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War, pandemic, and stock performance: A case of artificial intelligence–adopting firms

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Abstract: Firm performance is affected by extreme events including war and pandemic. In 2020, the COVID-19 pandemic weakened the performance of stock markets worldwide. Two years later, on 24 February 2022, the Russia-Ukraine war started and took a toll on the world economy, pushed up inflation, and increased the risk of severe adverse outcomes. There is a growing number of studies on the severity of stock market responses to the pandemic and the war in different regions and economies. The enormous increase in economic uncertainty has taught business executives valuable lessons about digital transformation and innovation. The IBM Artificial Intelligence (AI) Adoption Index shows a steady increase in global adoption of AI. However, studies regarding the impacts of the war and pandemic on AI-adopting firms are relatively new and scant.

Using data of 231 AI-adopting firms worldwide in developed and emerging markets from January 2013 to April 2022, this paper examines how AI stocks respond to the COVID-19 pandemic and the Russia-Ukraine war. We employ the two-step system Generalized Method of Moments estimation of linear dynamic panel-data model estimation to estimate the firm, market, and extreme event effects on the AI stock performance. Understanding the impacts of different determinants on the success or failure of AI adoption will support firms and investors to manage risks and investment portfolios for sustainable performance.

The results show that AI stocks respond to different extreme events differently. The performance of AI-adopting firms is not severely affected by the COVID-19 pandemic. The impact of the Russia-Ukraine war is more severe than the impact of the COVID-19 pandemic. AI-adopting firms in developed markets outperform those in emerging markets when the war broke out. In emerging markets, large firms benefit more from adopting AI in business than small firms.

Keywords: *Artificial intelligence, AI, war, pandemic, stock performance*

1. INTRODUCTION

Firm performance is affected by extreme events including war and pandemic. In 2020, the COVID-19 pandemic weakened the performance of stock markets worldwide. Two years later, on 24 February 2022, the Russia-Ukraine war started and took a toll on the world economy, pushed up inflation, and increased the risk of adverse outcomes. Military conflicts increase uncertainty which makes investors' perceptions of companies' future profitability more unpredictable and causes fluctuations in stock prices (Brune et al. 2015). There is a growing number of studies that investigate on how the Russia-Ukraine conflict affects firm performance (Boubaker et al. 2022; Boungou and Yatié 2022; Umar et al. 2022; Yousaf et al. 2022). These studies show that the severity of stock market responses to the crisis varies widely among different regions and economies.

The enormous increase in economic uncertainty has taught business executives valuable lessons about digital transformation and innovation. McKendrick (2021) shows that artificial intelligence (AI) can help alleviate skill shortages, boost productivity, deliver new products and services, and provide disruption management during the COVID-19 pandemic. A stream of literature indicates that the potential of AI technology enables organizations to enhance productivity by automating business processes (Duan et al. 2019), reduce uncertainty with improved prediction (Agrawal et al. 2019), and spark business innovation (Babina et al. 2022).

However, it remains unclear how AI stocks react to great uncertainty caused by different extreme events. Empirical studies regarding the performance of AI-adopting firms are relatively scant. Therefore, we investigate the impacts of the Russia-Ukraine war and the COVID-19 pandemic on AI-adopting listed firms. Our study contributes to the literature to what extent AI stocks respond to various exogenous shocks. We explain the influence of different factors (firm and country determinants) on the performance of AI-adopting firms. Understanding the impacts of different determinants on the success or failure of AI adoption will support firms and investors manage risks and investment portfolios for sustainable performance.

Using data of 231 AI-adopting firms from January 2013 to April 2022 and the two-step system Generalized Method of Moments (GMM) estimation of linear dynamic panel-data model, the results show that AI stocks respond to different extreme events differently. The performance of AI-adopting firms is not severely affected by the COVID-19 pandemic. The Russia-Ukraine war creates more severe impact than the COVID-19 pandemic. AI-adopting firms in developed markets outperform those in emerging markets when the war broke out. In emerging markets, large firms benefit more from adopting AI in business than small firms.

