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Bougias, Alexandros and Episcopos, Athanasios and Leledakis, George N.

Athens University of Economics and Business - Department of Accounting and Finance, Athens University of Economics and Business - Department of Accounting and Finance, Athens University of Economics and Business - Department of Accounting and Finance

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Alexandros Bougias[a], Athanasios Episcopos[a], George N. Leledakis[a]

[a]*Department of Accounting and Finance, Athens University of Economics and Business, Greece*

Abstract

We infer the asset value dynamics of European firms during the Russia-Ukraine war via the structural model of Merton (1974). Using high-frequency stock price data, we find that the war led to lower corporate security prices and higher asset volatility, eventually shifting asset values closer to the default region. On average, the balance sheet of European firms is expected to shrink by 2.05% and their 1-year default probability to increase from 0.32% to 2.12%. Regression analysis on asset and equity returns as well as default probability changes suggests that these effects are stronger for firms with large revenue exposure to Russia.

Keywords: European firms, Merton model, Russia-Ukraine war, Asset returns, Default risk

JEL codes: G12, G14, G32

*Correspondence to: Athanasios Episcopos, Department of Accounting and Finance, School of Business, Athens University of Economics and Business, 76 Patission Str., 104 34, Athens, Greece. Tel. (+30) 2108203364.

Email addresses: alexbougias@gmail.com (Alexandros Bougias), episcopos@aueb.gr (Athanasios Episcopos), gleledak@aueb.gr (George N. Leledakis)

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1. Introduction

On February 24, 2022, Russia initiated a full-scale invasion of Ukraine, after recognizing the Donbass and Luhansk regions as independent states two days earlier. The start of the war marked a culmination point in the deteriorating Russia-Ukraine relations since 2014, and triggered an immediate reaction by Western governments. European countries, along with Canada and the USA, imposed a package of sanctions against Russia, including the removal of several banks from the SWIFT system and the freezing of the Russian Central Bank's assets.[1] The sanctions aimed at cutting off the Russian economy from most of its export markets, while major multinational corporations announced their exit from Russia.

It quickly became evident that the ongoing war would impact companies worldwide, particularly those heavily involved in Russian and Ukrainian economic trade. Factors such as the exposure of financial institutions to Russia, the falling household disposable income due to the rising energy and food prices, the supply chain issues, and the increased input costs would severely disrupt business activities. Further, high inflation concerns would put an additional pressure on government budget and public finances, eventually undermining economic growth. These somber expectations accelerated policy actions with a lasting effect on the economy. For instance, in Europe, which is the focus of our investigation, the European Central Bank indicated its reluctance to continue with its quantitative easing policy in the third quarter of 2022, implying a rise in sovereign bond yields especially for highly indebted countries. Overall, the impact of the war on asset prices is expected to be large, with important implications on default risk and security valuation.

The purpose of this paper is to quantify the aggregate cost of war on European firms by exploiting the informational content embedded in the stock market. To this end, we estimate the structural model of Merton (1974) using high-frequency stock price data, and recover the latent firm asset value dynamics for a 20-trading-day window around February 24, 2022. This structural approach allows us to map changes in observed equity prices to changes in asset and debt values, and calculate a series of default risk indicators before and after the start of war. Our empirical results suggest that firms faced higher levels of uncertainty during the first days of the war, and their asset values declined significantly, moving closer to the default region. Noteworthy, these effects are stronger for firms with a large exposure to the Russian economy. Regression analysis shows that revenue exposure to Russia is a statistically significant pricing factor of asset and equity returns as well as default

[1] For a timeline of the sanctions adopted in response to Russian invasion, see https://www.piie.com/blogs/realtime-economic-issues-watch/russias-war-ukraine-sanctions-timeline

probability changes during the outbreak of war, and is robust to firm-specific, industry, and currency controls.

