Dynamic analysis of the capital structure of S&P 500 firms under unconventional monetary policy using score-driven panel data models

Astrid Ayala and Szabolcs Blazsek*

School of Business, Universidad Francisco Marroquín, Ciudad de Guatemala, Guatemala

Abstract: The unconventional monetary policy of the Federal Reserve System motivated several US firms to change their capital structures in the last two decades, by issuing debt and engaging in stock repurchase programmes. The hypothesis of this paper is that US firms increased the proportion of external debt financing in periods of decreasing or low interest rate levels, and the opposite was implemented in periods of increasing interest rates. We use a new score-driven panel data model, which is able to identify structural changes in the capital structure of firms, to perform a robust test of this capital structure hypothesis. The motivation for the use of the score-driven panel data model is that the firm-specific local level filter in the score-driven model is optimal, according to the Kullback--Leibler divergence in favour of the true data generating process. Capital structure of firms is measured by using data on the book value of financial debt to book value of equity plus book value of financial debt (debt-to-capital). The empirical results on the debt-to-capital of S&P 500 firms support the capital structure hypothesis for US firms for the period of 1997 Q4 to 2019 Q3.

Keywords: Unconventional monetary policy; capital structure of firms; score-driven panel data model; dynamic conditional score; generalized autoregressive score

JEL classification codes: C22, C23, C51

*Corresponding author. Postal address: Escuela de Negocios, Universidad Francisco Marroquín, Calle Manuel F. Ayau, Zona 10, Ciudad de Guatemala 01010, Guatemala. E-mails: sblazsek@ufm.edu (S. Blazsek), aayala@ufm.edu (A. Ayala).

1. Introduction

During the last two decades, the Federal Reserve System significantly decreased the effective federal funds rate twice, in response to the 1995-2002 Dotcom Bubble and the 2007-2008 US Financial Crisis, respectively (Fig. 1). Firstly, from 2000 Q3 until 2004 Q1, when the effective federal funds rate decreased from 6.5 to 1%. Secondly, during the 2008 US Financial Crisis from 2007 Q3 to 2008 Q4, when the effective federal funds rate decreased from 4.5 to 0.18%. Afterwards, from 2008 Q4 to 2015 Q3, the effective federal funds rate was held at a near-zero and approximately constant level during the period of unconventional monetary policy in the US (Rudebush 2018). The lower borrowing costs motivated the stock repurchases of several US firms (Wang 2020).
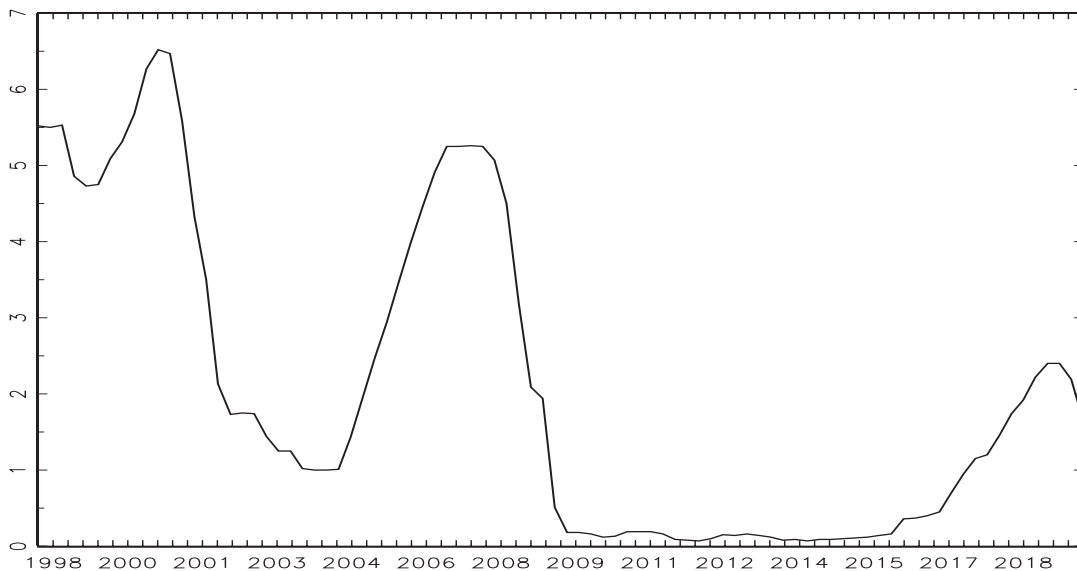
Fig. 1. Effective federal funds rate for the period of 1997 Q4 to 2019 Q3 (source: Bloomberg).

