Earthquakes in Chile-Peru and the price of copper

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Abstract

Chile and Peru produce 40% of the world's copper. In parallel, they are both seismic countries, affecting copper stocks and therefore prices. Global warming will increase the demand for copper as well as the number of earthquakes, making it necessary to investigate the relationship between these phenomena. Our estimates show that earthquakes in Chile and Peru generate positive cumulative abnormal returns greater than 2%, but geographical earthquake coverage and the level of available copper inventory also play a role. In the event of an earthquake, actions are taken both in the financial market and in the physical copper market, which generates positive abnormal returns. The interaction between both can increase the short-term price volatility caused by the uncertainty of the effects of the earthquake. Investors can take actions to mitigate this volatility by controlling related news on days 1 and 2 of the event.

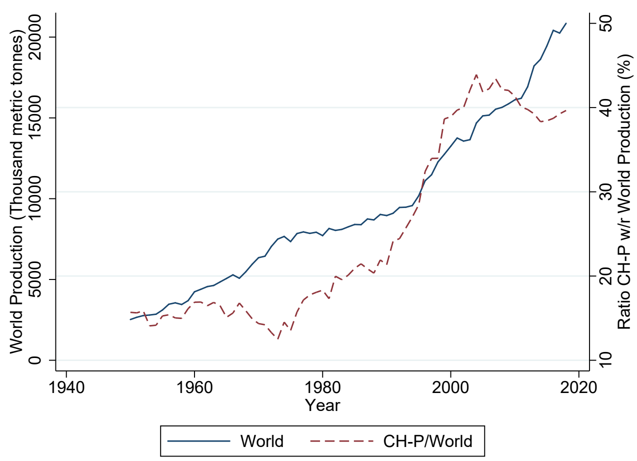
JEL codes: G11, G12, G15, Q54
Keywords: Copper, earthquakes, event studies.

I Introduction

Copper is a mineral that is used as a productive input in the infrastructure and construction industries (Bessler and Wolff, 2015) and also in investment portfolios (Daskalaki and Skiadopoulos, 2011; Erb and Harvey, 2006). Natural disasters leave observable effects on stock markets (Cao et al., 2015; Carter and Simkins, 2004; Worthington* and Valadkhani, 2004) and commodities such as oil (Fink et al., 2010; Orbaneja et al., 2018) and gold (Wang et al., 2019). There is not much information for copper, in this regard, despite the fact that estimates of copper demand suggest that, in the worst case, demand will be three times higher than current levels by the end of the 21st century (Schipper et al., 2018).

In the year 2000, copper production quadrupled with respect to levels before the 80s. Within the same period, Chile and Peru boasted more than 40% of world production, as can be seen in Figure 1. In fact, currently, Chile and Peru are the largest copper producers in the world. On the other hand, both countries are characterized by being highly seismic countries (Giesecke et al., 2004), concentrating 25% of the earthquakes of greater Richter magnitude between 2005-2020 (see, Table 2, Annex). When the mining companies in these countries have seen an impact on their copper production and, therefore, stock levels, the price of this metal also changes (Bieritz and Mönnig, 2018; Del Águila et al., 2017). Therefore, after experiencing an earthquake, mining companies should expect potential variations in copper production, which in turn would affect the price of copper due to high levels of uncertainty in the financial market related to copper (Guzmán and Silva, 2018).

Figure 1: World copper production versus participation of Chile and Peru.



Note: The solid line represents the annual world production from 1950 to 2020 (Left axis). The dashed line represents the percentage of world production covered by Chile and Peru (right axis). Source: Prepared by COCHILCO and MINEM.

Research indicates that a 1.5°C rise in temperature will cause an increase in demand for copper, possibly driven by its use in renewable energy plants and electric vehicles (Watari et al., 2022). At the same time, this global warming will increase natural disasters such as earthquakes (Berlemann and Eurich, 2021), affecting copper stocks. Therefore, our research objective is to provide evidence of how the coverage and the level of inventory are involved in the returns of copper when its largest producers, located in Chile and Peru, face an earthquake. A telluric movement can cause irreparable damage to copper mining companies, so, in the short term, agents will have incomplete information about the real effects of the earthquake. This causes a rise in copper prices, generating positive abnormal returns.

