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Do Investors Care About Water Scarcity?

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Abstract

Global warming, a growing world population, and inefficient water use have put pressure on water availability across the globe. The United Nations Sustainable Development Goals address the issue of increasing water scarcity, and recent droughts have shown the potential effects on profitability of companies when the well runs dry, but do investors care? The findings of this study suggest that they do, but selectively. In this study, I measure the effect of corporate water scarcity risk exposure on stock returns and find that companies with a higher water scarcity risk exposure generate higher returns than companies with a lower exposure, although the results depend on the metrics used to determine water scarcity risk. The findings suggest investors require a 'water scarcity premium', providing support for the 'doing good but not well' hypothesis.

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1. Introduction

1.1 Introduction

Water is abundant; it covers around 70% of Earth's surface (National Geographic, n.d.). Yet, 2 billion people currently live in areas of extreme water scarcity and 83 out of 204 basins in the United States are projected to experience monthly water shortages between 2021 and 2045 (United Nations, UN, 2019; Brown, Mahat and Ramirez, 2019). While water is abundant, the vast majority of it is salty or ice, leaving only 0.007% available for use as fresh water (National Geographic, n.d.). With a world population estimated to grow to 8.5 billion people in 2030 and 9.7 billion in 2050 (UN, 2019), and an increase in water use per person (Florke, Kynast, Barlund, Eisner, Wimmer & Alcamo, 2013), the world is facing a water crisis. In fact, for eight years consecutively since 2012, the World Economic Forum (WEF) has listed water crises in the top 5 most impactful risks in its Global Risk Report, where it defines a water crisis as a "significant decline in the available quality and quantity of fresh water, resulting in harmful effects on human health and/or economic activity" (WEF Global Risk Report 2020).

This study focuses on those effect on economic activity by studying the relation between firm exposure to water scarcity and stock returns. Changes in stock returns of exposed firms result from changes in investor perception of such firms or from changes in cash flows following the firms' exposure to water scarcity. In water-dependent industries, such as agriculture, the automotive industry and chemical manufacturing, the insufficient availability of water could reduce firm profitability, by reducing production output and revenue or by increasing costs to secure water from elsewhere. Just in 2018, the agricultural industry of Cape Town suffered economic losses of around 400 million USD, following governmental orders to restrict water use by 60% in an effort to avoid the city having to close the taps altogether (World Wildlife Fund, 2018). Cape Town is not the only metropolis to face water shortages that might lead to economic losses; the city of Melbourne estimated in 2017 it might run out of water in just over a decade and São Paolo had water reserves for just another 20 days in 2015 (Welch, 2018). In what follows, I aim to measure the extent to which the stock market values firms with a large exposure to such water shortages differently than firms with smaller exposures. In other words, do investors care about water scarcity risk?

1.2 Most relevant literature

Questions about corporate water scarcity risk fit into the broad field of environmental, social and governance (ESG) research, that includes studies on topics ranging from child labor to transparency of corporate boards and many issues in between. More specifically, the topic of water scarcity is an environmental one and as such relates most to other environmental studies that measure the effects of climate change on stock returns. One of the most developed fields within the category of climate studies might be that of carbon risk studies, such as those by Bolton and Kacperczyk (2019); Gorgen, Jacob, Nerlinger, Riordan, Rohleder and Wilkens (2019); and In, Park and Monk (2019). These studies investigate the extent to which investors require a 'carbon premium' for investing in stocks of firms with high emissions. Other climate studies test the relation between extreme weather events or long-run temperature increases and stock returns (Bansal, Kiku and Ochoa, 2016; Balvers, Du and Zhao, 2016; and Kuman, Xin and Zhang, 2019), or measure whether residential properties that are exposed to sea level rise sell at a relative discount (Bernstein, Gustafson & Lewis, 2019; Baldauf, Garlappi and Yannelis, 2020; and Murfin and Spiegel, 2020). Most relevant for a study on the relation between water scarcity and stock returns are studies on drought risk. Compared to the considerable attention for the environmental and societal effects of drought (Mekonnen and Hoekstra, 2016; Barnabas, Jager and Feher, 2007), the academic community devotes little attention to the financial effects. A few exceptions are the studies by Hong, Weikai Li and Xu (2019) and Huynh, Nguyen and Truong (2020). While Hong et al. do not find evidence for a 'drought premium', Huynh et al. do find that companies that are more exposed to droughts generate higher stock returns than companies that are less exposed. The differences in findings might be attributable to their different samples and different definitions of drought. Across most categories of climate studies, findings vary and a consensus has yet to be reached. One possible general explanation for this lies in the novelty of the field, the sparse availability of reliable data, and the inherent uncertainty of climate change developments.