The hypothesis of this paper is that US firms changed their capital structures and increased the proportion of external debt financing in periods of decreasing or low interest rate levels, and the opposite was implemented in periods of increasing interest rates. This hypothesis is tested by using data on the book value of financial debt to book value of equity plus book value of financial debt (hereinafter, debt-to-capital), which is motivated by the work of Rajan and Zingales (1995). The present paper provides an empirical contribution to the literature on the capital structure of firms (Myers 2001).

We use a score-driven panel data model to perform a robust test of the capital structure hypothesis. The score-driven model is able to identify structural changes in debt-to-capital in a robust way, because:

(i) The local level component of debt-to-capital is updated by a firm-specific score-driven filter, which is optimal according to the Kullback–Leibler divergence in favour of the true data generating process (Blasques et al. 2015). (ii) A score-driven Student's t-distribution is used for debt-to-capital, which provides a score-driven filter that is robust to outliers (Harvey 2013). Score-driven time series models are introduced in the works of Creal et al. (2008) and Harvey and Chakravarty (2008).

The remainder of this paper is structured as follows: Section 2 presents the score-driven panel data model. Section 3 presents the statistical inference of the score-driven panel data model. Section 4 presents the dataset. Section 5 presents the empirical results.

2. Score-driven panel data model

The score-driven panel data model, for the debt-to-capital $y_{i,t}$ of $i = 1, \ldots, N$ firms, is:

$$y_{i,t} = \mu_{i,t} + v_{i,t} = c + \mu_{1,i,t} + \mu_{2,i,t} + v_{i,t} = c + \mu_{1,i,t} + \mu_{2,i,t} + \exp(\lambda)\epsilon_{i,t} \tag{1}$$

$$\mu_{j,i,t} = \phi_j \mu_{j,i,t-1} + \kappa_j u_{i,t-1} \tag{2}$$

for $t = 1, \ldots, T$ periods, where $j = 1, 2$, the error term $\epsilon_{i,t} \sim t(\nu)$ is independent and identically distributed (i.i.d.), $\nu > 0$ is the degrees of freedom parameter, $\exp(\lambda)$ is the scaling parameter where $\lambda \in \mathbb{R}$, and $u_{i,t}$ is a non-linear transformation of $v_{i,t}$ that is defined in Section 3.

The following specifications are estimated: (i) Local level model, by using conditions $c = 0$, $\phi_1 = 1$, $\kappa_1 \neq 0$, $\phi_2 = 0$ and $\kappa_2 = 0$ (Harvey 2013). For this model, parameters κ_1, λ and ν are estimated. (ii) First-order quasi-autoregressive, QAR(1), model with one component, by using conditions $|\phi_1| < 1$, $\kappa_1 \neq 0$, $\phi_2 = 0$ and $\kappa_2 = 0$ (Harvey 2013). For this model, parameters c, ϕ_1, κ_1, λ and ν are estimated. (iii) QAR(1) model with two components, by using conditions $|\phi_1| < 1$, $\kappa_1 \neq 0$, $|\phi_2| < 1$ and $\kappa_2 \neq 0$ (Harvey 2013). For this model, parameters c, ϕ_1, κ_1, ϕ_2, κ_2, λ and ν are estimated.