The remainder of the paper is organized as follows. Section 2 provides the literature and hypotheses development. Section 3 describes the data and methodology. Section 4 presents the results and discussions. Section 5 concludes the paper.

2. BACKGROUND

Firm performance during the extreme environment is of great importance to stakeholders as it provides valuable insights into how companies are able to navigate extreme events and uncertainty (Kordestani et al 2022). Regardless of the type of business - from a vegetable store to a technology company - the most important indicator of any business performance is profitability. Measurements of business performance vary depending on industries. For example, the typical business performance metrics for professional business services such as Digital, Marketing Agencies, and Construction companies are financial (e.g. billable-to-non-billable hours ratio), customer satisfaction (e.g. estimate-to-actual ratio), and employee satisfaction (e.g. hiring speed). For listed firms, any changes in these metrics will affect their stock prices and returns as a reflection of expected profitability and firm performance.

Studies on the impact of the recent Russia-Ukraine war on stock performance are relatively new. Boubaker et al. (2022) reveal that, on average, the invasion caused negative cumulative abnormal returns (CARs) for global stock market indices. Abbassi et al. (2022) show the heterogenic effects of the war on the stock performance of G7 countries. Companies in Canada and Italy show positive cumulative impacts, whereas Germany, Italy, and the United Kingdom (UK) exhibit negative CARs through the study period from 2 March 2021 to 8 March 2022. Remarkably, smaller firms outperform large firms in G7 stock markets. Firm size and book-to-market ratio are negatively associated with event-induced returns. Boungou and Yatié (2022) conclude that the war negatively affects the world's stock market returns; especially in countries bordering Ukraine and Russia.

The effects of the COVID-19 pandemic on stock market reaction differs from earlier disease outbreaks such as SARS, H1N1, and Ebola (Baker et al. 2020). The adverse effect is more pronounced among smaller firms (Gu et al. 2020; Han and Qian 2020). A number of studies focus on the aggregate impact of COVID-19 on the market performance across countries (Ali et al. 2020; Narayan et al. 2021; Sansa 2020). For instance, the pandemic weakened the performance of stock markets in major economies, including China, Japan, Korea, the

UK, and the United States (US) (Al-Awadhi et al. 2020; Liu 2022). The financial market environment eroded as the COVID-19 spread across geographical and continental boundaries. Even safer commodities like gold suffered when COVID-19 spread to the US (Ali et al. 2020). Firms with less leverage and greater financial flexibility, profitability and Corporate Social Responsibility activity show greater resilience during the COVID-19 pandemic (Ding et al. 2020; Fahlenbrach et al. 2020).

AI is defined as the theory and advancement of computer systems that can perform tasks that traditionally involve human intelligence, including visual perception, speech recognition, decision-making, and language processing (Deloitte 2017). AI drives business capability in challenging markets (Chen and Biswas 2021), maintains competitiveness (Agrawal et al. 2019; Lakshmi and Bahli 2020), makes better-informed decisions (Makridakis 2017; Mihet and Philippon 2019), enhances profitability through cost reduction and operating efficiency improvement (Brynjolfsson and McElheran 2016; Lakshmi and Bahli 2020). Using text analysis of AI product announcements, Xu et al. (2021) demonstrate that firms engaged in AI before the pandemic were less adversely affected in 2020. A recent study by Ho et al. (2022) compare the performance of the AI stock market indices to the traditional stock market indices. The findings indicate that AI stock markets were less hit and recovered more quickly than the conventional stock markets during the COVID-19 pandemic.