1.3 Approach and main findings

The studies by Hong et al. and Huynh et al. contribute to understanding the relation between firm drought exposure and stock returns and can form a necessary step in understanding the potential effects of firm water scarcity exposure. A distinction must be made between drought – the natural phenomenon of limited water availability due to the state of the climate – and water scarcity – the anthropogenic phenomenon of demand for water exceeding the availability (Van Loon & Van Lanen, 2013). This study explicitly investigates the potential stock return effects of water scarcity, for which measures of drought are necessary to determine water availability, but must be supplemented with measures of water use to determine demand. To the best of my knowledge, such a study has not yet been performed.

To contribute to understanding the potential firm-level effects of water scarcity, I measure the interaction effect of drought at the company production locations and firm-level water use on stock returns. Water supply at the firm production locations is measured by the level of drought, as retrieved from the Palmer Drought Severity Index (PDSI). Drought levels at the firms' production locations are aggregated to the firm-level and combined with water use data retrieved from Trucost to compute firm-level exposure to water scarcity, thus taking into account both water supply and demand. The relation between this water scarcity exposure and the firms' stock returns is the focal point of this study.

I find evidence for a return premium on stocks of companies with a higher water scarcity risk exposure across the cross-section and adjusted for common risk factors. Investors only seem to require a return, however, when companies with subsidiaries located in areas that have seen increasing drought also use high levels of water or are water intense in their revenue generation. Increases in water use from one year to the next do not seem to warrant a return premium, neither does having production locations in areas with a current severe or extreme drought ongoing. The findings thus seem to suggest that investors do care about water scarcity risk and require to be compensated, but only under certain conditions. I do not find evidence that investors require a higher premium during periods of increased market efficiency or for stocks with production locations in politically instable areas.

1.4 Contribution to the literature

This study is the first to measure the relation between water scarcity exposure – as a factor of both water supply and demand – and stock returns, and as such can form a valuable contribution to the field of climate studies. The inclusion of water demand measures allows to account for the fact that not all firms are affected by drought conditions in the same way; a firm that is highly water-dependent will be affected by a drought more than a neighboring firm that is not as water-dependent. Two additional contributions stem from the granular level at which local drought data is matched to the firm locations. First, I determine the company location not by its country of listing (Hong et al.) or the U.S. state in which its headquarters are located (Huynh et al.), but by the locations of its production subsidiaries worldwide. The rationale behind distinguishing between listing locations and headquarters on the one hand and production subsidiaries on the other, is that by the nature of their respective functions they are differently exposed to droughts. By identifying the location of the production subsidiaries separately, I can eliminate the unrealistic assumption that production takes place near the headquarters or even in the country of listing. Second, instead of aggregating drought data to the country level (Hong et al.) or state level (Huynh et al.), I match drought data to each production subsidiary on city level for a more precise indication of local drought risk.

1.5 Practical relevance

Climate risk is receiving increasing attention from investors in their security selection, and large institutional investors, such as pension funds, might be subject to regulations concerning climate risk assessments. In fact, European pension funds are obliged to report on the exposure of their portfolios to material climate risks, as part of a revised EU directive (IORP II), effective since 2019. The additional obligation of fund managers to report on their considerations of ESG issues in asset allocation decisions has made such issues undeniably relevant. To make responsible investment decisions, it is imperative that investors can reliably assess the risk related to stocks they are considering investing in and can determine whether the stocks generate a risk-appropriate return. The finding of a significant ‘water scarcity premium’ suggests that investors price water scarcity in to companies’ stock prices and that is relevant to know for conventional and green investors alike. The premium provides conventional investors willing to invest in riskier stocks with a higher return for their risk. For investors hoping to green their portfolio, the dependence of the risk premium on the specific drought and water use metrics applied allows for screening out stocks of large water users without sacrificing returns in some cases.

2. Literature review

This section covers the main literature that is relevant to this study, starting with an overview of studies on the relation between ESG investing and stock returns in section 2.1. Section 2.2 covers studies on climate risks for investors – both transition and physical risks – as a subset of ESG issues. Section 2.3 narrows down to studies on water-related risks, as a subset of climate risks.

