How Do Investors React to Investment-Opportunity Shock? Evidence from COVID-19 Pandemic and Taiwan Bio-Tech Firms*

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Abstract

While the stock market crashed in the first quarter after the outbreak of COVID-19, this paper finds that bio-tech firms and their investors could take advantage of the COVID-19 investment opportunity and earn positive abnormal returns. Bio-tech firms earn abnormal return of 1.63% per day around the event day when WHO declared COVID-19 as a global emergency, which could be translated into average capital gain about 86.7 million NT dollars per day. Positive returns continue after the event day. Moreover, small firms, firms with greater patent originality and receiving government R&D subsidies earn higher abnormal returns.

JEL Classification: G12; G14.
Keywords: COVID-19; Novel Coronavirus Diseases; Stock Returns; Bio-Tech Firms.

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Abstract

While the stock market crashed in the first quarter after the outbreak of COVID-19, this paper finds that bio-tech firms and their investors could take advantage of the COVID-19 investment opportunity and earn positive abnormal returns. Bio-tech firms earn abnormal return of 1.63% per day around the event day when WHO declared COVID-19 as a global emergency, which could be translated into average capital gain about 86.7 million NT dollars per day. Positive returns continue after the event day. Moreover, small firms, firms with greater patent originality and receiving government R&D subsidies earn higher abnormal returns.

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1. Introduction

Modern asset pricing literature suggests that the co-movement between asset prices and shocks of investment opportunities explains stock returns. In a production based asset pricing model, firms that are more likely to be exposed to exogenous shocks more tend to earn higher returns.[1] Examples of exogenous shocks include macroeconomic variables, government capital investment and public R&D. Many of exogenous shocks are related to investment opportunities. Namely, firms that are sensitive to investment opportunity shocks experience higher stock returns, which compensate the corresponding cash flow risks stemming from exogenous shocks. Several papers also develop theoretical models and justify this argument in various ways with U.S. data in last decade.[2] In this paper, we push the literature forward into examining an exogenous shock of coronavirus disease 2019 (COVID-19, also named as 2019 Novel Coronavirus or Wuhan Coronavirus) and investigate how the capital market responds to this huge and unexpected event in valuing the bio-tech and pharmaceutical firms.

COVID-19 broke out in the first quarter of 2020 and it only took a few months to spread to almost countries all over the world. According to the report of World Health Organization (WHO), up to 31 July, 2020, there are about 17 million of cumulative COVID-19 cases, and almost 670 thousand deaths directly caused by the coronavirus. The coronavirus lockdown in most countries causes significant shutdown of global economy. United Nations (UN) says that "COVID-19 slashes global economic output by $8.5 trillion over next two years".[3] The financial market,

[1] See, for example, Cochrane (1991), Liu, Whited, and Zhang (2009), Belo and Yu (2010), Croce, Kung, Nguyen, Schmid (2012), Croce (2014), Lansing (2015), Drechsler, Savov, and Schnabl (2018), and Chen, Chen, Liang, and Wang (2020).

[2] See, for instance, Papanikolaou (2011), Guo, Wang, and Yang (2013), Kogan and Papanikolaou (2013; 2014), and Adelino, Ma, and Robinson (2017).

[3] https://www.un.org/development/desa/en/news/policy/wesp-mid-2020-report.html.

however, only faced a temporary downturn and recovered due to strong supports of fiscal and monetary policies made by governments.[4]

Although COVID-19 pandemic causes pronounced economic damages, coronavirus vaccine developments and medical devices create investment opportunities to bio-tech and pharmaceutical firms (bio-tech firms, hereafter). CureVac, a Germany bio-tech company, is an example justifying this argument. On 14 August, 2020, Financial Times reported that "the race to develop a coronavirus vaccine heated up on global stock markets on Friday as shares in Germany's CureVac tripled on their opening in New York…".[5] Taiwan bio-tech firms could also gain from profits from COVID-19 outbreaks likewise. For instance, Formosa Laboratories, Inc., which is a Taiwan listed bio-tech company, is reported to have the ability to synthesize Remdesivir (a candidate of drug to cure coronavirus patients).[6] Therefore, we expect that Taiwanese bio-tech firms could earn positive returns after the COVID-19 pandemic because these firms could take advantage of the investment opportunity.

We collect the 125 Taiwan listed bio-tech and pharmaceutical firms in 2020 and examine their stock returns responding to the COVID-19. We identify the event day of COVID-19 on 31 January, 2020, when WHO declared a global emergency as COVID-19 broke out from China to other countries. We do so because COVID-19 is announced as a global emergency event that also greatly affects Taiwan since when. We find that value-weighted average of abnormal returns of bio-tech firms is 1.63% per day when WHO declared COVID-19 as a global emergency, which could be translated into average excess capital gain about 86.7 million NT dollars (equivalent to 2.9 million

[4] https://en.wikipedia.org/wiki/Financial_market_impact_of_the_COVID-19_pandemic.
[5] https://www.ft.com/content/9b6df40e-6ff1-4b29-b111-2b4f48407ce7.
[6] https://www.taiwan-healthcare.org/biob2b/breaking-news?articleTypeSysid=A.

US dollars) for each firm per day. The magnitude is statistically and economically significant, meaning that bio-tech firms are able to catch up investment opportunity and earn higher stock returns. The positive announcement abnormal return is larger for small firms than big firms. We also calculate post-event abnormal returns (until April end of 2020) and find that average daily abnormal returns are 0.248%, -0.112%, and 0.309% in first, second and third months, respectively.