Using the event study methodology (Binder, 1985; Karafiath, 1988; Malatesta, 1986), we found evidence that suggests that earthquakes of greater magnitude on the Richter scale[1], generate positive abnormal returns of more than 2%. We also find evidence that these abnormal returns are more affected when the earthquake is located on the shared border between Chile and Peru, also having a larger fluctuating impact on available copper reserves.

II Empirical Strategy

II.1 Data

We use the emergency database (EM-DAT) of the Center for Research on the Epidemiology of Disasters (CRED) to identify the earthquakes that occurred in Chile and Peru. These are detailed in Table 3 (see Annex). Copper prices and inventories are obtained from the Chilean Copper Commission[2] (COCHILCO) of the Chilean Ministry of Mining and the Ministry of Energy and Mines of Peru[3] (MINEM), which restricted the research period from 2005 to 2020 in order to include daily inventory levels in estimates. We also turn to the Federal Reserve Bank of St. Louis (FRED) to include controls related to these types of estimates.

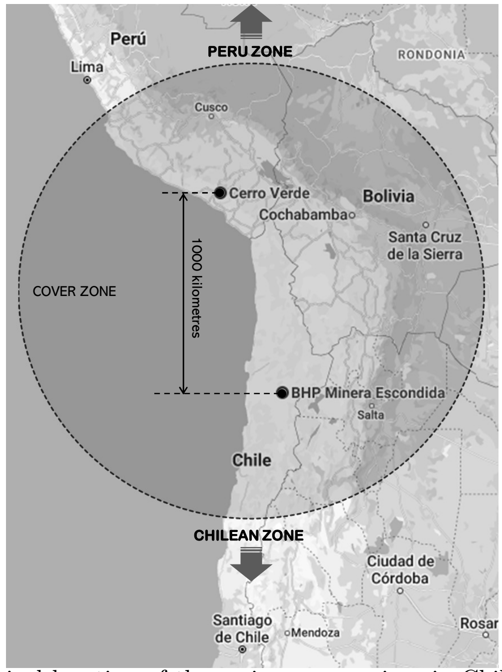
According to the National Seismological Centre (NSC) of the University of Chile, great earthquakes are those of magnitude 7 or higher on the Richter scalehttps://www.sismologia.cl/informacion/grandes-terremotos.html, on the other hand, it is considered that earthquakes of this magnitude can cause damage over large areas, which is why this type of telluric movement should be on the radar of investors. On the other hand, we note that the coverage of some of these earthquakes simultaneously affects copper mines in Chile and Peru, being one thousand kilometres apart, comparable to the distance between the states of New York and South Carolina in the United States or between the city of Paris (France) and Berlin (Germany) in Europe. The "cover zone" region sets its perimeter on the basis that the distance covered by the earthquake is less than 20 times its amplitude, causing the earthquake to affect both mines simultaneously, as described in Figure 2. The region outside the "cover zone" specifies the location where earthquakes only influence one of the mines.

[1]The Richter seismological scale is an arbitrary logarithmic scale that assigns a number to quantify the energy released by an earthquake. It depends on the duration and amplitude of the seismic waves..

[2]https://www.cochilco.cl/Paginas/Inicio.aspx

[3]https://www.gob.pe/minem

Figure 2: Geographical distribution of copper mining companies in Chile-Peru



Note: The geographical location of the main copper mines in Chile-Peru is described. They are located at a distance equivalent to that between New York and South Carolina in the United States, or between Paris and Berlin in Europe. Based on the amplitude and magnitude of the earthquake we define the cover zone, which indicates the area where the earthquakes affect both mines. We then established the region where the earthquakes only affect the copper mining company in Peru (Peru Zone) and the region where they only affect the copper mining company in Chile (Chilean Zone). Source: Own elaboration using google maps.