Several studies offer mixed results on the relationship between AI application and firm performance. For instance, using AI investment announcements of 62 listed firms, Lui et al. (2022) conclude that the AI companies' stock prices dropped by 1.77 per cent on the announcement day. Fotheringham and Wiles (2022) reveal that firms' announcements of the implementation of AI chatbots generate an abnormal return of 0.22 per cent, demonstrating that investors favor this practice. Kordestani et al. (2022) demonstrate that blockchain-based companies' share prices have higher sensitivity and slower loss recovery than non-blockchain-based counterparts during the COVID-19 pandemic. Babina et al. (2022) reveal that AI-investing firms experience higher growth in sales, employment, and market valuations through increased product innovation.

Overall, there is an increasing number of studies investigating firm performance in the context of COVID-19 and the Russia-Ukraine war from various perspectives. These studies show heterogeneous impacts on various stock markets, highlighting the need for further empirical analysis in different research contexts. To the best of our knowledge, no study has compared the impacts of the COVID-19 pandemic and the Russia-Ukraine war on the performance of AI-adopting listed firms. The adoption of AI technologies continues apace, and this raises the questions whether and how investments in AI technologies assist businesses during extreme events. It is important to investigate the determinants (firm and market factors) of AI-listed firm performance that can help stakeholders address the benefits and challenges in implementing AI and prepare for future risks. Therefore, we hypothesize the following relationships:

H1: The COVID-19 pandemic and the Russia-Ukraine war have no impact on the performance of AI stocks.
H2: AI stocks in developed markets outperform those in emerging markets, especially during extreme events.
H3: Large firms benefit more from adopting AI in business than small firms.

3. METHODOLOGY

To screen all stocks of AI-adopted listed firms available on Bloomberg, we first search for AI stock market indices and select the indices whose members' data we can access. We obtain six AI stock indices, FDSAINTR, IBOTZN2, SGMDROBO, SOAIESGN, SOLKBOTN, and STXAIV, with 274 members from January 2013 to April 2022. After removing duplicates among the six indices, we obtain a final sample of 231 AI stocks listed in 21 markets. To measure the performance of AI-adopting firms, the average day-to-day stock return at the end of each month (RET) is used and collected from Bloomberg. To examine the impacts of the COVID-19 pandemic and the Russia-Ukraine war on AI stocks, we use the following dynamic panel model with $RET_{i,t-1}$ as the momentum factor (Jegadeesh and Timan 1993; Fama and French 2012):

$$RET_{it} = \alpha_0 + \alpha_1 RET_{i,t-1} + \alpha_2 RF_t + \beta_j FF_{j,it} + \gamma_k FIRM_{k,it} + \theta_l CTRY_{l,it} + \varphi_1 COVID_t + \varphi_2 COVID_t ECO_i + \varphi_3 WAR_t + \varphi_4 WAR_t ECO_i + \varepsilon_{it} \quad (1)$$

where: RET_{it} is the average daily return of company i at the end of month t; $RET_{i,t-1}$ is the momentum factor; RF is risk-free rate of return; FF_j is a vector of control variable j (five Fama-French factors of CMA, HML, RP, RMW, SMB); $FIRM_k$ is a vector of firm characteristic variable k (SIZE, LVRG, TANG, CH, and CF); $CTRY_l$ is a vector of country characteristic variable l (FIN, WUI, WPUI, ECO); $COVID$ and WAR are two dummy variables showing the extreme events of the COVID-19 pandemic and Russia-Ukraine war, respectively; $COVID_t ECO_i$ and $WAR_t ECO_i$ are the interaction terms between the two extreme events and market effect; ε is the error term; and α, β, γ, θ, and φ are the estimated parameters.

Based on Sharpe's (1964) Capital Asset Pricing Model (CAPM), the monthly risk-free rate of return (RF) is added to control for expected returns. Applying the five-factor model of Fama and French (FF) (Fama and French, 2015), we use data from the Kenneth R. French data library (French 2022) that consist of the *Fama/French Developed-Emerging 5 Factors* monthly returns. The five FF factors are CMA (Conservative Minus Aggressive), HML (High Minus Low), RP (Risk Premium), RMW (Robust Minus Weak), and SMB (Small Minus Big). Table 1 presents the variables' descriptions and data sources.