Furthermore, we explore which types of firms might enjoy benefits from the investment opportunity of COVID-19 pandemic. We manually correct 1,698 patents and their patent profits of sample firms from Taiwan Intellectual Property Office (TIPO), including information about patent classifications and patent references.[7] We perform regression analysis for announcement abnormal returns and average daily return over a quarter after the event day. We find that there is no difference in the announcement returns between firms with and without bio-tech, medical and pharmaceutical related patents. We uncover that bio-tech firms earn higher abnormal returns for firms with high patent originality than firms with low patent originality. Moreover, firms experience higher abnormal returns when they receive R&D subsidy and tax credit from Taiwan government according to the Act for the Development of Biotech and New Pharmaceuticals Industry.[8] Furthermore, we examine how investors respond to the investment opportunity of COVID-19 by tracking the stock turnovers (i.e., trading volume scaled by shares outstanding). We find some evidence showing that investors trade more bio-tech stocks with high patent originality and receiving R&D subsidy. These results imply that investors not only read the financial statement

[7] We do not track forward citations of sample firms' patents because many patents of sample firms are granted in recent years and citations computation is vulnerable to severe patent truncation problem, suggested by Hall, Jaffe, and Trajtenberg (2001; 2005).

[8] The Act for the Development of Biotech and New Pharmaceuticals Industry, which was enacted in 2007, is aimed to stimulate research and development (R&D) investment of bio-tech and pharmaceutical companies through R&D tax credit, direct subsidy and other friendly policies.

information not only pay attention to non-financial statement information such as patent files and R&D subsidy status.

Our paper contributes to the literature in two ways. First, recent published and working papers actively investigate the stock market reaction to COVID-19 pandemic and quickly cumulate significant academic impacts and citations.[9] Among them, very few papers focus the positive impact of COVID-19 on stock market. This paper fills this gap and examines bio-tech, medical and pharmaceutical firms that could take advantage of this great investment opportunity. Second, past papers suggest that asset price co-moves with exogenous investment opportunity shocks and this correlation explains the stock return (e.g., Cochrane, 1991; Croce, Kung, Nguyen, Schmid, 2012; Belo and Yu, 2013; Chen, Chen, Liang, and Wang, 2020). However, none of them investigates a specific exogenous investment opportunity shock to verify the asset pricing theory. We are probably the first to specifically look at an important exogenous shock, the COVID-19 outbreak, and we find supportive evidence in support of this research stream.

The paper is organized as follows. Section 2 presents the data and research design. Section 3 provides empirical results, including stock returns and turnover of bio-tech firms and regression analysis. Section 4 finally concludes this paper.

2. Data and Methods

In this section, we first demonstrate the sources of the data and the sample construction. Next, we show how we calculate patent measures and illustrate the methodology used in the empirical

[9] See, for example, Al-Awadhi, Al-Saifi, Al-Awadhi, and Alhamadi (2020), Albuquerque, Koskinen, Yang, and Zhang (2020), Alfaro, Chari, Greenland, and Schott (2020), Baker, et al., (2020), Barrero, Bloom, and Davis (2020), Ramelli and Wagner (2020), and Zhang, Hu, and Ji (2020).

tests. Finally, we present the summary statistics of our sample.

2.1 Data

We start our sample with all firms listed in Taiwan Stock Exchange (TWSE) and Taipei Exchange (TPEx), and restrict our sample firms to be bio-tech firms. According to industry classification of TWSE, we define bio-tech firms to those classified in "Biotechnology & Medical Care" industry, which covers pharmaceutical manufacture, medical devices, applied biotechnology and healthcare services. We retrieve accounting data and market data from Taiwan Economic Journal (TEJ) database and manually collect 1,698 patents of our sample firms and corresponding data (including information about patent classifications and patent references) from Taiwan Intellectual Property Office (TIPO). We do not collect information of forward citations because many patents of our sample firms are granted in recent years, accordingly citations computation is vulnerable to severe patent truncation problem where latter patents have short time span to receive citations (Hall, Jaffe, and Trajtenberg, 2001; 2005).[10] R&D subsidy and tax credit data are collected from the Act for the Development of Biotech and New Pharmaceuticals Industry published by Industrial Development Bureau, Ministry of Economic Affairs of Taiwan.[11] Data of COVID-19 diagnoses in Taiwan are collected from Taiwan Centers for Disease Control, and global diagnoses data are collected from the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University.[12] We start our sample from 1 January, 2020 and end it on 30 April, 2020,

[10] 733 of patents of the sample firms are granted in 2018 or onward, accounting for 43% of patents. We also notice that the number of patents could be underestimated due to another patent truncation problem that many patents filed to TIPO have not yet been granted, as Hall, Jaffe, and Trajtenberg (2001) argue that time lag between patent application and patent publication is on averagely two years.

[11] The Act for the Development of Biotech and New Pharmaceuticals Industry is available in the following link: https://www.biopharm.org.tw/images/2020/Biotechnology-Industry-in-Taiwan-2020.pdf

[12] COVID-19 diagnoses data are available in Taiwan Centers for Disease Control (https://www.cdc.gov.tw/En) and

covering 75 trading days in total. The sample consists of 9,375 firm-day observations, and 125 bio-tech firms.

