	0.099	0.090	0.084	0.058	0.062	0.057
1990	0.099	0.097	0.085	0.058	0.072	0.055
1991	0.103	0.087	0.107	0.061	0.067	0.058
1992	0.113	0.101	0.128	0.070	0.061	0.056
1993	0.126	0.109	0.137	0.081	0.075	0.071
1994	0.128	0.123	0.174	0.104	0.098	0.091
1995	0.124	0.110	0.166	0.089	0.072	0.068
1996	0.130	0.131	0.173	0.088	0.089	0.077
1997	0.140	0.145	0.205	0.103	0.094	0.097
1998	0.146	0.103	0.152	0.090	0.077	0.079
1999	0.141	0.101	0.135	0.087	0.079	0.078
2000	0.160	0.150	0.159	0.097	0.091	0.093
2001	0.163	0.112	0.131	0.085	0.071	0.079
2002	0.163	0.112	0.132	0.099	0.078	0.084
2003	0.164	0.115	0.133	0.104	0.089	0.090
2004	0.182	0.130	0.145	0.124	0.099	0.110
2005	0.188	0.134	0.155	0.132	0.099	0.114
2006	0.186	0.122	0.130	0.136	0.090	0.096
2007	0.179	0.132	0.141	0.121	0.104	0.112
2008	0.164	0.128	0.135	0.106	0.094	0.097
Total	0.158	0.120	0.140	0.101	0.084	0.088

Figure 1: Average cash holding and the average optimal level of cash (C^T)

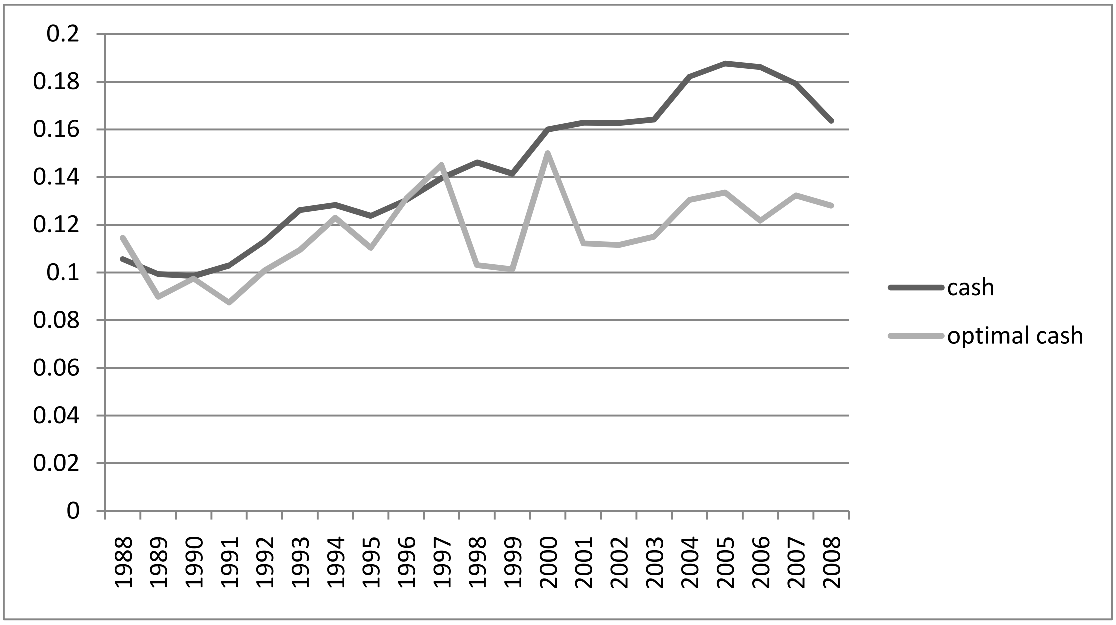


Figure 2: Impact of cash holding and leverage on the conditional mean of short-term finance