Section 2.4 presents the hypotheses that are formulated based on the gaps in the existing literature, which will be tested in this study.

2.1 ESG investing and stock returns

While investors seem to gradually integrate ESG issues into their investment strategies[1], academics do not conclusively agree on the effect of sustainability – in the broadest sense – on stock returns. The findings of studies on the topic can be broadly categorized into providing support for either the *'doing well while doing good'* hypothesis, or the *'doing good but not well'* hypothesis. The *'doing well while doing good'* hypothesis states that stocks of socially and environmentally responsible companies generate higher returns than conventional stocks (Hamilton, Jo and Statman, 1993). The *'doing good but not well'* hypothesis states the opposite and predicts lower returns for socially and environmentally responsible companies (Statman and Glushkov, 2009). For companies to be doing good but not well, the market must be at least somewhat efficient. The efficient market hypothesis (EMH) in the context of ESG performance assumes new information on corporate ESG performance to be incorporated into stock prices instantaneously. In an efficient market, a strong ESG performance should result in lower stock returns if it causes negative cash flow effects or reduces risk. Negative cash flow effects occur when the costs for a firm to increase ESG performance outweigh the financial benefits, thus destroying shareholder value and lowering the return on shareholders' investments to the extent that this was not anticipated by them (Statman and Glushkov, 2009). Alternatively, a strong ESG performance can drive down return via a reduction in ESG-related risk, such as the risk of increased carbon taxes or water shortages. A reduction in risk should reduce the cost of capital for the company and indeed should reduce returns for investors, to the extent that investors are aware of the risk.

The *'doing good but not well'* hypothesis is supported by many studies in the field. Theoretical support is provided by Heinkel, Kraus and Zechner (2001), and Pastor, Stambaugh, and Taylor

[1] By 2020, over 3,000 asset managers, with combined assets under management in excess of $100 trillion had signed the Principles for Responsible Investing (Principles of Responsible Investing, PRI, 2020). The PRI should help asset managers to create long-term value by integrating ESG issues into their investment strategies. One should remain critical about the extent to which the PRI are applied in the investment strategies of signatories, however; asset managers might have been enticed to sign, as it is often a requirement by pension funds, and lack the intrinsic motivation to pursue ESG integration beyond what is strictly required.

(2020), who theorize that investor preferences for and the reduced risk of strong ESG stocks relative to poor ESG stocks result in lower returns on strong ESG stocks. Heinkel, Kraus and Zechner (2001) specify that, in equilibrium, exclusion of polluting firms by green investors might cause investors in polluting firms to require higher returns to compensate for the reduced risk-sharing opportunities. Pastor, Stambaugh, and Taylor (2020) add that green firms might temporarily outperform brown[2] firms when concerns among investors over ESG issues surge. In equilibrium, however, their model predicts green firms to underperform brown firms. The predictions of these models are supported by empirical studies on the relation between ESG performance and stock returns. In a literature review of 58 papers published between 2008 and 2018, Gianfrate, Schoenmaker and Wasama (2015) indeed find that the majority of the studies suggests a negative relation between corporate environmental performance and stock returns. Similarly, Chava (2014) finds that stocks of companies with low environmental performance, such as oil and coal companies generate higher returns than stocks of companies with high environmental performance. Sharfman and Fernando (2008) test specifically the role of risk, and find that firms with a lower environmental risk exposure generate lower returns than firms with a higher environmental risk exposure.

Similar to proponents of the *'doing good but not well'* hypothesis, those of the *'doing well while doing good'* hypothesis might believe that ESG risks for companies exist. However, under the *'doing well while doing good'* hypothesis, the assumption is that investors currently underestimate these risks. Due to this underestimation, poor ESG firms are traded at higher prices and generating lower returns than the EMH would dictate. By the time the underestimated ESG risks materialize, the stock price of such firms will not have decreased enough to secure an appropriate return amid negative cash flow effects arising from the materialized risk; stocks of poor ESG firms will underperform those of strong ESG firms. The opposite would happen to strong ESG firms, which would maintain relatively low stock prices and high returns when ESG risks are underestimated. Additionally, these firms are less exposed to ESG risks and will suffer less to no negative cash flow effects after the risks materialize, causing them to outperform poor ESG firms and, indeed,