2.2 Methodology

We utilize four patent measures in our tests, including the number of patents (*# of patents*), the number of patents scaled by R&D expense (*# of patents/R&D*), the number of bio-tech related patents (*# of bio-tech related patents*), and the average of patent-level originality (*Patent originality*). *# of patents* is defined as the number of patents that a firm has ever applied and granted in TIPO. *# of patents/R&D* is calculated as *# of patents* divided by R&D expenditure (in million). *# of bio-tech related patents* is the number of bio-tech related patents that a firm has ever applied and granted in TIPO, where we identify bio-tech related patents by three-digit International Patent Classification (IPC) code of A61 (except IPC codes: A61C, A61D, and A61Q).[13] We identify both primary IPC code and secondary IPC codes of patents for this variable. We exclude A61C, A61D, and A61Q for patents under these categories are deemed to be less relevant to COVID-19 pandemic.[14] Following Hall, Jaffe, and Trajtenberg (2001; 2005), we define *Patent originality* as the sum of squared ratios of backward-citations divided by the number of total backward citations that belong to the same three-digit IPC code. To analyze the effect of government subsidies to the bio-tech firms, we further define a *R&D subsidy dummy*, which equals to one if a firm received R&D subsidy and tax credit; and zero otherwise.

Johns Hopkins CSSE (https://github.com/CSSEGISandData/COVID-19).

[13] According to World Intellectual Property Organization (WIPO), IPC code of A16 covers medical or veterinary science; hygiene. Subcategory A61C covers dentistry; apparatus or methods for oral or dental hygiene; A61D covers veterinary instruments, implements, tools, or methods; A61Q covers specific use of cosmetics or similar toilet preparations.

[14] A61C is for dentistry; A61D is for veterinary instruments, implements, tools, or methods; A61Q is for specific use of cosmetics or similar toilet preparations)

Other variables are described below. *Log(size)* is the logarithm of firm's capitalization (i.e., price multiplying shares outstanding) with base 10. *B/M* is the book value of common equity divided by size. *ROA* is earnings before interest, tax, depreciation and amortization. *R&D/Assets* is the R&D expenditures divided by book assets. *# of diagnoses (TW)* is the number of COVID-19 diagnoses per day in Taiwan. *# of diagnoses (Global)* is the number of COVID-19 diagnoses per day in the world. *# of deaths (TW)* is the number of deaths due to COVID-19 per day in Taiwan. *# of deaths (Global)* is the number of deaths due to COVID-19 per day in the world. Patent related variables are measured at the end of January in 2020. *Log(size)* and accounting variables are measured at the end of year 2019.

We define 30th January, 2020 as event day 0, the day when World Health Organization (WHO) declared a global emergency as Wuhan Coronavirus (COVID-19) spreads, for three reasons below. First, although COVID-19 became serious in China (especially Wuhan Province) in early January, 2020, it became a global event after 30 January when WHO notes it as a global emergent event. Second, there were Lunar New Year between 23 January and 29 January, no transaction data are available during the period. Another important event day, the Wuhan city lockdown, was on 23 January, yet there is no transaction at that day so that corresponding event study is less possible. Third, as we will show later on, the index dynamics were rather stable before the end of January, whereas there is an obvious change around 30 January.

We calculate abnormal returns (ARs) as the individual firm return minus corresponding TWSE market index return. As noted by MacKinlay (1997), using market model or market index return as the benchmark does not matter in the short-run return estimation, therefore we use market index return as the benchmark in computing ARs throughout this paper. In fact, this way is also popular in the finance literature (e.g., Foerster and Karolyi, 2000; Lee, 2001; Chan, Ikenberry, and

Lee, 2004). We then compute both equal-weighted and value weighted average of ARs of bio-tech firms around event day 0 and +2, and show the daily average return during the event window. Moreover, to facilitate the analysis on the impact of COVID-19 pandemic, we average the abnormal returns in additional four consecutive event windows: from day -29 to day -1, from day 3 to day 30, from day 31 to day 60, and from day 61 to day 90. We also examine firms' turnover, defined as trading volume divided by shares outstanding in the end of 2019. Likewise, to investigate the impact of COVID-19 on investors trading behavior, we average the daily turnover in the five consecutive event windows described above.

2.3 Sample Overview

Table 1 presents the summary statistics. In Panel A, we report, for each variable, the mean, median, standard deviation, and cross-sectional 5th, 25th, 75th and 95th percentiles. Mena of *log(size)* is 9.491. The unlogged number of *size* shows that average size of the 125 bio-tech firms is 5,314 (million), with a standard deviation around 6,046 (million).[15] The mean *# of patents/R&D* is 0.226, indicating that, on average, bio-tech firms spent around 4.42 million (=1/0.226) on developing one patent. The mean *# of patents* is 21.91 with a standard deviation of around 52.61, and the mean *# of bio-tech related patents* is 4.31 with a standard deviation of around 12.45, showing that the innovation capability differentiates significantly among bio-tech firms. The mean *R&D subsidy dummy* is 0.04, indicating that only 5 out of 125 bio-tech firms are granted with the government's subsidy and tax credit. Panel B shows the average COVID-19 diagnoses and death per day for Taiwan and global throughout the sample period. Panel C shows the correlation coefficients of the

[15] We use logarithm with base of 10.

variables.

[Insert Table 1 here]

3. Empirical Results

In this section, we show empirical results regarding abnormal returns, stock turnover and regression analyses of both abnormal returns and turnovers.