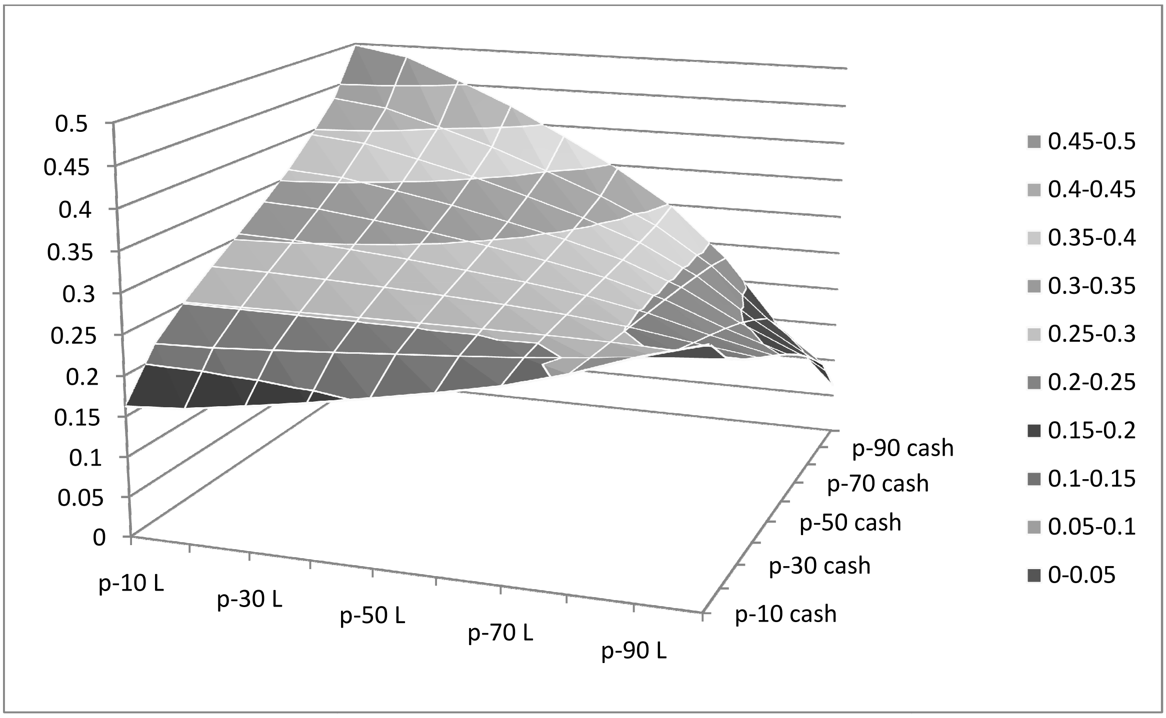
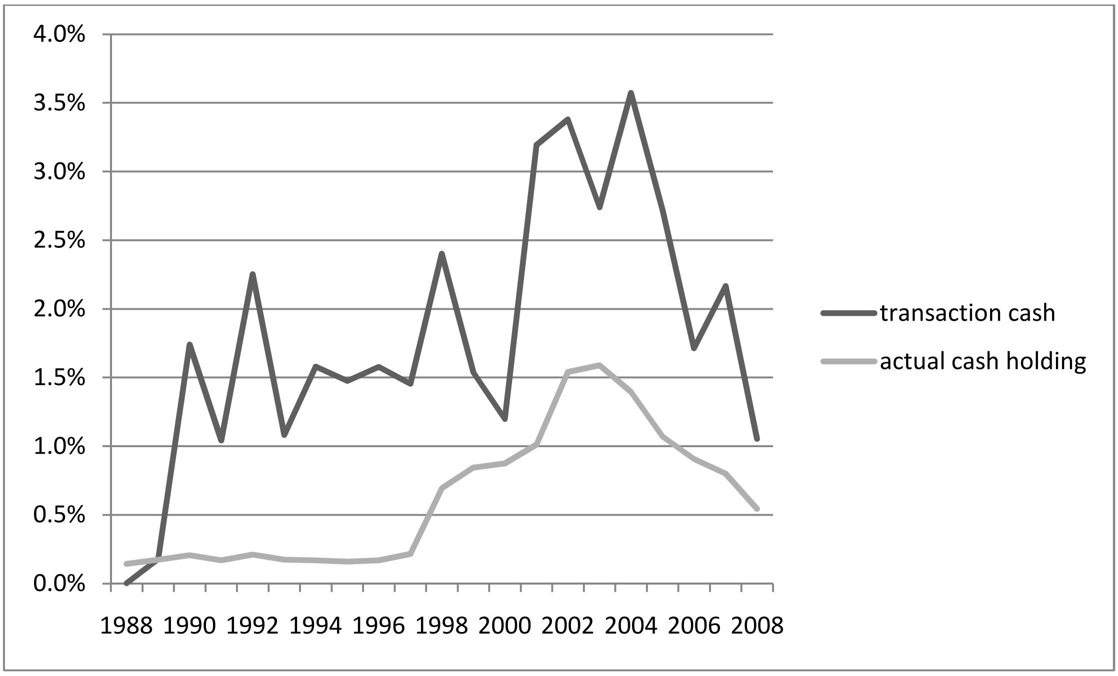