Our work contributes to the literature on the impact of major war conflicts on financial markets. Although there are papers that study equities or bonds (Frey and Kucher, 2001; Choudhry, 2010; Brune et al., 2015), to our knowledge there has been no paper using a structural modeling approach to the valuation of firms during a war, thus filling an obvious gap. The new feature of our approach is that it provides market-based estimates on the shocked balance sheet values, default probabilities, and credit spreads. Technically, our study is linked to the structural model literature, particularly to papers that use the Merton (1974) model to infer firm asset values and default risk indicators (Vassalou and Xing, 2004; Duffie et al., 2007; Jessen and Lando, 2015), and to papers that exploit high-frequency stock price data to estimate asset volatility (Zhang et al., 2009; Huang et al., 2019). Finally, our paper contributes to the ongoing debate about the expected consequences of the Russia-Ukraine war (Tosun and Eshraghi, 2022; Boungou and Yatié, 2022; Deng et al., 2022), and is the first to study its impact on default risk.

2. Methodology

From the model of Merton (1974), the equity value of a firm that issues a zero-coupon debt with maturity T and face value F is given by

$$E(V) = V\mathcal{N}(d_1) - Fe^{-rT}\mathcal{N}(d_2), \tag{1}$$

where V is the market value of assets, r is the risk-free rate, and σ_A is the asset volatility, with

$$d_1 = \frac{\ln(V/F) + (r + 0.5\sigma_A^2)T}{\sigma_A\sqrt{T}} \quad \text{and} \quad d_2 = d_1 - \sigma_A\sqrt{T}. \tag{2}$$

The debt value is calculated from the basic accounting identity as $D(V) = V - E(V)$. Equation 1 provides a non-linear relationship between V and E, that depends explicitly to all parameters including the leverage ratio F/V. This equation is used to estimate the implied asset values from the stock market as follows.

For a given trading day τ, we collect stock price data at a 10-minute frequency and calculate the market capitalization of each firm (stock price $\times$ common shares outstanding). Then, we recover the implied asset value series $\{V_{\tau,i}, i = 1, 2, ..., \delta\}$ that is consistent with the observed equity price series $\{E^{obs}_{\tau,i}, i = 1, 2, ..., \delta\}$, where δ denotes the sampling frequency.

Specifically, we employ the iterative procedure of Bohn and Crosbie (2003) and Vassalou and Xing (2004), and solve the following system of equations:

$$\begin{cases} E(V_{\tau,1}) & = E_{\tau,1}^{obs} \\ E(V_{\tau,2}) & = E_{\tau,2}^{obs} \\ & \vdots \\ E(V_{\tau,\delta}) & = E_{\tau,\delta}^{obs} \end{cases}. \tag{3}$$

Initially, we provide a guess to σ_A, and solve for the asset value series. Then, we set the asset volatility to the annualized sample standard deviation of $\{V_{\tau,i}, i = 1, 2, ..., \delta\}$, and repeat the process until convergence is achieved. Using the implied asset value series, we estimate the implied debt value and its credit spread, as well as the risk-neutral default probability at time T. The credit spread, s, is equal to

$$s = \frac{\ln(F/D)}{T} - r \tag{4}$$

and the default probability, PD, is

$$PD(T) = \mathbb{Q}(V_T < F) = \mathcal{N}(-DD) \tag{5}$$

where

$$DD = \frac{\ln(V/F) + (r - 0.5\sigma_A^2)T}{\sigma_A\sqrt{T}}. \tag{6}$$

Distance-to-default (DD) measures how far firm's assets are from the default region, and is considered a strong predictor of default risk (Duffie et al., 2007; Jessen and Lando, 2015).

The Merton model is estimated for a large sample of European firms in the period surrounding the Russian invasion. We retrieve stock market prices for the constituents of MSCI Europe All Cap index spanning the period from February 10, 2022 through March 9, 2022. Motivated by the event-study literature, we choose a 20-trading-day window around February 24, 2022 to isolate the impact of war on asset prices. We collect stock prices between 9:00 and 16:30 CET at a 10-minute frequency, resulting in approximately 45 observations per day. We remove firms having on average more than 2 missing observation per day, while for the remaining firms we use the latest observation to fill any missing values.