3. Statistical inference

The distribution of $y_{i,t}|(y_{i,1}, \ldots, y_{i,t-1})$ is the non-standardized t-distribution with location parameter $\mu_{i,t} = c + \mu_{1,i,t} + \mu_{2,i,t}$, scale parameter $\exp(\lambda)$ and degrees of freedom parameter ν. The log conditional

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density of $y_{i,t}$, given the vector of parameters Θ, is:

$$\ln f(y_{i,t}|y_{i,1},\ldots,y_{i,t-1};\Theta) = \ln\Gamma\left(\frac{\nu+1}{2}\right) - \ln\Gamma\left(\frac{\nu}{2}\right) - \lambda - \frac{\ln(\pi\nu)}{2} - \frac{\nu+1}{2}\ln\left[1 + \frac{(y_{i,t}-\mu_{i,t})^2}{\nu\exp(2\lambda)}\right] \quad (3)$$

where $\Gamma(x)$ is the gamma function. The conditional score with respect to $\mu_{i,t}$ (Harvey 2013) is:

$$\frac{\partial\ln f(y_{i,t}|y_{i,1},\ldots,y_{i,t-1};\Theta)}{\partial\mu_{i,t}} = \frac{\nu+1}{\nu\exp(2\lambda)}u_{i,t} \quad (4)$$

where the scaled score function (Harvey 2013) is:

$$u_{i,t} = \left[1 + \frac{v_{i,t}^2}{\nu\exp(2\lambda)}\right]^{-1} v_{i,t} = \frac{\nu\exp(\lambda)\epsilon_{i,t}}{\nu+\epsilon_{i,t}^2} \quad (5)$$

Scaled score function $u_{i,t}$ is i.i.d. with zero mean (Harvey 2013) and a non-linear transformation of the error term $v_{i,t}$. In Fig. 2, the corresponding non-linear transformation for the estimates of the local level model is presented. The figure indicates that extreme values of $v_{i,t}$ are discounted by a non-linear transformation. Thus, signal $\mu_{i,t}$ is not distorted by outliers, which appear in the error term $v_{i,t}$. This updating mechanism is optimal due to the following result. In the work of Blasques et al. (2015), it is shown that a score-driven update of a time series model reduces the Kullback–Leibler divergence in expectation and at every step, and only score-driven updates can have this property.
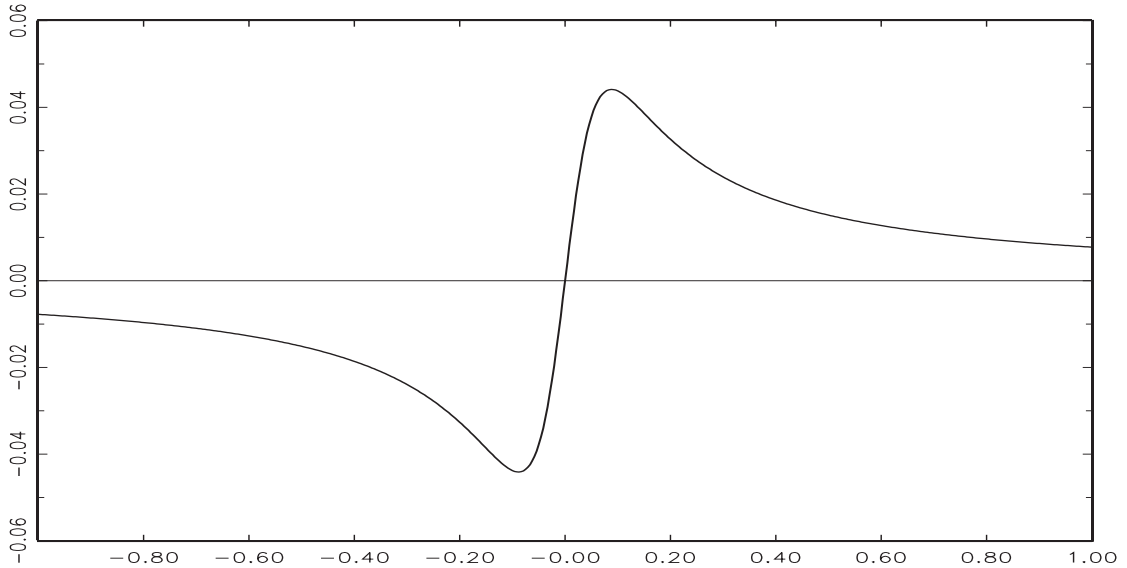
Fig. 2. Scaled score function $u_{i,t}$ as a function of $v_{i,t}$ for the local level model.