Figure 3: Probability of liquidity shortage



Appendix: proofs

A. 1 The critical level of net working capital WC_1^* (equation 1)

The benefit of continuation (the expected cash low in t=2) has to exceed the costs of financing net working capital.

$$T(1-k)(A_0-C_0)-r(WC_1^*-C_0)\geq 0$$

$$WC_1^*\leq \frac{T(1-k)(A_0-C_0)}{r}+C_0$$

If I divide this inequality by total assets A_0, I eliminate the scaling effect due to firm size and obtain an expression that can be interpreted easily.

$$\frac{WC_1^*}{A_0}\leq \frac{\frac{T(1-k)(A_0-C_0)}{A_0}}{r}+\frac{C_0}{A_0}$$

As long as the profitability measured by EBIT relative to total assets exceeds cost of short-term finance, net working capital can even exceed total assets. In addition, cash holding relative to total assets is an additional buffer. Even after introducing uncertain cash flows (see proposition 2) reflected in uncertain cost-income ratios, the critical level of working capital in percent of total assets is still above 1 if the expected profitability exceeds costs of short-term finance. One can argue that cash holding influences the critical net working capital. As long as the marginal profits of fixed assets exceed the marginal costs of short-term finance, the partial impact of cash holding on the critical working capital is negative. Yet if T(1-k) > r, the critical net working capital can exceed total assets, so the impact of cash holding is negligible.

$$\frac{d(WC_1^*/A_0)}{d\,(C_0/A_0)}=1-\frac{T(1-k)}{r}$$

Hence I simplify the calculation by assuming that the partial impact of cash holding on the critical net working capital is zero. Otherwise I would have to consider the derivative of the upper boundary of the integral when applying the Leibniz rule. This makes the notation more complex without adding much to the interpretation of results.

A. 2 Deriving proposition 1 (equation 2)

I take the first derivative with respect to C_0 of equation 1 by applying the Leibniz rule.

$$\frac{dU_E(WC_1^*)}{dC_0} = \frac{d}{dC_0}\Bigg[-F_{WC}(WC_1^*) \cdot C_0 \cdot T(1-k) + lC_0 - r \cdot \left(\int_{C_0}^{WC_1^*} (WC_1 - C_0) f_{WC}(WC_1)\, dWC_1\right)\Bigg]$$

$$= -F_{WC}(WC_1^*) \cdot T(1-k) + l + r\int_{C_0}^{WC_1^*} f_{WC}(WC_1)\, dWC_1$$

$$= -F_{WC}(WC_1^*) \cdot T(1-k) + l + r\big(F_{WC}(WC_1^*) - F_{WC}(C_0)\big)$$

To determine the second derivative with respect to C_0, I apply the Leibniz rule.

$$\frac{d^2U_E(WC_1^*)}{dC_0^2} = -r \cdot f_{WC}(C_0) < 0$$

Accordingly, proposition 1 determines a global maximum of shareholders' utility by selecting an optimal level of cash holding. Note that I did not include a discount factor, which should reflect the weighted average cost of capital, as I only have one trading period.