Regarding the model parameters, we follow the literature (Brockman and Turtle, 2003; Huang et al., 2019) and proxy the face value of debt F with the book value of total liabilities,

while the debt maturity T is set to 1 year. The risk-free rate r is given by the 1-year deposit rate depending on the currency that stock prices are denominated.[2] Both accounting and market data are retrieved from the Thomson Reuters Eikon database. The final sample includes 964 firms.

3. Empirical results

Figure 1 provides the cross-sectional distribution dynamics of equity market prices, and asset and debt values as derived from the Merton model. We observe that corporate security values declined after the start of invasion and the accumulation of sanctions against Russia. The asset values series has a lower cross-sectional variation and a higher median compared to the equity price series. The debt value distribution is quite stable over time, and its variation is driven by changes in asset volatility.

[Insert Figure 1 here]

Table 1 contains the summary statistics of the estimation results. Panel A provides the risk measures backed out from the Merton model for the period before and after the start of the war. For an average European firm with a leverage ratio of approximately 43%, asset volatility increased from 19.78% to 29.14%, whereas distance-to-default decreased from 6.41 to 3.94. The 1-year default probability increased from 0.32% to 2.12%, and the credit spread on firm's debt risen by 33 basis points. Panel B shows the realized return distribution of corporate securities during the first 10 days of the war. Consistent with Figure 1, we see that equity returns are much lower than asset and debt returns. On average, the cumulative asset and equity return is -2.05% and -4.66%, respectively. The cumulative debt return distribution is less volatile and has a mean value of -0.50%.

[Insert Table 1 here]

Overall, our first results suggest that Russia-Ukraine war led to lower security prices and higher levels of volatility, eventually increasing the default risk of European firms. Those aggregate results are clear in the cross-section of firms, but provide only a rough estimate on the true cost of war at the firm-level. The announcement of the war is likely to have a heterogeneous impact across firms, as companies with a higher (lower) revenue exposure to the Russian and Ukrainian trade are expected to experience larger (smaller) negative shocks

[2]Stock prices are denominated in EUR, CHF, GBP, DKK, NOK or SEK.

on their security prices. To confirm this, we retrieve from the Thomson Reuters Eikon database estimates for the revenue exposure of each firm to Russia and Ukraine based on the StarMine Countries of Risk (CoR) model. The CoR model uses a proprietary algorithm that weighs multiple factors such as the firms' geographical distribution of revenues, the location of headquarters, the filing currency, and the country of primary security listing to quantify firms' exposures to different countries. The CoR Revenue Fraction data item, which is used in our paper, provides estimates on the fractional revenue exposures allocated to the company's top 20 countries of risk. In our sample, 649 firms have non-zero exposure to Russia while only 5 have a revenue exposure to Ukraine, and therefore, we consider only exposure to Russia as a grouping variable in our analysis.

Figure 2 provides the model results in conjunction with the revenue exposure to Russia. It is clear that firms with no direct exposure are less affected by the war, with their average asset and equity return being -0.87% and -3.46%, respectively. On the contrary, firms with a very large exposure ($> 5\%$) lost on average 9.09% of their market capitalization, which translates to a shrinkage of their balance sheet by -3.34%. In other words, a large revenue exposure creates a wedge on asset and equity returns of 2.47% and 5.63%, respectively. Figure 2 also shows the firms with a large exposure to Russia realizing the lowest asset returns. This group includes firms which halted their operations in Russia or announced their full exit from the market, such as: (i) Coca Cola HBC which generates roughly 12.6% of its revenues from Russia and operates 10 plants in the country, (ii) Carlsberg which has a revenue exposure of 9.8% and employes 8.400 people in the country, (iii) Pirelli which operates two tire plants in Russia and has a revenue exposure of 8.13%, and (iv) Renault which is the largest western automaker in Russia with a revenue exposure of 14.41%.[3]

[Insert Figure 2 here]

The findings above suggest that firms with higher exposure to Russia experienced lower asset and equity returns after the start of war, and eventually higher levels of credit risk. To examine whether this conclusion is statistically significant, we perform a regression analysis in the cross-section of firms using the revenue exposure as an independent variable. In the regressions, we include firm-specific variables (such as leverage, asset volatility, liquidity, and size), industry dummy variables based on the 2-digit SIC code, and dummy variables based