Table 1. Variables description and data sources

Variable	Name	Variable type	Description	Source
RET	Return	Dependent	Monthly average day-to-day total return.	Bloomberg
RF	Risk-free rate of return	Control	Monthly Treasury Bill return.	French (2022)
CMA	Conservative Minus Aggressive	Control	Difference in monthly average return between the two conservative investment portfolios and the two aggressive investment portfolios.	French (2022)
HML	High Minus Low	Control	Difference in monthly average return between the two value portfolios and the two growth portfolios.	French (2022)
RP	Risk Premium	Control	Monthly excess return on the market.	French (2022)
RMW	Robust Minus Weak	Control	Difference in monthly average return between the two robust operating profitability portfolios and the two weak operating profitability portfolios.	French (2022)
SMB	Small Minus Big	Control	Difference in monthly average return between the nine small stock portfolios and the nine big stock portfolios.	French (2022)
SIZE	Firm size	Firm effect	Natural logarithm of market capitalization.	Bloomberg
LVRG	Leverage	Firm effect	Monthly net debt to free cash flow to firm ratio.	Bloomberg
TANG	Tangibility	Firm effect	Monthly tangible equity to tangible assets ratio.	Bloomberg
CH	Cash holding	Firm effect	Monthly cash generated to cash required ratio.	Bloomberg
CF	Cash flow	Firm effect	Monthly cash flow to net income ratio.	Bloomberg
FIN	Financial advancement	Country effect	Percentage of monthly stock market capitalization to GDP.	Bloomberg
ECO	Economy	Country effect	Dummy variable = 1 for developed market, 0 otherwise.	WB (2021)[1]
WUI	World Uncertainty Index	Country effect	Aggregate uncertainty at the country level. Quarterly data are applied to all months within that quarter.	WUI (2022)
WPUI	World Pandemic Uncertainty Index	Country effect	Pandemic uncertainty at the country level. Quarterly data are applied to all months within that quarter.	WPUI (2022)
COVID	COVID Pandemic	Event effect	Dummy variable = 1 from 03/2020 to 04/2022, 0 otherwise.	WHO (2020)[1]
WAR	Russia-Ukraine War	Event effect	Dummy variable = 1 from 02/2022 to 04/2022, 0 otherwise.	European Council (2022)[1]

Note: [1] Authors' calculation.

To capture the firm effect, following Hu and Zhang (2021), we use firm size (SIZE), leverage (LVRG), tangibility (TANG), cash holding (CH), and cash flow (CF) to control for firm characteristics. For the country effect, we consider a series of country-specific variables that may absorb the adverse effect of external shocks. First, advanced financial markets can mitigate financial constraints and provide cushions against unexpected shocks. Therefore, we use the percentage of monthly stock market capitalization to GDP collected from Bloomberg as a measure of financial advance. Second, given the performance of firms can be influenced by government actions and economic policies (Demir and Ersan 2017; Iqbal et al. 2020), we include the World Uncertainty Index (WUI) and World Pandemic Uncertainty Index (WPUI) of Ahir et al. (2018) to reflect the extent of uncertainty from government policies and health-related events during the study period.

To examine the impact of extreme events on the performance of AI stocks, we use two dummy variables, COVID and WAR. The World Health Organization (WHO) announced the COVID-19 outbreak as a pandemic on 11 March 2020 (WHO 2020). Therefore, COVID equals 1 from March 2020 to April 2022, otherwise 0. The Russia-Ukraine war started on 24 February 2022 (European Council 2022). Thus, WAR equals 1 from February 2022 to April 2022, otherwise 0 (see Table 1). The descriptive statistics and correlation matrix of the variables are available on request.