[2] In the academic literature on ESG issues, different terms are used to indicate a firm's environmental performance. The distinction between 'green' and 'brown' firms in this case can be interpreted as distinguishing between firms with strong and weak environmental performance respectively.

to ‘do well while doing good’. In line with this reasoning, Andersson, Bolton and Samama (2016) make the case for investing in a decarbonized index. They argue that an index with a 50% lower carbon footprint and minimal tracking error will outperform the benchmark index when carbon risk materializes, while generating similar returns until then. They assume indeed that carbon risk is currently not priced in. A plethora of research has been conducted to empirically measure the extent to which carbon risk is priced in, and while there is some evidence in support of the *‘doing well while doing good’* hypothesis (e.g. In, Park and Monk, 2019), other studies come to different conclusions (Bolton and Kacperczyk, 2019; Gorgen, Jacob, Nerlinger, Riordan, Rohleder and Wilkens, 2019), although possibly in part attributable to different samples, periods and variable definitions. Evidence for the *‘doing well while doing good’* hypothesis for ESG performance in general is presented by Friede, Busch and Bassen (2015), who report that the majority of over 2000 studies since the early 1970s find a positive relation between corporate financial performance and ESG performance. Event studies by Krueger (2015) over the period 2001-2007 and Flammer (2013) over the period 1980-2009 seem to refute this conclusion and find that there is a pricing reaction to corporate social responsibility. Both report stock price increases following the announcement of positive CSR news, although stock prices might decrease if the CSR initiative causes a loss in shareholder value when the costs outweigh the benefits (Krueger, 2015). The varying findings on the relation between ESG or CSR and financial performance might be attributable to the choice of ESG issues and the types of companies to include in the study, as not all issues are material to all companies. In that context, Khan, Serafeim and Yoon (2016) only find outperformance in stocks of U.S. companies between 1992 and 2013 that improve on sustainability issues that are material for the company’s particular industry, as determined by the Sustainability Accounting Standards Board (SASB), and do not find outperformance in stocks of companies that improve on immaterial issues.

2.2 Climate risk literature

Within the broad category of ESG studies, findings might differ as a result of different definitions of environmental, social and governance issues and varying emphases on either of the three subcategories. The field of climate risk studies, within which this study should be placed, emphasizes the environmental aspect of ESG studies, and makes a further distinction between physical risk and transition risk. The Task Force on Climate-Related Financial Disclosures

(TCFD, 2017) describes transition risk as possible adverse financial or reputational effects to firms following the transition to a more sustainable society. These transition risk might arise from government policies to mitigate climate change or from changing consumer perception of unsustainable businesses. Additionally, innovations in cleaner products or methods of production can threaten the existence of unsustainable businesses. The TCFD describes physical risk as the potential impairment of production due to extreme weather events, such as floods and tropical storms, or adverse longer-term trends, such as increased drought or sea level rise (TCFD, 2017).

2.2.1 Transition risk

Prominent studies in the field of transition risk are those measuring the effects of carbon policies – such as carbon taxes and emission caps – on financial performance of firms and investors. Investors might be expected to require a premium for investing in stocks of large emitters in particular, as these firms are naturally more exposed to volatility in fossil-fuel prices, carbon regulations and technology risk from the renewable energy industry (Bolton and Kacperczyk, 2019). In line with their expectations, Bolton & Kacperczyk find that stocks of U.S. firms with high or increasing levels of emissions generate higher returns than stocks of firms with lower or decreasing levels between 2005 and 2007. The same relation does not seem to exist between emissions intensity – measured as emissions per unit of revenue – and stock returns (Bolton and Kacperczyk, 2019; Gorgen, Jacob, Nerlinger, Riordan, Rohleder and Wilkens, 2019). In fact, In, Park and Monk (2019) find that stocks of U.S. firms with lower emissions intensities generate higher returns than stocks of U.S. firms with higher emissions intensities between 2010 and 2015. In other words, high levels of emissions seem related to higher returns, while higher intensities seem related to lower returns. A possible explanation lies in the fact that carbon taxes and emission caps are generally determined on the levels of emissions and not on the intensities, causing firms with high levels of emissions to be exposed to a carbon risk to which firms with high intensities of emissions are not exposed. The exact formulation of government policy can thus affect stocks of different firms differently and influence the risk of and return to investors accordingly.