[3]For more details, see the news articles "Coca-Cola Announces Suspension of Operations in Russia" (Bloomberg, March 8, 2022), "Pirelli puts brake on Russian activities" (Reuters, March 17, 2022), "Renault, the biggest Western automaker in Russia, halts operations there" (The New York Times, March 23, 2022), "Beer giants Heineken and Carslberg join exodus from Russia" (Reuters, March 28, 2022).

on the currency that stock prices are denominated. In this way, we ensure that our results are not driven by other latent risk factors.

The model outputs are provided in Table 2.[4] As expected, exposure to Russia has a statistically significant impact on asset and equity returns as well as default probability changes. Equity and debt returns are lower for highly indebted firms, while the effect of leverage on asset returns is statistically insignificant.[5] In addition, firms with more volatile assets experience lower debt returns and higher default probability changes, whereas the size and liquidity factors have no explanatory power on realized security returns. Overall, our empirical results suggest that losses in asset and equity values are driven by two effects: (i) a reduction in expected future revenues for firms directly exposed to Russia, i.e., a cash-flow effect, and (ii) an increase in default and volatility risk premia after the start of war (as shown in Table 1), i.e., a discounting effect.

[Insert Table 2 here]

4. Conclusion

In this paper we use a structural model to measure the immediate impact of the Russia-Ukraine war on the valuation of European firms. Based on high-frequency stock price data, we compute the implied asset value, and find that it has declined by approximately 2% on average. The war has also led to higher asset volatility, credit spreads, and default probabilities, particularly for firms with a significant revenue exposure to the Russian economy.

[4]Internet Appendix contains a summary of the Merton model estimates grouped by industry and currency. Also, we provide the summary statistics and the correlation matrix for the variables used in the regressions.

[5]Note that this relationship is expected within the Merton model where the Miller-Modigliani theorem holds (see, e.g., Sundaresan (2013)).

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Figure 1: Cross-sectional distribution dynamics of observed equity prices, and implied asset and debt values

The figure displays the cross-sectional distribution of observed equity prices, and implied asset and debt values in the 20-trading-day window around February 24, 2022 (February 10, 2022 through March 9, 2022). The corporate security values are scaled to 100 at the start of the window, and in each time-point the empirical distribution is derived from the cross-section of 964 European firms. The black line indicates the median value, the red band indicates the 25th to 75th percentile interval, and the grey band indicates the 10th to 90th percentile interval.

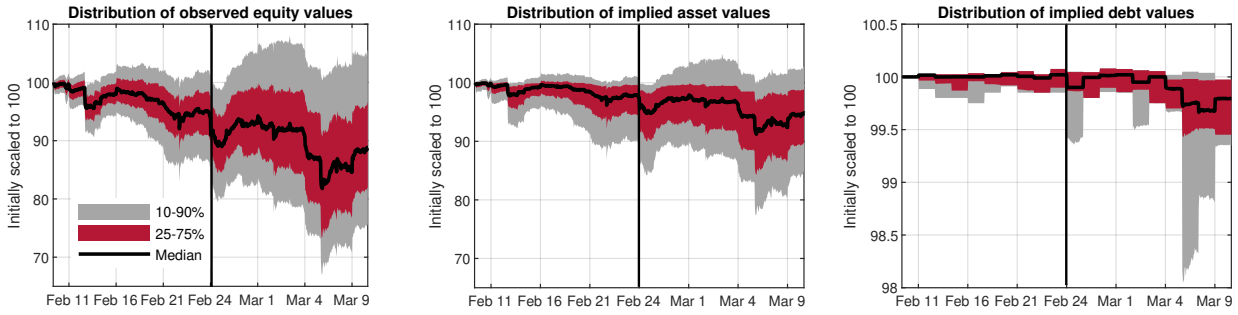

Figure 2: Firm revenue exposure to Russia, asset and equity returns

The figure on the left displays the firm-average cumulative asset and equity return during the first 10 trading days of the war across different exposure levels to Russia. *Exposure to Russia* measures the fractional risk exposure of each firm to Russia based on the StarMine Countries of Risk model. The figure on the right shows the top 20 firms with the lowest asset return in our sample having an exposure to Russia higher than 5%.