3.1 Abnormal Returns

To illustrate the relationship among the returns of bio-tech firms, market returns, and COVID-19, we plot in Figure 1 the time-series trend of cumulative abnormal returns (CARs) of the focal firms, the market index returns, and the COVID-19 diagnoses of Taiwan. We also highlight some important dates of COVID-19 pandemic, and the four red dots stand for the days with a circuit breaker in U.S. stock market. The figure entails some implications, as discussed below. First, there were dramatically jump in CARs for bio-tech firms but obvious drop in CAR for market index returns at the day when WHO declared COVID-19 as a global emergency event. Another trend of our interest is around early March, when the COVID-19 broke out in Euro (especially in Italy). During early March, asset prices of bio-tech firms appreciated while market index went down. The trend between late January and early March implies that Taiwan bio-tech firms earn excess capital gain and that they are likely to catch up the investment opportunities. There were four times of market shocks that deep decreases in stock prices triggered circuit breakers in the U.S. stock market in middle of March. Both CARs of bio-tech firms and market index dropped, though the magnitude of decreases in the market index is larger. Then, it was announced that Taiwan-U.S.

conducted consultation and cooperation on combatting the COVID-19 virus, including new drugs and vaccines development on 18 March, 2020. Meanwhile, Taiwan government as well as governments in other countries adopted strong fiscal and monetary policies to simulate economic, and stock prices gradually increased since when.

[Insert Figure 1 here]

Next, we start our analysis from the return analysis. To investigate how COVID-19 pandemic impacted the stock market and how bio-tech firms performed, we calculate both the equal-weighted and value-weighted ARs for the 125 bio-tech firms in the five consecutive event windows. We also group the firms by size, with size below (above) the median categorized as small (big) firms. Table 2 shows the abnormal returns of bio-tech firms around the outbreak of COVID-19. As shown in Panel B, the bio-tech firms earn an abnormal return of 1.632% per day around the outbreak of COVID-19, which could be translated into an average capital gain about 86.7 million NT dollars (equivalent to 2.9 million US dollars) per day. The number reaches 2.341% per day (or an equivalent of 124.4 million NT dollars per day) for small bio-tech firms. Since small firms are more sensitive to exogenous shocks, the stock return should be higher.

[Insert Table 2 here]

Next, to investigate whether investors recognize the technology niches of bio-tech firms, we conduct similar abnormal return analysis by sorting the firms into two categories by bio-tech related patents. That is, we take the average of AR in the five event windows respectively for the

firms with or without bio-tech related patents. We report the results in Table 3. Though firms with bio-tech related patents earn an abnormal return of 1.740% per day around the outbreak of COVID-19, it is not significantly different from that of firms without bio-tech related patents. However, if we focus on the (61, 90) window, we find that the firms with bio-tech related patents earn an abnormal return significantly higher than the firms with no bio-tech related patents. This implies that, during the spread of COVID-19, investors gradually start to realize the importance of technology niches in certain bio-tech firms. However, other innovation measures might drive out this effect, as we will introduce it in the regression analysis in later part of this paper.

[Insert Table 3 here]

Moreover, we sort the firms by patent originality and conduct the abnormal return analysis. Patent originality states to what extent a firm's patents rely on a specific patent technology class. Whenever the patent originality is high, the firm may have better patent quality. High patent originality means more original ideas that combine different technologies into a patent. For example, the blood vessel 3D models that are medical-engineering combined technology help surgeons to plan a safer operation. In Table 4, firms with patent originality below (above) median are labeled as high (low) patent originality. We find that the differences of the average announcement abnormal returns between firms with high patent originality and firms with low patent originality are significantly insignificant. Yet, we do find some significance in the first month after event day.

[Insert Table 4 here]

3.2 Stock Turnover

We calculate the stock turnover of bio-tech firms around the outbreak of COVID-19 in order to learn how investors may participate the transaction on bio-tech firms. In Panel A of Table 5, we find that stock turnover exhibits a sharp increase at the event day, showing that there are more active transaction around the event day. High turnover continues after the event day. The stock turnover after the event day is about three times of the turnover in the pre-event period. In Panel B and Panel C, we sort the sample firms into whether or not firms having bio-tech related patents. , and into high and low patent originality. From the univariate test, we find insignificant difference between two groups in both panels.

[Insert Table 5 here]

3.3 Regression Analysis

Finally, we perform regression analyses for abnormal returns and stock turnovers in order to control for multiple factors at the same time. Dependent variable in Model 1 is the average daily abnormal return during days 0 to 2. Dependent variable in Model 2 is the average daily abnormal return during days 3 to 90. Model 1 is the average daily abnormal return during days 0 to 2. Dependent variable in Model 3 is the average turnover during day 0 to 2. Dependent variable in Model 4 is the average turnover during days 3 to 90. Other variables are defined in Table 1. We report *t*-values based on White (1980) standard errors in the regression models.

In Model 1, we find that the coefficient of *patent originality* is 2.249, which is significant at the 1% level, suggesting that bio-tech firms with high originality earn higher announcement

abnormal returns. The coefficient of *R&D subsidy dummy* is 1.009, which is significant at the 5% level. This result shows that firms could be better in take advantage of the investment opportunity especially when they gain government subsidy, a result in part consistent with Belo (2013) and Chen, Chen, Liang and Wang (2020). We also notice that the coefficient of *# of bio-tech related patents* is insignificant in the regression analysis. We interpret the result together with the patent originality, and argue that innovation quality is more important than the innovation quantity in catching up the investment opportunities. Furthermore, we find that results are quantitatively similar when we regression post-event daily average abnormal returns in Model 2. In Models 3 and 4, we find that *patent originality* and *R&D subsidy dummy* affect stock turnovers around and post event windows, respectively.