II.2 Model

The model described in Equation (1) shows the behavior of copper returns, where the days that make up the event window are individualized. $s = 0$ is the first business day on which the earthquake occurred. For its estimation, the strategy described by Karafiath (1988), Binder (1985) and Malatesta (1986), was used: the event window is between days -1 to $+5$. The choice of a window 1 day prior to the event is to illustrate the great change in magnitude obtained with respect to the day of the event. The control estimation period (normal), is between lags 60 to 2 prior to the event.

$$R_t = \alpha_y + \alpha_e + \beta_1 \cdot R_{t-1} + \beta_2 \cdot RM_t + \beta_3 \cdot \mathbf{X}_t + \sum_{s=-1}^{5} \theta_s \cdot E_{s,t} + \varepsilon_t \tag{1}$$

Equation (1) includes R_t , which is the continuous return of copper prices. R_{t-1} is the first lag of this return as a predictor, which seeks to correct the momentum effect present in commodities (Zaremba et al., 2019). RM_t is the market return created with the $S\&P500$ and $E_{s,t}$ t is a binary variable that takes value 1 for day s in the window $[-1, +5]$ del eventoof the event, accompanied by the interest coefficient θ_s, which represents the "*abnormal return*" (AR) for each day of the event, such that $\sum_{s=-1}^{+5} \theta_s$ represents the "*cumulative abnormal returns*" (CARs) for the various windows of the event. For estimation purposes, we also control for the fixed effect of the event and year, and the errors will also be grouped by event.

Following research of this type, we also include the VIX (Chicago Board Options Exchange Market Volatility Index) that allows us to measure the uncertainty of the global economy. We expect a negative relationship with commodity prices (Byrne et al., 2013). BDI (Baltic Dry Index) represents the entire maritime freight market as an approximation of global economic growth, since maritime trade constitutes 90% of world trade, including metallic raw materials (Bandyopadhyay and Rajib, 2021). The daily dollar index, $Dollar\_Index$, shows a negative relationship with copper returns (Yin and Han, 2013). We also include the exchange rate of the Chilean peso with respect to the dollar, Ex_Chile, since a greater entry of dollars due to the higher price of copper would cause the exchange rate to appreciate (Pedersen et al., 2015; Spilimbergo, 2002). As a result, we would expect a negative relationship with copper returns. This set of controls is represented in the vector $\mathbf{X}_t$ of the model described in Equation (1).

$$R_t = \alpha_y + \alpha_e + \beta_1 \cdot R_{t-1} + \beta_2 \cdot RM_t + \beta_3 \cdot \mathbf{X}_t + \sum_{s=-1}^{5} (\theta_s \cdot E_{s,t} + \lambda_s \cdot E_{s,t} \cdot D_{s,t}) + \varepsilon_t \tag{2}$$

The earthquakes that occur within the shared border between the large mining companies of Chile and Peru should, logically, cause a greater rise in copper prices, compared to those that affect the mining companies of a single country. For this reason, we include an interactive variable that considers the coverage of the earthquake among the large mining companies ($Cover$). This is represented by the binary variable D, which takes the value 1 when their distance is less than 20 times the amplitude of the seismic waves, in other words, when the earthquake affected the mining companies of the two countries simultaneously and the value 0 when it affected only one country. This is described in Equation (2), where $\sum_{s=-1}^{+5} \lambda_s$ is the excess return produced by greater geographical earthquake coverage.

$$R_t = \alpha_y + \alpha_e + \beta_1 \cdot R_{t-1} + \beta_2 \cdot RM_t + \beta_3 \cdot \mathbf{X}_t + \beta_4 \cdot q_t + \sum_{s=-1}^{5} (\theta_s \cdot E_{s,t} + \phi_s \cdot E_{s,t} \cdot q_{s,t}) + \varepsilon_t \tag{3}$$

When large copper mining companies suffer an earthquake, their investors may overestimate the damage caused by it, which, in turn, would cause an increase in both the demand and the price of copper. If earthquakes were predictable, these increases would be more controlled with the use of reserves ($Stock$). As they are not predictable, they create uncertainty for copper returns related to stocks. To examine this phenomenon, we include, as a control variable, the total daily copper inventory belonging to the London Metal Exchange (LME), COMEX and the Shanghai Futures Exchange (SHFE), which is represented by the variable q in Equation (3), which is described as a continuous percentage daily rate that is also evaluated interactively. $\sum_{s=-1}^{+5} \phi_s$ is the cumulative excess return due to the use of available inventories when an earthquake occurs.

III Results

Our estimates show that, if the large copper mining companies in Chile and Peru suffer an earthquake considered to be of greater magnitude, positive abnormal returns are generated. For the day of the event the cumulative effect is almost 2% with respect to the day before, as shown in $CAR[-1, 0]$ in the *Base* column of Table 1, reaching a maximum of 2.47% in the window $CAR[-1,+1]$ of the same column. When widening the window, the cumulative effect returns to zero, demonstrating that investors react quickly by taking steps to mitigate the effects of the earthquake, as observed in Figure 3.a.