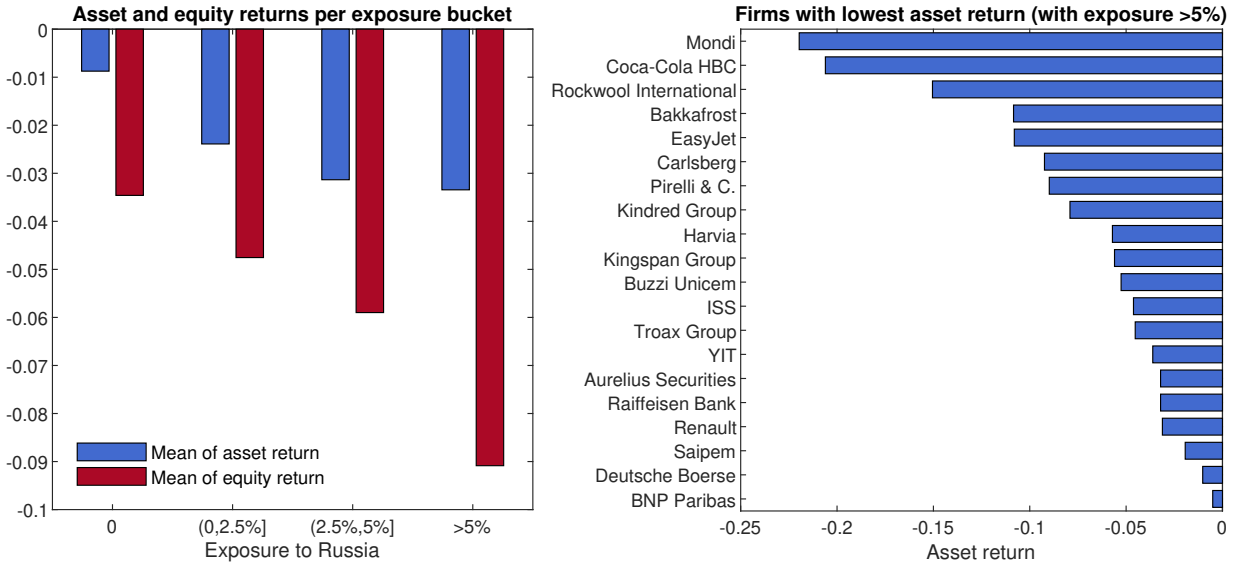

Table 1: Estimated risk measures and corporate security return distributions

The table provides summary statistics for the sample of 964 European firms. Panel A contains the estimated risk measures from the Merton model. Pre-war period (February 10, 2022 through February 23, 2022) and during-war period (February 24, 2022 through March 9, 2022) columns show the time-series average of each measure before and after the start of war. *Asset volatility* and *Distance-to-default* measures are backed out from the Merton model as described in the main text. *Leverage* is defined as the ratio of total liabilities to implied asset value. *Default probability* denotes the 1-year risk-neutral default probability. *Credit spread* denotes the 1-year credit spread on firm's debt. Panel B shows the distribution of cumulative (logarithmic) asset, equity and debt returns in the during-war period.

Panel A: Estimated risk measures from the Merton model						
	Pre-war period			During-war period		
	Mean	Median	SD	Mean	Median	SD
Asset volatility (%)	19.78	15.95	15.86	29.14	25.16	20.63
Leverage (%)	42.24	38.81	27.44	43.61	40.98	27.89
Distance-to-default	6.41	5.75	3.23	3.94	3.52	2.14
Default probability (%)	0.32	0.00	1.17	2.12	0.38	4.18
Credit spread (bps)	7.17	0.01	43.55	40.64	3.23	137.27