[Insert Table 6 here]

4. Conclusion Remark

In this paper, we examine how COVID-19 pandemic, an exogenous shock in investment opportunity in 2020 for bio-tech firms, could affect the asset prices of bio-tech firms in Taiwan. This study could also echo the asset pricing model's prediction on the co-movement between asset price and exogenous investment opportunity and corresponding stock return dynamics. COVID-19 broke out in the first quarter of 2020 and it only took a few months to spread to almost countries all over the world, creating huge damage to the global economy. Yet, COVID-19 also brings significant expected benefits to bio-tech companies, including Taiwan bio-tech firms. Therefore, we use Taiwan bio-tech and pharmaceutical firms as our sample and explore the effect of COVID-19 on stock returns of bio-tech firms.

We collect the 125 Taiwan listed bio-tech and pharmaceutical firms in 2020 and examine their stock returns responding to the COVID-19. We use the event day of COVID-19 on 31 January, 2020 because WHO declared a global emergency as COVID-19 on that day. Empirically, we find that value-weighted average of abnormal returns of bio-tech firms is 1.63% per day when WHO declared COVID-19 as a global emergency, which could be translated into average excess capital gain about 86.7 million NT dollars (equivalent to 2.9 million US dollars) for each firm per day. We also examine post-event period stock returns and find that average daily abnormal returns are 0.248%, -0.112%, and 0.309% in first, second and third months, respectively. We also uncover that investors trade more around and after WHO declared COVD-19 as a global emergency.

Next, we investigate which types of firms might enjoy benefits from the investment opportunity of COVID-19 pandemic. By using regression analysis for announcement abnormal returns and average daily return over a quarter after the event day, we find that bio-tech firms with high patent originality and bio-tech firms receiving R&D subsidy and tax credit from Taiwan government both earn higher abnormal returns. These results imply that investors not only read the financial statement information not only pay attention to non-financial statement information such as patent files and R&D subsidy status.

This paper has two policy implications. First, Taiwan government passed the Act for the Development of Biotech and New Pharmaceuticals Industry to foster bio-tech and pharmaceutical industries and stimulate the R&D investments in these booming technology areas. In the ex post viewpoint, the policy is successful where firms experience higher abnormal returns when they receive R&D subsidy and tax credit from Taiwan government according to the act. Therefore, government R&D stimulation policy should continue to maintain the competitive advantages. Second, patent originality plays an important role for bio-tech firms during the COVID-19

pandemic. Policymakers should emphasize innovation quality but not quantity in the innovation policy.

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Table 1 Summary Statistics

This table presents summary statistics and correlation coefficients between variables. Log(size) is the logarithm of firm's capitalization (i.e., price multiplying shares outstanding). B/M is the book value of common equity divided by size. ROA is earnings before interest, tax, depreciation and amortization. R&D/Assets is the R&D expenditures divided by book assets. # of patents/R&D is the number of patents of a firm divided by R&D expenditure (in million), where # of patents/R&D is the number of patents that a firm has ever applied and granted in Taiwan Intellectual Property Office (TIPO). # of bio-tech related patents is the number of bio-tech related patents that a firm has ever applied and granted in TIPO, where we identify bio-tech related patents by three-digit International Patent Classification (IPC) code of A61 (except IPC codes: A61C, A61D, and A61Q). Patent originality is the average of patent-level originality, where patent-level originality is the sum of squared ratios of backward-citations divided by the number of total backward citations that belong to the same three-digit IPC code. R&D subsidy dummy is equal to one if a firm received R&D subsidy and tax credit from Taiwan government according to the Act for the Development of Biotech and New Pharmaceuticals Industry, and zero otherwise. # of diagnoses (TW) is the number of COVID-19 diagnoses per day in Taiwan. # of diagnoses (Global) is the number of COVID-19 diagnoses per day in the world. # of deaths (TW) is the number of deaths due to COVID-19 per day in Taiwan. # of deaths (Global) is the number of deaths due to COVID-19 per day in the world. Patent related variables are measured at the end of January in 2020. Log(size) and accounting variables are measured at the end of year 2019. Panel A presents the summary statistics of firm characteristics. Panel B presents the summary statistics of diagnoses and deaths. Panel C shows the correlation coefficients between variables.

	Mean	SD	p5	p25	p50	p75	p95
Panel A: Firm characteristics							
Log(size)	9.491	0.459	8.733	9.161	9.459	9.777	10.305
Size	5314.120	6045.941	2881.526	544.514	1447.034	2881.526	5978.716
B/M	1.228	2.431	0.049	0.217	0.483	1.095	5.620
ROA	-1.002	4.517	-10.545	-1.895	-0.020	1.350	3.606
R&D/Assets	0.017	0.033	0.000	0.002	0.007	0.014	0.089
# of patents/R&D	0.226	0.584	0.000	0.001	0.048	0.228	0.667
# of patents	21.91	52.61	0	0	6	18	83.70
# of bio-tech related patents	4.31	12.45	0	0	1	3	21.10
Patent originality	0.595	0.251	0	0.500	0.665	0.773	0.861
R&D subsidy dummy	0.040	0.197	0.000	0.000	0.000	0.000	0.000
Panel B: Diagnoses and deaths							
# of diagnoses (TW)	3.55	6.139	0	0	1	3	18.9
# of diagnoses (Global)	25,592	33,333.8	0	876	3,258	64,522.5	84,606
# of deaths (TW)	0.05	0.253	0	0	0	0	0
# of deaths (Global)	1,800.79	2,619.23	0	32	118	3,631.5	6,712.9