A.3 Deriving the critical cost-income ratio k^* and partial derivatives (equation 3 and 4)

I define default by setting shareholders' utility (equation 1) smaller than zero and solve for the critical cost-income ratio k^*. This implies negative equity, as the firm is liquidated in t=2. Hence, if the liquidation value is not sufficient to pay debt holders, the firm defaults, and debt holders cannot receive their contractual payments. To simplify notation, I assumed that working capital is used to pay back short-term debt, as $WC_2=0$. Note that the remaining (repaid) working capital goes back into cash holding.

$$k^* = 1 - \frac{{}^{D_0}/_{A_0}(1+i) + {}^{r}/_{A_0}\left(\int_{C_0}^{WC_1^*}(WC_1 - C_0) f_{WC}(WC_1)\, dWC_1\right) - {}^{C_0}/_{A_0}\, l - 1 + l}{F_{WC}(WC_1^*) \cdot \left(1 - {}^{C_0}/_{A_0}\right) \cdot T}$$

To determine the impact of cash holding on the critical cost-income ratio k^*, I derive the partial derivative with respect to C_0.

$$\frac{\partial k^*}{\partial C_0}|_{L\leq\bar{L}} = -\left[F_{WC}(WC_1^*)\cdot\left(1-{C_0}/{A_0}\right)\cdot T\right]^{-2}$$

$$\cdot\left\{\left[F_{WC}(WC_1^*)\cdot\left(1-{C_0}/{A_0}\right)\cdot T\right]\right.$$

$$\cdot\left[-{r}/{A_0}\left(F_{WC}(WC_1^*)-F_{WC}(C_0)\right)-{l}/{A_0}\right]$$

$$-\left[L(1+i)+{r}/{A_0}\left(\int_{C_0}^{WC_1^*}(WC_1-C_0)f_{WC}(WC_1)\,dWC_1\right)-{C_0}/{A_0}\,l-1\right.$$

$$\left.\left.+\,l\right]\left[-F_{WC}(WC_1^*)\cdot{T}/{A_0}\right]\right\}>0$$

Taking the first partial derivative with respect to financial leverage L shows that firms with higher leverage have a lower critical cost-income ratio and thus a higher default risk.

$$\frac{\partial k^*}{\partial L} = -\frac{1+i}{F_{WC}(WC_1^*)\cdot\left(1-{C_0}/{A_0}\right)\cdot T}<0$$

Taking the second derivative with respect to cash holding and financial leverage reveals that the benefit of cash holding in increasing the critical cost-income ratio is jeopardised by higher financial leverage.

$$\frac{\partial^2 k^*}{\partial C_0\partial L} = -\frac{1+i}{F_{WC}(WC_1^*)\cdot\left(1-{C_0}/{A_0}\right)\cdot T}\left(F_{WC}(WC_1^*)\cdot{T}/{A_0}\right)<0$$

I can also derive the critical level of financial leverage. To ensure that cash holding increases the critical cost-income ratio, financial leverage has to be below the following threshold.

$$L<(1+i)^{-1}\left\{\frac{\left[F_{WC}(WC_1^*)\cdot\left(1-{C_0}/{A_0}\right)\cdot T\right]\cdot\left[{r}/{A_0}\left(F_{WC}(WC_1^*)-F_{WC}(C_0)\right)+{l}/{A_0}\right]}{F_{WC}(WC_1^*)\cdot{T}/{A_0}}\right.$$

$$\left.-{r}/{A_0}\left(\int_{C_0}^{WC_1^*}(WC_1-C_0)f_{WC}(WC_1)\,dWC_1\right)+{C_0}/{A_0}\,l+1-l\right\}\equiv\bar{L}$$