Panel B: Asset, equity, and debt return distribution							
	Mean	SD	Min	Q1	Median	Q3	Max
Asset return (%)	-2.05	7.52	-50.66	-5.41	-1.93	0.40	51.35
Equity return (%)	-4.66	11.91	-55.76	-11.34	-5.16	0.86	52.43
Debt return (%)	-0.50	2.15	-41.67	-0.40	-0.12	-0.10	2.84

Table 2: Determinants of realized corporate security returns and default probability changes

The regression is estimated on the sample of 964 European firms. The dependent variables are the cumulative asset, debt, and equity returns during the war period, as well as the change in risk-neutral default probability. The latter is measured by the difference in the average 1-year default probability before and after the start of war. *Exposure to Russia* measures the fractional risk exposure of each firm to Russia based on the StarMine Countries of Risk model. *Leverage* measures the average ratio of total liabilities to implied asset value over the sample period. *Asset volatility* denotes the average asset volatility over the sample period. *Firm size* is the logarithm of total assets (in EUR). *Liquidity* is the ratio of cash & equivalents to total assets. Industry controls are included as dummy variables based on the 2-digit SIC code of each firm. Currency controls are dummy variables based on the currency that stock prices are denominated. Robust standard errors adjusted for heteroskedasticity are displayed in parentheses. Coefficients marked with ***, **, and * are significant at the 1%, 5%, and 10% level.

	(1) Asset return	(2) Equity return	(3) Debt return	(4) Change in default prob.
Exposure to Russia	-0.553***	-1.046***	-0.039	0.313**
	(0.163)	(0.257)	(0.032)	(0.128)
Leverage	0.030*	-0.069***	-0.019***	0.124***
	(0.017)	(0.025)	(0.006)	(0.009)
Asset volatility	0.064	0.021	-0.048***	0.130***
	(0.058)	(0.068)	(0.014)	(0.017)
Firm size	0.002	-0.003	-0.001	-0.000
	(0.002)	(0.003)	(0.001)	(0.001)
Liquidity	0.041*	0.018	0.005	-0.007
	(0.025)	(0.030)	(0.004)	(0.007)
Constant	-0.102*	0.035	0.027**	-0.065***
	(0.059)	(0.077)	(0.013)	(0.021)
Industry controls	✓	✓	✓	✓
Currency controls	✓	✓	✓	✓
Observations	964	964	964	964
Adjusted R^2	0.090	0.157	0.057	0.365

Internet appendix for "Valuation of European firms during the Russia-Ukraine war"

ALEXANDROS BOUGIAS, ATHANASIOS EPISCOPOS and GEORGE N. LELEDAKIS

Abstract. The internet appendix contains additional tables to support the main text. In particular, we provide the summary statistics of the estimated parameters and risk measures implied by the model of Merton (1974) grouped by (i) industry and (ii) currency. Further, we present the summary statistics and correlation matrix for the variables used in the regressions.

Table A1: Estimation results grouped by industry and currency

The table contains the estimation results grouped by industry and currency. *Leverage* measures the average ratio of total liabilities to implied asset value over the sample period. *Asset volatility* denotes the average asset volatility over the sample period. *Asset return* denotes the cumulative return of the implied asset value after the start of war (February 24, 2022 through March 9, 2022). *Equity return* denotes the cumulative return of the observed equity value after the start of war. *Debt return* denotes the cumulative return of the implied debt value after the start of war. Industry classification is based on the 2-digit SIC code of each firm, whereas currency refers to the local currency that stock prices are denominated.

	N	Leverage (%)	Asset volatility (%)	Asset return (%)	Equity return (%)	Debt return (%)
Panel A: Grouped by industry						
Agriculture, Forestry, Fishing	6	16.52	40.68	-5.03	-6.04	-0.67
Mining	38	43.77	29.98	3.32	7.36	-1.86
Construction	39	54.85	17.01	-1.91	-3.91	-0.82
Manufacturing	366	30.87	29.92	-2.48	-4.37	-0.39
Transportation & Public utilities	106	53.51	18.36	0.01	-1.71	-0.46
Wholesale Trade	21	37.61	23.69	-3.47	-5.18	-0.41
Retail trade	56	42.72	22.10	-4.55	-7.81	-0.81
Finance, Insurance and Real Estate	179	70.08	11.19	-1.52	-8.28	-0.20
Services	153	31.28	32.03	-3.22	-5.03	-0.60
Panel B: Grouped by currency						
Danish Krone	37	36.83	26.41	-0.09	-0.79	-0.09
Euro	450	50.05	19.88	-2.64	-6.48	-0.45
Norwegian Krone	57	34.62	37.00	2.61	3.47	-0.71
Swedish Krona	158	30.60	37.00	-1.09	-1.97	-0.44
Swiss Franc	49	37.09	20.22	-2.32	-5.32	-0.03
United Kingdom Pound	213	41.66	22.11	-3.06	-5.50	-0.75