2.2.2 Physical risk

The field of physical risk studies the effects of changes in weather and climate on financial performance, whereby the effects of temperature rise and sea level rise receive considerable attention. Studies such as those by Bansal, Kiku and Ochoa (2016), and Balvers, Du and Zhao

(2016) suggest that investors require a significant premium for investing in firms with a risk exposure to long-run temperature rises; an indication that investors perceive temperature rises as a potential risk to the value of their assets. A similar risk awareness is found in the residential property market with respect to sea level rise. Bernstein, Gustafson & Lewis (2019) find that U.S. residential properties that are exposed to a risk of sea level rise sell at a 7% discount between 2007 and 2016, relative to properties that are less exposed. However, the discount seems to vary with the extent to which inhabitants of the area believe in and worry about climate change (Bernstein, Gustafson & Lewis, 2019; Baldauf, Garlappi and Yannelis, 2020). Additionally, different ways of measuring sea level rise and temperature rise might lead to a reversal of the effects altogether (Kuman, Xin and Zhang, 2019 ; Murfin and Spiegel, 2020).

2.3 Water risk literature

This study aims to contribute to the nascent literature on water scarcity risk for investors. It fits in the subcategory of physical climate risks studies and is inevitably rooted in the richer literature from the field of hydrology, the natural science concerned with the behavior and management of water. While the effects of water scarcity on food and other production seem to be widely acknowledged among hydrologists – as evidenced by the introduction of such metrics as the Water Footprint by Hoekstra in 2002[3] – there seems to have been no research into the relation between water scarcity and stock returns of companies.

Closely related to research on the financial effects of water scarcity are studies that measure the financial effect of drought. There are only a few such studies, of which the most notable are those by Hong et al. and Huynh et al. Both study the relation between stock returns and drought, whereby drought is measured as a long-term trend or a current state respectively. Hong et al. study the relation for food industries in 31 countries, while Huynh et al. include all industries in their sample and limit their geographical scope to the United States. The combination of different drought definitions and different samples might contribute to their opposite findings; Hong et al. find a negative relation between drought and stock returns, while Huynh et al. find a positive relation, suggesting investors require a 'drought premium'. Hong et al. explain the negative

[3] The Water Footprint measures the total consumption of fresh water in the production of a good, along the entire supply chain and is in that sense akin to the Carbon Footprint (Hoekstra, Chapagain, Mekonnen and Aldaya, 2011).

relation between drought and stock return by unanticipated decreases in profitability. They find that food industries in countries exposed to drought generate lower profitability, but do not witness a commensurate decrease in stock prices, thus resulting in lower returns for investors. In other words, the potential effects of drought on profitability are not efficiently priced in for food industries (Hong et al.). Huynh et al., on the other hand, find that for US companies across industries, investors do require a premium for drought exposure, and in fact that the premium increases with the severity of the drought. More studies should be conducted in this area to adequately understand the effects of drought risk on stock returns.

2.4 Hypotheses

In this study, I aim to determine the extent to which investors consider water scarcity to be a risk worth pricing in. If they do, stocks of companies with a high exposure to water scarcity risk should generate a higher return than those of companies with a lower exposure. Investors will demand a higher return if they expect that water scarcity will have a negative impact on the future cash flows of the company. A manifestation of such cash flow effects was seen in Cape Town in 2018, when the wine industry suffered economic losses of around 400 million USD following extreme drought (Welch, 2018). It might be reasonable to expect that companies in other industries, in other regions and in other times have experienced economic losses as a result of drought as well. Following the approach by Hong et al., I start my research by measuring the relation between corporate drought exposure and profitability. This should give an indication of the extent to which drought has adverse cashflow affects. The remainder of the study will focus on the interaction effect of water use and drought. I formulate my first hypothesis as follows:

> *Hypothesis 1: Companies with a higher exposure to drought risk generate a lower profitability than companies with a lower exposure to drought risk.*

While measuring the relation between drought and profitability allows for inferences on the materialization of drought risk, it does not suffice for estimating the interaction effects of water use and drought. It might be reasonable to assume that companies that use more water will be more vulnerable to the effects of droughts in the future. To discern something about expectations for the future, the remainder of this study will focus on stock returns, as the relation between water scarcity and stock returns depends on investors' expectations of future cash flows, and while such expectations might be informed by current cash flow effects, they might also occur in the sole anticipation of such effects. Ultimately, investors' expectations of future cash flows are informed by their assessment of water scarcity risk. Assuming higher returns for higher risk, I formulate hypothesis 2 as follows.