The estimates of the CARs for Equation (2) are found in the *Cover* column of Table 1, which shows us how investors act differently when it comes to covering the earthquake. For example, if the earthquake occurs on the border between Chile and Peru, one day after the event it will have 1.23% more abnormal return than if it occurred in the mining companies of a single country (see *Cover*, Table 4, Annex). This could explain why the $CAR[-1,+1]$ remains within 2% but the result is not significant, as shown by the confidence intervals of the CAR in Figure 3.b.

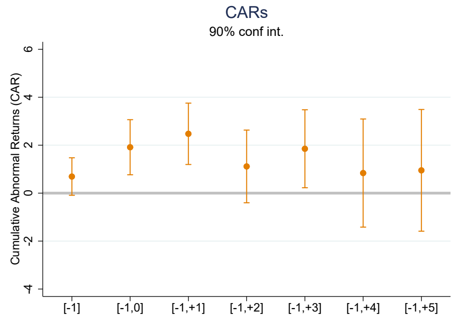
Table 1: CARs for earthquakes Chile-Peru.

CAR	Base	Cover	Stock
$[-1]$	0.6917	0.1345	0.4431
	(1.4551)	(0.4461)	(0.8116)
$[-1,0]$	1.9145***	2.3353*	2.0381***
	(2.7396)	(1.8352)	(2.8312)
$[-1,+1]$	2.4746***	2.1377	2.6588***
	(3.1808)	(1.3852)	(3.9513)
$[-1,+2]$	1.1138	1.1169	1.1046
	(1.2084)	(0.4873)	(1.2279)
$[-1,+3]$	1.8506*	1.5422	2.0270***
	(1.8717)	(0.7319)	(3.2052)
$[-1,+4]$	0.8377	0.3162	0.2139
	(0.6112)	(0.1380)	(0.1903)
$[-1,+5]$	0.9506	0.8766	0.3505
	(0.6161)	(0.3682)	(0.2285)
Observations	403	403	403

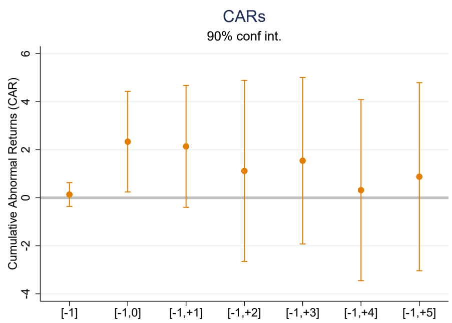
Note: The table reports the estimates of the CARs for the study of earthquake events in Chile and Peru for the period 2005-2020. The *Base* column shows the CARs for Equation (1), the *Cover* column corresponds to the CARs for Equation (2), while *Stock* refers to the CARs for Equation (3). All estimates control for the event and year fixed effects. The estimates correspond to $CAR = \sum_{s=-1}^{+5} \theta_s$ for various windows of the event. The estimates are made with clustering event errors. Source: Own production. Standard error in parentheses. */**/*** significant at 10%/5%/1%, respectively.

The news that the most important copper producers have suffered an earthquake generates such uncertainty that copper prices suffer upward pressure. Investors looking for stable copper prices should therefore take actions to minimize the immediate news. Our results suggest that the actions of investors are the reason for the CAR window not exceeding more than one day after the earthquake $CAR[-1,+1] = 2.66\%$ (see *Stock* column, Table 1) and then returning to zero, as seen in Figure 3.c. At the same time, investors take actions in the physical market of the metal, resorting to available copper reserves, generating excess returns that change in magnitude, sign and significance (see Column [5] of Table 4, Annex).

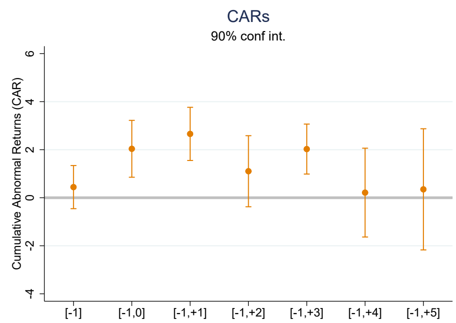
Figure 3: CARs de terremotos entre 2005 al 2020.