The dynamic model of equation (1) may encounter endogenous issues (Arellano and Bover 1995; Blundell and Bond 1998), incorrect standard errors (Windmeijer 2005), incorrect estimates and incorrect results of over-identification tests caused by omitted coefficients (Kripfganz 2020). To minimize any potential risk in estimating equation (1), we use the two-step system Generalized Method of Moments estimation of linear dynamic panel-data model DPDGMM (Kripfganz 2019; 2020). ECO, COVID, and WAR are time-invariant variables in our models and their coefficients can be over-identified. Therefore, the DPDGMM is used to avoid imprecise coefficients (see Kripfganz (2019)). The two-step sequential (two-stage) estimation of linear panel-data models (SELPDM) (Kripfganz and Schwarz 2019) is used for robustness check. The SELPDM estimates (available on request) show that our results are robust. We use Arellano and Bond (1991) tests to test for the

absence of higher-order serial correlation and Hansen (1982) tests to test the validity of the over-identifying restrictions.

4. RESULT

Table 2 present the regression results. The results show that the determinants of the performance of AI stocks are the risk-free rate, five FF factors, and Russian-Ukraine war. Although the five FF factors affect the AI stock performance, in general, AI stock returns are not affected by HML in developed markets and are not influenced by CMA in emerging markets. We also find that, in emerging markets, size, cash holding, cash flow, financial advancement, WUI, and COVID-19 are additional factors determining the performance of AI stocks.

Table 2. Regression results of extreme event effect

Variable	(1) Baseline	(2) Event effect (All)	(3) Event effect (ECO=1)	(4) Event effect (ECO=0)	(5) Event effect (ECO difference)
L.RET	-0.0553**	-0.0617**	-0.0525*	-0.0128	-0.0606**
	(0.0268)	(0.0277)	(0.0293)	(0.0444)	(0.0277)
RF	4.922	-11.30	6.199	-64.42*	-8.069
	(3.347)	(11.31)	(11.58)	(33.81)	(11.22)
CMA	-0.451**	-0.0302	-0.866***	2.029***	-0.150
	(0.221)	(0.270)	(0.245)	(0.685)	(0.264)
HML	-0.108	-0.349*	0.183	-2.844***	-0.287
	(0.152)	(0.191)	(0.173)	(0.410)	(0.188)
RP	1.123***	1.034***	1.001***	1.453***	1.030***
	(0.0688)	(0.0806)	(0.0645)	(0.515)	(0.0804)
RMW	0.225	0.152	0.139	1.300	0.178
	(0.194)	(0.211)	(0.187)	(0.891)	(0.208)
SMB	0.363**	0.489***	0.130	1.258*	0.472***
	(0.173)	(0.183)	(0.157)	(0.678)	(0.183)
SIZE	-0.0522	0.0171	-0.135	1.344***	0.00877
	(0.115)	(0.122)	(0.114)	(0.499)	(0.121)
LVRG	0.00210	0.00171	-0.000410	0.00338	0.00171
	(0.00342)	(0.00329)	(0.00386)	(0.00409)	(0.00325)
TANG	0.00953	0.00878	0.00639	0.00809	0.00898
	(0.00756)	(0.00746)	(0.00722)	(0.0404)	(0.00755)
CH	-0.000202	-0.000257	-0.000456	0.0348***	-0.000240
	(0.000575)	(0.000592)	(0.000575)	(0.0122)	(0.000581)
CF	0.0131	0.0103	0.00668	0.00604	0.00960
	(0.0103)	(0.00947)	(0.00885)	(0.0117)	(0.00907)
FIN		0.762	0.555	6.014***	0.784
		(0.559)	(0.559)	(2.290)	(0.559)
WUI		-3.439**	0.165	-7.812	-3.019*
		(1.577)	(1.591)	(6.970)	(1.628)
WPUI		0.00665	-0.0288	-0.0886	0.00152
		(0.0242)	(0.0259)	(0.0932)	(0.0245)
COVID		-2.899*	0.630	-6.875	0.253
		(1.719)	(1.741)	(4.358)	(3.022)
WAR		-4.350***	-2.181**	-4.040*	-7.638***
		(0.801)	(0.872)	(2.275)	(1.172)
ECO		-0.882			0.819
		(1.108)			(2.159)
1.ECO*1.COVID					-2.842
					(2.756)
1.ECO*1.WAR					4.530***
					(1.389)
Constant	1.396	4.475*	1.389	-2.122	2.266
	(1.281)	(2.503)	(2.635)	(8.617)	(3.078)
Observations	3,180	3,180	2,716	464	3,180
Number of id	145	145	104	41	145
Number of instruments	14	20	19	19	22
AR(2) (p-value)	0.084	0.8075	0.8295	0.8752	0.81
AR(3) (p-value)	0.1581	0.6785	0.6506	0.9174	0.6854
Hansen test (p-value)	0.119	0.0866	0.2141	0.1038	0.0871