A.4 Deriving Proposition 2 (equation 7)

I start with the modified utility of shareholders (equation 5) and take the first derivative with respect to cash holding based on the Leibniz rule.

$$\frac{dU_E(WC_1^*, S_1, k)}{dC_0}$$

$$= \frac{d}{dC_0}\left(1 - \int_0^{WC_1^*-C_0} f_S\,(S_1|\Omega)dS_1\right) \cdot F_{WC}(WC_1^*) \cdot FA_0 \cdot T\big(1 - E(k)\big)$$

$$- D_0(1+i) - r \cdot \left(\int_{C_0}^{WC_1^*} (WC_1 - C_0) f_{WC}(WC_1)\, dWC_1\right)$$

$$\cdot \left(1 - \int_0^{WC_1^*-C_0} f_S\,(S_1|\Omega)dS_1\right) + FA_0(1-l) + C_0$$

Step 1:

$$\frac{dU_E(WC_1^*)}{dC_0} = \left(1 - \int_0^{WC_1^*-C_0} f_S\,(S_1|\Omega)dS_1\right)$$

$$\cdot \left[\left(-F_{WC}(WC_1^*) \cdot T(1 - E(k))\right) + r\left(F_{WC}(WC_1^*) - F_{WC}(C_0)\right)\right] + l$$

$$+ \left(f_S(WC_1^* - C_0|\Omega) - \int_0^{WC_1^*-C_0} \frac{\partial}{\partial C_0} f_S\,(S_1|\Omega)dS_1\right)$$

$$\cdot \Bigg[F_{WC}(WC_1^*) \cdot (A_0 - C_0) \cdot T(1-k) - r$$

$$\cdot \left(\int_{C_0}^{WC_1^*} (WC_1 - C_0) f_{WC}(WC_1)\, dWC_1\right)\Bigg]$$

To determine the partial derivative of $f_S(S_1|\Omega)$ with respect to cash holding C_0, I assume that short-term access to finance S_1 follows a log-normal distribution with mean μ_S and variance σ_S^2.

$$f_S(S_1|\mu, \sigma) = \frac{1}{S_1 \cdot \sigma_S \cdot \sqrt{2\pi}} exp[-0.5\sigma_S^{-2} \cdot (\ln(S_1) - \mu_S)^2]$$

Furthermore, I assume that the conditional mean $E(S_1|\Omega)$ is determined in the following log-linear model based on the covariates cash holding and a vector of predetermined variables (in t=0) **z**.

$$E(\ln(S_1)\,|\Omega) = \hat{\beta}_C \ln\,(C_0) + \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}} \boldsymbol{z}$$

The partial derivative of $f_S(S_1|\Omega)$ with respect to cash holding C_0, can be determined as follows.

$$\frac{\partial}{\partial C_0} f_S(S_1|\Omega) = \frac{1}{S_1 \cdot \sigma \cdot \sqrt{2\pi}} exp\left[-0.5\sigma_S^{-2} \cdot \left(\ln(S_1) - \hat{\beta}_C \ln(C_0) - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z}\right)^2\right]$$

$$\cdot \left[\sigma_S^{-2} \cdot \left(\ln(S_1) - \hat{\beta}_C \ln(C_0) - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z}\right) \cdot \hat{\beta}_C C_0^{-1}\right]$$

$$= f_S(S_1|\Omega) \cdot \left[\sigma_S^{-2} \cdot \left(\ln(S_1) - \hat{\beta}_C \ln(C_0) - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z}\right) \cdot \hat{\beta}_C C_0^{-1}\right]$$

Substituting back into step 1, we need to assess the following integral.