(a) Base



(b) Cover



(c) Stock

Note: The vertical axis shows the CAR in percentage points and with its 90% confidence interval. The horizontal axis indicates the size of the windows, which increase to the right. Graph (a) shows the representation of the CARs for the *Base* model, Graph (b) shows the estimated CARs for the *Cover* case and Graph (c) shows the estimates of the CARs for the *Stock* case. Source: Own production.

IV Conclusions

Even if copper is used more efficiently or recycled, its demand will inevitably increase progressively (Watari et al., 2022) both in frequency and severity due to climate change (Berlemann and Eurich, 2021), as will natural disasters such as earthquakes. Therefore, our research increases the limited existing literature on this metal as an actor in financial markets, exploring the response of its returns to an earthquake. We find solid empirical evidence in favor of the hypothesis that the uncertainty caused by earthquakes of greater magnitude in mining companies located in Chile-Peru generates positive cumulative abnormal returns of over 2%, based on a volume of 40% of copper production, worldwide.

Our evidence also shows that, if the earthquake occurs on the border shared by Chile and Peru, the abnormal return one day after the event is 1.23% higher than if it only affected one country. This suggests to us that investors should take preliminary measures on the day of the earthquake, which are then modified or supplemented depending on the epicenter and coverage of the earthquake. We note that the information that investors internalize not only refers to the magnitude of the earthquake, but also to its coverage, generating actions that take place after the event.

Finally, we find that the $CAR[-1, +1]$ reaches 2.66% at the time of the earthquake, when we control for daily copper inventory. When interacting with the days of the telluric event, this produces additional abnormal returns that are positive on the day of the event but then turn negative. It is likely that this behavior is the result of the actions taken to mitigate the unexpected consequences of the earthquake, which will affect the financial market. For this reason, we believe that, when facing an earthquake affecting the large mining companies of Chile and Peru, there are actions in the financial and physical market for this metal that will surely interact, potentially amplifying the abnormal effects on return. As a result, possible extensions to this research could be to study the actions that are taken when this type of event occurs and their success, as they may produce additional volatility to that of the earthquake.

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Compliance with Ethical Standards **Potential conflicts of interest**: None.

V Annex

Table 2: Earthquakes considered epic or cataclysmic on the planet.

#	Date	Country	Scale Richter
1	11-03-2011	Japan	9.1
2	27-02-2010	**Chile**	8.8
3	11-04-2012	Sumatra	8.6
4	28-03-2005	Indonesia	8.6
5	12-09-2007	Indonesia	8.4
6	16-09-2015	**Chile**	8.3
7	15-11-2006	Kuril Islands	8.3
8	24-05-2013	Sea of Okhotsk	8.3
9	19-08-2018	Fiji	8.2
10	08-09-2017	Mexico	8.2
11	11-04-2012	Sumatra	8.2
12	01-04-2014	**Chile**	8.2
13	01-04-2007	Solomon Islands	8.1
14	13-01-2007	Kuril Islands	8.1
15	29-09-2009	Samoa	8.1
16	03-05-2006	Tonga	8.0
17	15-08-2007	**Peru**	8.0
18	26-05-2019	**Peru**	8.0
19	06-02-2013	Solomon Islands	8.0
20	22-01-2017	Papua New Guinea	7.9

Note: A summary of the earthquakes with a magnitude greater than 7.9 on the Richter scale, considered epic or cataclysmic, that occurred on the planet between 2005-2020. 25% of these earthquakes occurred in the Chile-Peru region.

Table 3: List of earthquakes that occurred in Chile and Peru, 2005-2020.