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations

For the extreme event effect (H1), we find a weak impact of COVID-19 on the performance of AI stocks in all markets. For example, the coefficients of COVID in model (2) in Table 2, is significant only at 10%, which

means that the COVID-19 pandemic does not severely affect AI firms. When considering WPUI, the uncertainty caused by health-related events, all coefficients of WPUI are insignificant. This confirms that H1 is correct for health-related events; AI stocks are not significantly exposed to pandemic risk. In contrast, we find that the Russia-Ukraine war severely affects the performance of AI stocks in all markets, which means that H1 is rejected regarding a war event. The coefficients of WAR in models (2)-(5) show that the negative impact of war is greater in magnitude and significance. The extent of the impact is over -4% for the whole sample. All coefficients of WAR are significant at the 1% level. We conclude that AI stocks respond to different extreme events differently. The impact of war is more severe than the impact of the COVID-19 pandemic.

Interestingly, convincing evidence of a country effect (H2) exists when considering the war shock. No difference in the impact of COVID-19 between developed and emerging markets is found. However, the results in models (3) and (4) in Table 2, show that the war shock effect is much lower in developed markets than emerging markets (-2.2% and -4%, respectively). Model (5) shows the coefficients of the interaction term, 1.ECO*1.WAR, are positive and significant (about 4.5% at the 1% level), confirming the different effect of war on the performance of AI stocks in different stock markets. We conclude that the impact of war on AI stock performance in developed markets is less severe than in emerging markets. For the firm size effect (H3), we find strong evidence that large firms in emerging markets benefit more from adopting AI in business than small firms. No evidence of an effect of firm size is found in developed markets (see the coefficient values of SIZE in Table 2). Therefore, H3 is accepted for emerging markets.

5. CONCLUSION

This study investigates the performance of 231 AI stocks worldwide in developed and emerging markets from January 2013 to April 2022. Using the two-step system GMM estimation of linear dynamic panel-data model, we estimate the firm, market, and extreme event effects on the AI stock performance. The results show that the performance of AI-adopted firms is not severely affected by the COVID-19 shock. The risk-free rate, five FF factors, and war shock determine the performance of AI stocks. AI stocks in developed markets outperform AI stocks in emerging markets during extreme events related to wars or international conflicts. Our findings contribute to the underexplored literature on the benefits of adopting AI in firms using data at the firm level on the equity market. This is the first study to investigate how pandemic and war risks affect the performance of AI stocks. We add new empirical evidence on the impacts of different determinants on the success and failure of firms' AI adoption in different markets.

We did not examine all AI stocks in the global equity market because of data limitation. We include the AI stocks of only six AI stock market indices. Future research can enlarge the sample size to all available AI stocks to obtain greater data coverage. Future study can expand the study period to 12 months or longer for better observation and conclusion on the AI firm performance and war shock. Further, it is important to compare the performance between AI stocks and conventional stocks in different industries to understand how firms can use AI to embrace exogenous shocks. We used the two-step system GMM estimation of linear dynamic panel-data model. Future study can incorporate nonlinear moment conditions in the estimation.

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