Table 1 (Continued)

Panel C: Correlation coefficients

	B/M	ROA	R&D/Assets	# of patents /R&D	# of patents	# of bio-tech related patents	Patent originality	R&D subsidy dummy
Log(size)	0.325	0.040	0.104	0.044	0.264	0.221	0.207	0.042
B/M		0.023	-0.098	0.015	0.024	0.033	0.022	0.154
ROA			-0.683	0.010	0.065	0.096	-0.012	-0.117
R&D/Assets				-0.146	-0.022	0.030	0.169	0.127
# of patents/R&D					0.662	0.294	0.236	-0.073
# of patents						0.837	0.343	-0.057
# of bio-tech related patents							0.288	-0.068
Patent originality								-0.110

Table 2 Abnormal Returns of Bio-Tech Firms around the Outbreak of COVID-19

This table present average abnormal returns (ARs) around the outbreak of COVID-19. Event day 0 is 30th January, 2020, when the day is that World Health Organization (WHO) declared global emergency as Wuhan Coronavirus (COVID-19) spreads. '-29 ~ -1' covers event days between day -29 and day -1 and shows averaged daily AR in prior-event period, '0 ~ 2' covers event days between day 0 and day +2 and shows averaged daily AR during the period, and other event windows are defined similarly. We compute ARs of firms based on Capital Asset Pricing Model (CAPM). Small (big) firms are firms with firm size below (above) the median of our sample. Panel A presents equal-weighted average of ARs and Panel B presents value-weighted average of ARs. 'Diff' indicates the AR difference between two groups. Numbers in the parentheses are *t*-values.

	N	-29 ~ -1	0~2	3 ~ 30	31 ~ 60	61 ~ 90
Panel A: Equal-weighted AR						
Whole sample firms	125	-0.072	1.575	0.206	-0.214	0.272
		(-1.657)	(5.395)	(3.301)	(-2.935)	(3.914)
Small firms	62	-0.013	2.295	0.264	-0.288	0.146
		(-0.187)	(5.467)	(2.527)	(-2.508)	(1.595)
Big firms	63	-0.131	0.867	0.150	-0.141	0.396
		(-2.408)	(2.228)	(2.152)	(-1.564)	(3.851)
Diff		-0.1182	-1.4276	-0.1139	0.1466	0.2505
		(-1.358)	(-2.496)	(-0.910)	(1.005)	(1.819)
Panel B: Value-weighted AR						
Whole sample firms	125	-0.062	1.632	0.248	-0.112	0.309
		(-1.392)	(5.575)	(3.659)	(-1.509)	(4.314)
Small firms	62	-0.005	2.341	0.307	-0.176	0.189
		(-0.078)	(5.605)	(2.738)	(-1.506)	(2.020)
Big firms	63	-0.117	0.933	0.19	-0.048	0.427
		(-2.077)	(2.370)	(2.464)	(-0.527)	(3.995)
Diff		-0.1121	-1.4077	-0.1170	0.1280	0.2380
		(-1.266)	(-2.453)	(-0.864)	(0.863)	(1.674)

Table 3 Abnormal Returns of Bio-Tech Firms around the Outbreak of COVID-19: Sorted by Bio-Tech Related Patents

This table present average abnormal returns (ARs) around the outbreak of COVID-19. Event day 0 is 30th January, 2020, when the day is that World Health Organization (WHO) declared a global emergency as Wuhan Coronavirus (COVID-19) spreads. '-29 ~ -1' covers event days between day -29 and day -1 and shows averaged daily AR in prior-event period, '0 ~ 2' covers event days between day 0 and day +2 and shows averaged daily AR during the period, and other event windows are defined similarly. We compute ARs of firms based on Capital Asset Pricing Model (CAPM). Firms with bio-tech related patents are the firms with at least one patent that belongs to three-digit IPC code of A61 (except IPC codes: A61C, A61D, and A61Q). Panel A presents equal-weighted average of ARs and Panel B presents value-weighted average of ARs. 'Diff' indicates the AR difference between two groups. Numbers in the parentheses are *t*-values.

	N	-29 ~ -1	0~2	3 ~ 30	31 ~ 60	61 ~ 90
Panel A: Equal-weighted average AR						
Firms with bio-tech related patents	66	-0.094 (-1.907)	1.672 (3.978)	0.181 (2.188)	-0.310 (-3.157)	0.417 (4.615)
Other firms	59	-0.048 (-0.647)	1.466 (3.619)	0.235 (2.461)	-0.106 (-0.987)	0.110 (1.061)
Diff		-0.045 (-0.518)	0.206 (0.351)	-0.055 (-0.436)	-0.204 (-1.404)	0.306 (2.236)
Panel B: Value-weighted average AR						
Firms with bio-tech related patents	66	-0.079 (-1.533)	1.740 (4.134)	0.218 (2.443)	-0.220 (-2.253)	0.451 (4.792)
Other firms	59	-0.042 (-0.568)	1.510 (3.714)	0.281 (2.711)	0.009 (0.081)	0.150 (1.413)
Diff		-0.037 (-0.411)	0.231 (0.392)	-0.064 (-0.468)	-0.229 (-1.550)	0.300 (2.124)