#	Date	Location	Country	Scale	km to Peru	km to Chile	Cover
1	13-06-2005	Iquique	Chile	7.8	395.67	457.17	Yes
2	26-09-2005	Moyobamba	Peru	7.5	1291.13	2104.64	–
3	15-08-2007	Pisco	Peru	8.0	669.66	1280.94	No
4	14-11-2007	Antofagasta	Chile	7.7	700.16	151.53	Yes
5	27-02-2010	Biobio	Chile	8.8	2561.8	1790.89	No
6	25-09-2013	Arequipa	Peru	7.0	376.22	984.7	–
7	01-04-2014	Arica	Chile	8.2	350.37	445.21	Yes
8	16-09-2015	Coquimbo	Chile	8.3	1669.53	895.91	No
9	14-01-2018	Yauca	Peru	7.1	340.46	984.7	–
10	26-01-2019	Libertad	Peru	8.0	1310.19	2074.24	No

Note: The list of earthquakes in Chile and Peru of greater magnitude that occurred in Chile and Peru for the period 2005-2020. It includes the date of the earthquake, the country considered "of origin", the magnitude in Richter scale, the distance from the epicenter to each country, using the *Escondida* mining company for Chile and *Cerro Verde II* for Peru as reference. The *Cover* column indicates the earthquakes where their impact distance should be less than 20 times the amplitude of the seismic waves, discarding earthquakes 2, 6 and 9. It indicates *Yes* when the earthquake occurred on the common border between Chile and Peru, and with a *No*, when it affected only one country (see *cover zone* in Figure 2).

Table 4: Estimates of the abnormal returns (E) of the earthquake event in Chile and Peru

Variables	*Base* [1]	*Cover* [2]	[3]	*Stock* [4]	[5]
R_{t-1}	-0.1587	-0.1464		-0.1713	
	(-1.3391)	(-1.1403)		(-1.4773)	
RM_t	-0.0837	-0.1234		-0.0778	
	(-0.4439)	(-0.6579)		(-0.3861)	
VIX	-0.0381*	-0.0417*		-0.0396	
	(-2.0914)	(-2.2505)		(-1.9506)	
BDI	0.0425*	0.0427*		0.0590*	
	(1.9597)	(2.2615)		(2.3293)	
Dolar_index	-0.5954	-0.5966		-0.6019	
	(-1.7058)	(-1.6803)		(-1.9240)	
Ex_Chile	-0.4315**	-0.4400**		-0.4662**	
	(-2.5941)	(-2.5420)		(-2.9057)	
Stock				-0.0795**	
				(-3.2654)	
E_{-1}	0.6917	0.1345	1.2908	0.4431	-0.4012
	(1.4551)	(0.4461)	(1.4491)	(0.8116)	(-0.8875)
E_0	1.2229	2.2008	-1.6263	1.5950*	1.2123
	(1.9230)	(1.8302)	(-1.1866)	(2.2698)	(1.6964)
E_{+1}	0.5600	-0.1976	1.2365***	0.6207**	-0.6865***
	(1.5199)	(-0.5475)	(4.0387)	(2.5725)	(-4.1236)
E_{+2}	-1.3608	-1.0208	-0.5312	-1.5541	-0.1725
	(-1.8148)	(-0.6987)	(-0.3186)	(-1.8141)	(-0.8482)
E_{+3}	0.7368*	0.4253	0.6058	0.9224**	-0.1634
	(2.2456)	(0.6712)	(0.7243)	(2.4966)	(-1.0495)
E_{+4}	-1.0129	-1.2261***	0.4788	-1.8131**	-1.2460***
	(-1.4655)	(-5.0940)	(0.2687)	(-2.8158)	(-4.0515)
E_{+5}	0.1129	0.5604	-1.0285	0.1366	0.1034
	(0.3598)	(1.9328)	(-1.9240)	(0.3030)	(0.3313)
Constant	-0.0485*	-0.0471		-0.0491*	
	(-1.9897)	(-1.7895)		(-2.1818)	
Observations	403	403		403	
R-squared	0.1203	0.1320		0.1539	
FE date_event	YES	YES		YES	
FE Year	YES	YES		YES	
Range	NO	YES		NO	
Stock	NO	NO		YES	

Note: The table reports the results of the study of earthquake events that occurred in Chile and Peru. The coefficients θ_s associated with the binary variable E_s represent the AR of each day s of the event. Column [1] shows the estimates of Equation (1), which is the Base model. Column [2] are the estimates of Equation (2) for the case in which earthquake coverage is considered, thus Column [3] corresponds to abnormal returns interacting with earthquake coverage. Column [4] contains the estimates of Equation (3) for inventory (*Stock*), with Column [5] being the abnormal returns interacting with the inventory. The estimates are made with clustering event errors. $t-statistic$ in parentheses. */**/*** significant at 10%/5%/1%, respectively.