Table A2: Correlation matrix

The correlation matrix is based on the variables used in the regressions of the main text. *Asset return* denotes the cumulative return of the implied asset value after the start of war (February 24, 2022 through March 9, 2022). *Equity return* denotes the cumulative return of the observed equity value after the start of war. *Debt return* denotes the cumulative return of the implied debt value after the start of war. *Change in default probability* measures the difference in the average 1-year risk-neutral default probability before and after the start of war. *Exposure to Russia* measures the fractional risk exposure of each firm to Russia based on the StarMine Countries of Risk model. *Leverage* measures the average ratio of total liabilities to implied asset value over the sample period. *Asset volatility* denotes the average asset volatility over the sample period. *Firm size* is the logarithm of total assets (in EUR). *Liquidity* is the ratio of cash & equivalents to total assets.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Asset return	1.000								
(2)	Equity return	0.855	1.000							
(3)	Debt return	0.136	0.009	1.000						
(4)	Change in default prob.	-0.064	-0.262	-0.370	1.000					
(5)	Exposure to Russia	-0.138	-0.141	-0.010	0.101	1.000				
(6)	Leverage	0.019	-0.234	0.010	0.443	-0.082	1.000			
(7)	Asset volatility	0.100	0.252	-0.146	-0.097	0.019	-0.749	1.000		
(8)	Firm size	-0.050	-0.242	0.076	0.167	0.037	0.663	-0.770	1.000	
(9)	Liquidity	0.092	0.105	-0.062	-0.009	0.041	-0.324	0.492	-0.375	1.000

Table A3: Summary statistics of regression variables

The table contains the summary statistics of the variables used in the regression analysis of the main text. *Asset return* denotes the cumulative return of the implied asset value after the start of war (February 24, 2022 through March 9, 2022). *Equity return* denotes the cumulative return of the observed equity value after the start of war. *Debt return* denotes the cumulative return of the implied debt value after the start of war. *Change in default probability* measures the difference in the average 1-year risk-neutral default probability before and after the start of war. *Exposure to Russia* measures the fractional risk exposure of each firm to Russia based on the StarMine Countries of Risk model. *Leverage* measures the average ratio of total liabilities to implied asset value over the sample period. *Asset volatility* denotes the average asset volatility over the sample period. *Firm size* is the logarithm of total assets (in EUR). *Liquidity* is the ratio of cash & equivalents to total assets.

Variable	N	Mean	SD	Min	Q1	Median	Q3	Max
Asset return (%)	964	-2.05	7.52	-50.66	-5.41	-1.93	0.40	51.35
Equity return (%)	964	-4.66	11.91	-55.76	-11.34	-5.16	0.86	52.43
Debt return (%)	964	-0.50	2.15	-41.67	-0.40	-0.12	-0.10	2.84
Change in default prob. (%)	964	1.80	3.75	-5.68	0.01	0.30	1.78	33.14
Exposure to Russia (%)	964	1.31	1.68	0.00	0.00	0.72	2.15	14.42
Leverage (%)	964	42.93	27.64	0.17	20.05	39.86	62.71	99.88
Asset volatility (%)	964	24.46	17.97	0.41	13.00	20.80	30.41	114.99
Firm size	964	22.37	2.18	7.60	21.18	22.34	23.54	28.59
Liquidity (%)	964	16.19	16.13	0.00	6.03	11.28	20.33	96.03