Table 4 Abnormal Returns of Bio-Tech Firms around the Outbreak of COVID-19: Sorted by Patent Originality

This table present average abnormal returns (ARs) around the outbreak of COVID-19. Event day 0 is 30th January, 2020, when the day is that World Health Organization (WHO) declared a global emergency as Wuhan Coronavirus (COVID-19) spreads. '-29 ~ -1' covers event days between day -29 and day -1 and shows averaged daily AR in prior-event period, '0 ~ 2' covers event days between day 0 and day +2 and shows averaged daily AR during the period, and other event windows are defined similarly. We compute ARs of firms based on Capital Asset Pricing Model (CAPM). High (low) patent originality are firms with patent originality below (above) the median of our sample. Patent originality is the average of patent-level originality, where patent-level originality is the sum of squared ratios of backward-citations divided by the number of total backward citations that belong to the same three-digit IPC code. Panel A presents equal-weighted average of ARs and Panel B presents value-weighted average of ARs. 'Diff' indicates the AR difference between two groups. Numbers in the parentheses are *t*-values.

	N	-29 ~ -1	0~2	3 ~ 30	31 ~ 60	61 ~ 90
Panel A: Equal-weighted average AR						
High patent originality	45	-0.066	1.865	0.351	-0.139	0.423
		(-1.251)	(3.299)	(3.000)	(-1.161)	(3.366)
Low patent originality	45	-0.145	1.371	0.098	-0.351	0.360
		(-2.242)	(3.015)	(1.173)	(-3.025)	(3.574)
Diff		0.079	0.494	0.253	0.212	0.064
		(0.942)	(0.681)	(1.757)	(1.274)	(0.394)
Panel B: Value-weighted average AR						
High patent originality	45	-0.054	1.927	0.405	-0.029	0.467
		(-1.010)	(3.419)	(3.162)	(-0.241)	(3.546)
Low patent originality	45	-0.131	1.449	0.141	-0.266	0.385
		(-1.917)	(3.143)	(1.479)	(-2.248)	(3.745)
Diff		0.077	0.478	0.264	0.238	0.082
		(0.886)	(0.656)	(1.657)	(1.411)	(0.491)

Table 5 Turnover of Bio-Tech Firms around the Outbreak of COVID-19

This table present average stock turnover around the outbreak of COVID-19. Event day 0 is 30th January, 2020, when the day is that World Health Organization (WHO) declared a global emergency as Wuhan Coronavirus (COVID-19) spreads. '-29 ~ -1' covers event days between day -29 and day -1 and shows averaged turnover in prior-event period, '0 ~ 2' covers event days between day 0 and day +2 and shows averaged turnover during the period, and other event windows are defined similarly. We compute turnover of firms as averaged daily trading volume divided by shares outstanding in the end of 2019. Panel A presents average of turnovers for whole sample and size subsamples. Small (big) firms are firms with firm size below (above) the median of our sample. Panel B presents average of turnovers sorted by firms' bio-tech patent status. Firms with bio-tech related patents are the firms with at least one patent that belongs to three-digit IPC code of A61 (except IPC codes: A61C, A61D, and A61Q). Panel C presents average of turnovers for patent originality subsamples. High (low) patent originality are firms with patent originality below (above) the median of our sample. Patent originality is the average of patent-level originality, where patent-level originality is the sum of squared ratios of backward-citations divided by the number of total backward citations that belong to the same three-digit IPC code. 'Diff' indicates the turnover difference between two groups. Numbers in the parentheses are *t*-values.

	N	-29 ~ -1	0~2	3 ~ 30	31 ~ 60	61 ~ 90
Panel A: Turnover of whole sample and subsamples sorted by firm size						
Whole sample firms	125	0.376	1.131	0.925	1.224	1.228
		(6.655)	(6.571)	(5.654)	(6.859)	(6.174)
Small firms	62	0.275	0.862	0.955	1.162	1.123
		(4.190)	(4.519)	(3.248)	(4.034)	(3.428)
Big firms	63	0.476	1.397	0.894	1.285	1.332
		(5.259)	(4.934)	(5.993)	(5.996)	(5.798)
Diff		0.201	0.534	-0.061	0.123	0.209
		(1.796)	(1.561)	(-0.186)	(0.343)	(0.523)
Panel B: Turnover of subsamples sorted by bio-tech related patent status						
Firms with bio-tech related patents	66	0.345	1.229	1.027	1.185	1.295
		(4.348)	(4.903)	(3.720)	(4.601)	(4.127)
Other firms	59	0.412	1.023	0.810	1.267	1.154
		(5.082)	(4.353)	(5.109)	(5.131)	(4.891)
Diff		-0.067	0.206	0.217	-0.082	0.141
		(-0.590)	(0.596)	(0.661)	(-0.230)	(0.353)
Panel C: Turnover of subsamples sorted by patent originality						
High patent originality	45	0.337	1.454	1.355	1.735	1.653
		(6.740)	(3.908)	(3.551)	(4.297)	(3.818)
Low patent originality	45	0.394	1.182	0.790	0.969	1.187
		(3.403)	(4.225)	(4.000)	(4.836)	(3.913)
Diff		-0.057	0.271	0.565	0.766	0.466
		(-0.455)	(0.583)	(1.316)	(1.699)	(0.882)

Table 6 Regression Analyses for Abnormal returns and Turnovers

This table presents regression analyses for abnormal returns (Panel A) and turnover (Panel B). Dependent variable in Model 1 is the average daily abnormal return during days 0 to 2. Dependent variable in Model 2 is the average daily abnormal return during days 3 to 90. Model 1 is the average daily abnormal return during days 0 to 2. Dependent variable in Model 3 is the average turnover during day 0 to 2. Dependent variable in Model 4 is the average turnover during days 3 to 90. Other variables are defined in Table 1. Numbers in the parentheses are *t*-value based on White (1980) standard errors.