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Score-driven panel data models are estimated by using the maximum likelihood (ML) method:

$$\hat{\Theta}_{\mathrm{ML}} = \arg\max_{\Theta} \mathrm{LL}(y_{i,1}, \ldots, y_{i,T}; \Theta) = \arg\max_{\Theta} \sum_{i=1}^{N} \sum_{t=1}^{T} \ln f(y_{i,t}|y_{i,1}, \ldots, y_{i,t-1}; \Theta) \qquad (6)$$

where LL denotes log-likelihood. The standard errors of $\hat{\Theta}_{\mathrm{ML}}$ are estimated by using inverse information matrix; we assume that the information matrix equality holds (Harvey 2013).

4. Data

Quarterly data are used for the period of 1997 Q3 to 2019 Q3 ($T = 88$) for all companies of the S&P 500 (source: Bloomberg). Variables book value of equity $E_{i,t}$ and book value of financial debt $D_{i,t}$ define the debt-to-capital ratio $y_{i,t} = D_{i,t}/(E_{i,t} + D_{i,t})$ of $i = 1, \ldots, N$ firms for $t = 1, \ldots, T$ periods. For several firms, there are missing observations for some initial periods of the sample. Therefore, some firms are excluded from the sample according to the following methods. The sample period is divided into: (i) 1997 Q3 to 2008 Q3 (44 quarters); (ii) 2008 Q4 to 2019 Q3 (44 quarters). The selection of 2008 Q4 is motivated by the fact that the effective federal funds rate decreased to 0.18% in that quarter, indicating the start of the unconventional monetary policy. We only include those firms in the sample, for which at least 20 observations are available for the period of 1997 Q3 to 2008 Q3. Therefore, 92 firms are excluded from the S&P 500, and $N = 408$ firms are studied in this paper. For 63 out of the 408 firms, there are still some missing observations for the initial periods of the sample. Those missing values are replaced by using the 'next observation carried backward' (NOCB) method.

5. Results

In Table 1, the ML estimates of the local level model, QAR(1) model with one component, and QAR(1) model with two components are presented. The parameter estimates support the conditions for all models (Section 2). For the estimates of ϕ_1, the t-test supports that $|\phi_1| < 1$ for both QAR(1) models, at the 1% level of significance. For the QAR(1) model with two components, $\mu_{1,i,t}$ represents the more persistent component, which measures structural changes in the debt-to-capital ratio; similarly to $\mu_{1,i,t}$ of the local level model and the QAR(1) model with one component.

Statistical performances are compared by using the LL, Akaike information criterion (AIC), Bayesian information criterion (BIC), and Hannan–Quinn criterion (HQC) metrics (Harvey 2013), and the likelihood-ratio (LR) test. According to AIC, BIC and HQC, the local level model is superior to both QAR(1) models. Nevertheless, the LR test supports the use of the QAR(1) model with two

components. Therefore, the estimates of $\mu_{1,i,t}$ for all models are used and the corresponding results are compared in the remainder of this paper.

Table 1. Score-driven panel data models

	Local level model	QAR(1) model, one component	QAR(1) model, two components
c	NA	$-0.0006(0.0307)$	$0.0010(0.0113)$
ϕ_1	NA	$0.9963^{***}(0.0013)$	$0.9963^{***}(0.0009)$
κ_1	$1.7482^{***}(0.1772)$	$1.7464^{***}(0.1738)$	$2.4995^{***}(0.0862)$
ϕ_2	NA	NA	$0.4002^{***}(0.0698)$
κ_2	NA	NA	$-0.5816^{***}(0.0878)$
λ	$-3.1799^{***}(0.0736)$	$-3.1717^{***}(0.0735)$	$-3.2302^{***}(0.0565)$
ν	$4.5033^{***}(0.7930)$	$4.8096^{***}(0.8587)$	$4.1247^{***}(0.4820)$
mean LL	1.5285	1.5357	1.5567
mean AIC	-2.9889	-2.9577	-2.9544
mean BIC	-2.9045	-2.8169	-2.7573
mean HQC	-2.9549	-2.9010	-2.8750
LR test	NA	510.3323^{***}	1513.3608^{***}

Notes: Not available (NA). The LR tests compare: QAR(1) with one component and the local level model; QAR(1) with two components and QAR(1) with one component. Standard errors are in parentheses. *** is significance at the 1% level.