$$\int_0^{WC_1^*-C_0} f_S(S_1|\Omega) \cdot \left[\sigma_S^{-2} \cdot \left(\ln S_1 - \hat{\beta}_C \ln C_0 - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z}\right) \cdot \hat{\beta}_C C_0^{-1}\right] dS_1$$

$$= \sigma_S^{-2} \cdot \hat{\beta}_C C_0^{-1} \left[\int_0^{WC_1^*-C_0} \left(\ln S_1 \cdot f_S(S_1|\Omega)\right) dS_1 - \hat{\beta}_C \ln \mathrm{C}_0\right.$$

$$\left. \cdot F_S(WC_1^* - C_0|\Omega) - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z} \cdot F_S(WC_1^* - C_0|\Omega)\right]$$

I need to determine the following term.

$$\int_0^{WC_1^*-C_0} \ln S_1 \cdot f_S(S_1|\Omega) dS_1 = \ln S_1 \cdot F_S(WC_1^* - C_0|\Omega)$$

$$- \int_0^{WC_1^*-C_0} \frac{1}{\mathrm{S}_1} \cdot F_S(WC_1^* - C_0|\Omega) dS_1 = \ln S_1 \cdot F_S(WC_1^* - C_0|\Omega)$$

$$- F_S(WC_1^* - C_0|\Omega) \int_0^{WC_1^*-C_0} \frac{1}{\mathrm{S}_1} dS_1$$

To avoid an improper integral, S_1 needs to be larger than 1. Under this condition, which is due to the assumed log-normal distribution of S_1, I can solve as follows.

$$\int_0^1 \frac{1}{\mathrm{S}_1} dS_1 + \int_1^{WC_1^*-C_0} \frac{1}{\mathrm{S}_1} dS_1 = \int_0^1 \frac{1}{\mathrm{S}_1} dS_1 + \ln(WC_1^* - C_0)$$

Substituting back into step 1 gives the following expression.

Step 2:

$$\frac{dU_E(WC_1^*, S_1, k)}{dC_0}$$

$$= \left(1 - F_S(WC_1^* - C_0|\Omega)\right)$$
$$\cdot \left[\left(-F_{WC}(WC_1^*) \cdot T(1-k)\right) + r\left(F_{WC}(WC_1^*) - F_{WC}(C_0)\right)\right] + l$$
$$+ \left(f_S(WC_1^* - C_0|\Omega) - \sigma_S^{-2} \cdot \hat{\beta}_C C_0^{-1}\right.$$
$$\left. \cdot F_S(WC_1^* - C_0|\Omega)\left[\ln S_1 - ln(WC_1^* - C_0) - \hat{\beta}_C lnC_0 - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z}\right]\right)$$
$$\cdot \left[F_{WC}(WC_1^*) \cdot (A_0 - C_0) \cdot T(1-k) - r\right.$$
$$\left. \cdot \left(\int_{C_0}^{WC_1^*} (WC_1 - C_0) f_{WC}(WC_1)\, dWC_1\right)\right]$$

To simplify the notation, I introduce the partial expectations operator and rewrite step 2, which results in proposition 2.

$$\frac{dU_E(WC_1^*, S_1, k)}{dC_0}$$

$$= \left(1 - F_S(WC_1^* - C_0|\Omega)\right)$$
$$\cdot \left[\left(-F_{WC}(WC_1^*) \cdot T(1-k)\right) + r\left(F_{WC}(WC_1^*) - F_{WC}(C_0)\right)\right] + l$$
$$+ \left(f_S(WC_1^* - C_0|\Omega) - \sigma_S{}^{-2} \cdot \hat{\beta}_C C_0^{-1}\right.$$
$$\left. \cdot F_S(WC_1^* - C_0|\Omega)\left[\ln(S_1) - ln(WC_1^* - C_0) - \hat{\beta}_C \ln C_0 - \hat{\boldsymbol{\gamma}}^{\boldsymbol{T}}\boldsymbol{z}\right]\right)$$
$$\cdot \left[F_{WC}(WC_1^*) \cdot (A_0 - C_0) \cdot T(1 - E(k)) - r \cdot E_{C_0}^{WC_1^*}(WC_1 - C_0)\right]$$