> *Hypothesis 2: Companies with a higher exposure to water scarcity risk generate a higher stock return than companies with a lower exposure to water scarcity risk.*

Hypothesis 2 is a specification of the general *'doing good but not well'* hypothesis, as formulated by Statman and Glushkov, which predicts lower returns for strong ESG firms relative to poor ESG firms. For information on corporate water scarcity risk to significantly affect stock returns, the stock market needs to be efficient to a certain degree. The more efficient the market, the better it is able to incorporate water scarcity information into the stock price and, by extension, the stock return. I, therefore, formulate hypothesis 3 as follows.

> *Hypothesis 3: During periods of high market efficiency, companies with a higher exposure to water scarcity risk will outperform companies with a lower exposure to water scarcity risk more than during period of low market efficiency.*

Apart from market efficiency, the case can be made that the relation between water scarcity and stock returns will likely in part depend on the political stability of the countries in which the company uses water. A study by Gleick and Iceland (2018) for the World Resource Institute and The Pacific Institute recounts several conflicts in the Middle East and Africa during which access to water in areas of the opponent was deliberately restricted. The so-called Islamic States has controlled several dams in the Tigris-Euphrates Basin in an effort to restrict access to water (UN, 2016), and likewise the Syrian government has been accused of using 'water as a weapon', by controlling water flows to rebel-occupied areas (Gleick and Iceland). Such obstructions impair companies' ability to access water from other regions at a reasonable price when faced with scarcity at their production locations. I expect rational investors to interpret these limitations as increasing the risk of lower revenue or higher costs, and lower future cash flows. Again assuming higher returns to higher risk, I formulate hypothesis 4 as follows.

> *Hypothesis 4: Companies with a higher exposure to water scarcity risk will outperform companies with a lower exposure to water scarcity more when the companies with a higher risk exposure are located in politically instable countries.*

3. Data and methodology

This section provides an overview of the collected data and applied methodology to test the formulated hypotheses. Section 3.1. briefly outlines the data for the dependent variables of profitability and stock return. Section 3.2 provides an in-depth report on the data collection of the independent variables related to corporate water use and drought exposure. I provide an argumentation for the definition of each of these data variables and document the data collection process. Section 3.3 present the moderating variables of market efficiency and political instability to test hypotheses 3 and 4. Section 3.4 present the control variables, section 3.5 provides data cleaning steps and descriptive statistics, and section 3.6elaborates on the applied methodology.

3.1 Dependent variables

The dependent variables for which the relation with water scarcity risk are measured are the change in firm profitability in hypothesis 1 and stock return in hypothesis 2, 3 and 4. For both corporate performance metrics, I collect data from Compustat Global. I collect annual profit (Compustat code NICON) and total assets (AT) to compute the return on assets. I winsorize the annual change in ROA at 2.5% to minimize the influence of outliers on the analysis. To test hypothesis 2, 3, and 4, I compute monthly returns in percentages from daily stock price data (PRCCD), adjusted for stock splits and dividends (AJEXDI). I winsorize the returns at 1% to minimize the influence of outliers.

3.2 Independent variables

To test the relation between water scarcity – as a product of water demand and supply – and firm performance, I measure the interaction effect of corporate water use and drought exposure. I document the data collection process for the water use and drought variables in this section.

3.2.1 Water use data

For an initial sample of 16,692 global firms between 2005 and 2018, I collect water data from the Trucost Environment Database. In absence of specific data on annual water use, I consider the sum of water purchased from water service companies and the water pumped from water sources by the company directly as a proxy for annual water use in cubic meter. From the annual water use, I compute the percentage change from one year to the next as a second metric of water use. Third, I collect the water use intensity from Trucost, measured as the water use (proxied as before) per million USD in revenue. I include the three metrics for water use separately in interactions with drought exposure variables to test different types of water risk exposure; water use levels measure the per year exposure, changes in water use levels measure an increase or decrease in exposure, and water use intensity measures the dependency on water for revenue generation. The inclusion of the different metrics serves to capture potential differences in investor sensitivity to levels of exposure and changes in exposure.

3.2.2. Drought data

I compute three metrics of firm-level drought exposure, aggregated from drought data at the firm's production facilities. The three firm-level drought metrics report the percentages of production facilities that are located in areas that have seen increasing drought over the past 100 years, computed using an AR(1) model; the percentages of production facilities that are located in areas with a current 'severe' drought; and the percentages of production facilities are located in areas with a current 'extreme' drought. The three metrics measure different types of exposure; the first measures the exposure to increasing drought over the long term, whereas the second and third each describe a current state of drought. The inclusion of different drought metrics serves to capture potential differences in investor sensitivity to long-run exposure and short-run exposure.