Under the capital structure hypothesis, the evolution of the effective federal funds rate (Fig. 1) implies the following strategies: (P1) For the period of 1997 Q4 to 2000 Q3, a decreasing or stable debt-to-capital ratio is expected for most of the firms. (P2) 2000 Q4 to 2004 Q1, an increasing or stable debt-to-capital ratio is expected for most of the firms. (P3) 2004 Q2 to 2007 Q1, a decreasing or stable debt-to-capital ratio is expected for most of the firms. (P4) 2007 Q2 to 2015 Q3, an increasing or stable debt-to-capital ratio is expected for most of the firms. (P5) 2015 Q4 to 2019 Q3, a decreasing or stable debt-to-capital ratio is expected for most of the firms. To study the evolution of debt-to-capital for each firm i, the following structural break regression is estimated:

$$\hat{\mu}_{1,i,t} = \alpha_{1,i}\mathrm{DU}_{\mathrm{P1},t} + \ldots + \alpha_{5,i}\mathrm{DU}_{\mathrm{P5},t} + \beta_{1,i}\mathrm{TIME}_{\mathrm{P1},t} + \ldots + \beta_{5,i}\mathrm{TIME}_{\mathrm{P5},t} + \xi_{i,t} \tag{7}$$

for $t = 1, \ldots, T$, where $\hat{\mu}_{1,i,t}$ is the estimate of $\mu_{1,i,t}$ for each model, dummy variable $\mathrm{DU}_{k,t}$ takes the value one if $t \in k$ and zero otherwise. Moreover, $\mathrm{TIME}_{\mathrm{P1},t} = t$ if $t \in \mathrm{P1}$ and zero otherwise, $\mathrm{TIME}_{\mathrm{P2},t} = t - T_1$ if $t \in \mathrm{P2}$ and zero otherwise, $\mathrm{TIME}_{\mathrm{P3},t} = t - T_2$ if $t \in \mathrm{P3}$ and zero otherwise, $\mathrm{TIME}_{\mathrm{P4},t} = t - T_3$ if $t \in \mathrm{P4}$ and zero otherwise, and $\mathrm{TIME}_{\mathrm{P5},t} = t - T_4$ if $t \in \mathrm{P5}$ and zero otherwise, where the time index of the last observations of $\mathrm{P1}, \mathrm{P2}, \ldots, \mathrm{P5}$ are denoted by $T_1, T_2, \ldots, T_5$, respectively. The regression model is estimated by using the ordinary least squares method and assuming homoscedasticity.

In Table 2, the percentage of the S&P 500 firms, for which the capital structure hypothesis is supported, is presented for each period: (P1) $\hat{\beta}_{1,i}$ is significantly negative or non-significant; (P2) $\hat{\beta}_{2,i}$ is significantly positive or non-significant; (P3) $\hat{\beta}_{3,i}$ is significantly negative or non-significant; (P4) $\hat{\beta}_{4,i}$ is significantly positive or non-significant; (P5) $\hat{\beta}_{5,i}$ is significantly negative or non-significant. The results are robust for different models and the capital structure hypothesis of this paper is supported.

Table 2. Capital structure hypothesis test

Hypothesis is supported	Local level model	QAR(1) model, one component	QAR(1) model, two components
from 1997 Q4 to 2000 Q3	64.71%	64.71%	69.12%
from 2000 Q4 to 2004 Q1	68.87%	69.12%	71.57%
from 2004 Q2 to 2007 Q1	83.33%	83.58%	85.05%
from 2007 Q2 to 2015 Q3	67.65%	67.40%	69.36%
from 2015 Q4 to 2019 Q3	61.52%	61.52%	65.93%

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