	AR(0~2)	AR(3~90)	Turnover(0~2)	Turnover(3~90)
	Model 1	Model 2	Model 3	Model 4
Intercept	17.585	-0.969	-3.120	3.093
	(2.71)	(-0.99)	(-0.85)	(1.21)
Log(size)	-1.774	0.092	0.421	-0.331
	(-2.51)	(0.87)	(1.05)	(-1.16)
B/M	-0.012	-0.010	-0.092	-0.028
	(-0.16)	(-0.42)	(-2.18)	(-0.82)
ROA	0.050	0.024	0.044	0.058
	(0.54)	(1.66)	(1.32)	(1.64)
R&D/Assets	-6.697	4.024	-4.372	8.123
	(-0.32)	(1.34)	(-0.68)	(1.37)
# of patents/R&D	-0.276	0.068	-0.298	0.145
	(-1.05)	(1.73)	(-1.66)	(1.89)
# of bio-tech related patents	-0.015	-0.003	0.009	-0.007
	(-0.67)	(-1.06)	(1.01)	(-1.30)
Patent originality	2.249	0.255	0.962	0.381
	(2.63)	(1.95)	(2.26)	(1.07)
R&D subsidy dummy	1.009	0.446	-0.037	1.263
	(2.37)	(1.82)	(-0.16)	(1.96)
AR(0~2)		0.054		
		(2.86)		
Turnover(0~2)				0.910
				(4.51)
Adj. R-sq	0.059	0.206	0.066	0.627
N	118	118	118	118

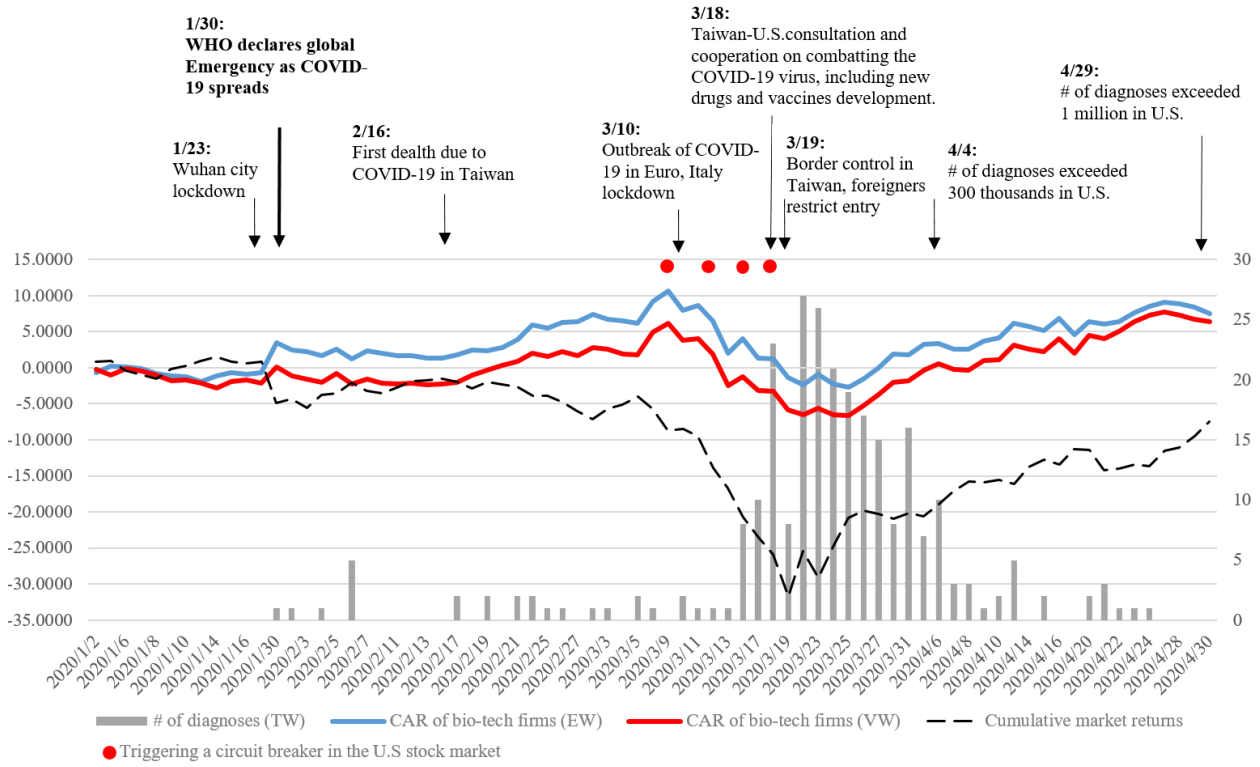

Figure 1 Cumulative Abnormal Returns, Market Index Returns and COVID-19 Pandemics in Time Series

This figure plots the equal-weighted cumulative abnormal returns (blue line), value-weighted cumulative abnormal returns (red line) of bio-tech firms and the number of diagnoses in Taiwan (gray bar). The dash line represents the market index returns. Four red dot stands for the days with a circuit breaker in U.S. stock market.