The drought data and classifications (i.e. 'severe' and 'extreme') are retrieved from the Palmer Drought Severity Index (PDSI) and accessed via the US National Center for Atmospheric Research (NCAR). The PDSI provides monthly global drought severity levels from 1850 until 2018, at a 2.5° by 2.5° precision level[4]. Drought levels are computed on the basis of temperature and precipitation data, and range from -10 to 10, whereby a lower score signifies more drought. The PDSI classifies drought levels between -3 and -4 as 'severe' droughts, during which damage to or losses of crops are 'likely'. Drought levels below -4 indicate 'extreme' drought, during which 'major' losses in crops occur and water users experience shortages and restrictions (United States Drought Monitor, n.d.). The PDSI was first developed by Palmer (1965), is widely used in the academic literature (Alley, 1984) and is relevant for a study on water risk due to its correlation

[4] Due to the curvature of Earth, 2.5° does not translate to the same distance across the globe. A full 360° circle around the world at the North Pole will require less travel than a full 360° circle around the Equator. Similarly, a length of 2.5° degrees at the latitude of Amsterdam is roughly the distance to the German border, while 2.5° in Central Africa equate to slightly longer distances.

with water storage levels (NCAR, n.d.). I have created a visualization of the available drought data in a world map and have included it in the appendix.

3.2.3 Company location data

For the purpose of measuring drought exposure accurately, I collect drought data for the company subsidiary locations at which production is likely to take place. I collect data on the subsidiaries of European sample firms from Amadeus (via Compustat) and for non-European firms from Orbis. Subsidiary data is available for 5,327 firms of the initial sample, with a combined total of 325,016 subsidiaries. I make a few assumptions, the first of which is that the firms have outsourced their production activities to subsidiaries. I further assume that the North American Industry Classification System (NAICS) provides an accurate indication of the activities of each subsidiary, and I therefore keep only subsidiaries whose four-digit NAICS code indicates production, manufacturing or farming activities. Table 1 in the appendices provides an overview of the industries that are considered to be active in these areas and on the basis of which the subsidiaries are included in the sample. This selection has reduced the sample to 62,861 subsidiaries of 3,371 companies. Since subsidiary data is only available in Amadeus and Orbis for the most recent reporting year, I make the final assumption that subsidiaries have stayed constant over the period 2005-2018.

To determine drought levels and drought trends at the production facilities, I retrieve the latitude and longitude of the city in which the subsidiary is located from the GeoNames database and Google Maps. I remove all subsidiaries from the sample for which the city is not reported, resulting in a final sample of geographical coordinates for 60,250 subsidiaries of 3,250 firms. For each subsidiary, I determine the closest coordinates for which the PDSI provides drought data using the Haversine equation:

$$hav(\Theta) = \text{hav}(\varphi_2 - \varphi_1) + \cos(\varphi_1)\cos(\varphi 2)\, hav(\lambda_2 - \lambda_1)$$

where φ_1 *and* φ_2 are the latitudes of point 1 and 2, and λ_1 and λ_2 are the longitudes of point 1 and 2.

The Haversine equation is well-suited to determine distances between two points on a globe, taking into consideration the curvature of Earth. I assign the drought data of the closest location to the subsidiary as a proxy for the drought levels at the exact location. Given the 2.5° by 2.5° grids for which the PDSI provides data, every company location can be assigned to a datapoint that is at most 1.25° removed. I argue this is an appropriately accurate proxy.

I aggregate the subsidiary-level drought data back to the firm to determine drought exposure at the firm-level by computing the percentages of subsidiaries in places with an increasing long-term drought trend, with a 'severe' drought and an 'extreme' drought ongoing. These firm-level percentages constitute the three drought exposure variables, which, in interaction with firm-level water use variables, are hypothesized to be related to firm profitability and stock return.

3.3 Moderating variables

3.3.1 Market efficiency

To test hypothesis 3, I develop a market efficiency variable from the price data of the FTSE All-World Index, retrieved from Datastream. The FTSE All-World Index contains 90 to 95% of investible market capitalization and has over 4,000 constituents (FTSE, 2021). The inclusion of large and midcap constituents from both developed and emerging markets makes this index an appropriate proxy for the market from which the sample companies in this research are collected. To compute a measure of market efficiency, I calculate the monthly returns of the index and determine the extent to which returns are related to returns of the previous months, using an AR-1 model and a 20-month rolling window. I label the months where the autoregressive coefficient is not significantly different from 0, as months with efficient markets, and for all other months, I register the coefficient as the level of market inefficiency. I use these values to test whether market efficiency has a moderating effect on the relation between water scarcity risk and stock return.

3.3.2 Political instability

To test hypothesis 4 on the moderating effect of political instability, I collect data from the World Governance Indicators (WGI), published by the World Bank. The WGI contain a category of 'Political Stability and Absence of Violence/Terrorism', which measures the threat of politically motivated violence. The data are presented in a ranking of each country in the world relative to the others, whereby a large threat results in a low ranking. I determine the political stability rank of each subsidiary, based on its location and take the average of all subsidiary rankings as the firm-level political stability ranking.

3.4 Control variables

To more reliably ascribe any changes in stock returns to changes in the independent variables, I control for a set of firm characteristics and risk factors. From Compustat Global, I collect the common shares outstanding (CSHO) and the daily stock price (PRCCD) to compute market capitalization; total common equity (CEQ) to divide by the market capitalization and compute the book-to-market ratio; long-term debt (DLTT) and short-term debt (LCT) to divide by the total assets (AT) and compute the book leverage; net capital expenditures (CAPX) to divide by total assets (AT) and compute the investments; revenue (SALE) to compute sales growth, normalized by the market cap; and earnings per share (EPSFI) to compute EPS growth, normalized by the share price (PRCCD). I further control for the momentum and volatility of returns, calculated as the mean and standard deviation of return over a 12-month rolling window. From the Kenneth French website, I collect returns on the five factors (Mkt-RF, SMB, HML, RMW, CMA) and the risk-free rate (RF). I remove all firms for which annual fundamental data is not available, resulting in a final sample of 2,926 firms.

3.5 Data cleaning

In a final step before analysis, I merge the separate dataset on the firm International Securities Identification Number (ISIN), and adjust the dataset for outliers, non-normality and multicollinearity. I winsorize excess returns at 1%, and ROA, water use change, water use intensity, and control variables at 2.5% to minimize the effect of outliers on the analysis. I log-transform the level of water use and firm size to adjust for excessive positive skewness in their distribution. Furthermore, the independent variable in the analysis is an interaction term between water use and drought exposure and naturally exhibits a high correlation with the main variables making up the interaction term. Since both the main variables and the interaction term must be included in the analysis to avoid omitted variable bias, the analysis would suffer from high multicollinearity if the variables were included in their non-standardized form. To adjust for the multicollinearity these variables and the control variables alike, I standardize all variables before running the analysis. Table 2 presents the descriptive statistics of the winsorized and log-transformed, non-standardized variables.

Table 2

This table presents the descriptive statistics for the dependent variable, variables to construct the independent variables, the moderating variables, and the control variables. The sample period is 2006-2018 and all variables, except for the market efficiency and the variables in panel D are computed at the firm level. **Panel A** reports the annual firm level water use data and monthly drought data aggregated from the subsidiary to the firm-level. 'LOG Water Use' is the annual water use as proxied by the sum of water purchased from water service companies and water pumped directly from the water basin by the firm; 'Water Use Change is the change in water use from one year to the next; 'Water Use Intensity' is the amount of water used (in cubic meters) per million USD in revenue; 'Fraction Negative Trend' is the fraction of production locations per firm that is located in an area that has seen increasing drought over the past 100 years; 'Fraction Severe' is the fraction of production locations per firm that is located in an area of 'severe drought', as determined by the PDSI; 'Fraction Extreme' is the fraction of production locations per firm that is located in an area of 'extreme drought', as determined by the PDSI; **Panel B** reports the 'Market Efficiency of the FTSE-All World Index; and the 'Political Instability Rank' as the firm-level average across the rankings of the subsidiary countries. **Panel C** reports the monthly stock return and annual fundamental data. 'ROA' is net income divided by total assets; 'ROE' is net income divided by total shareholders equity; 'ROA Growth' and 'ROE Growth' are the percentage growth from year *t* to year *t+1*; 'Excess Return' is the excess stock return, adjusted for stock splits and dividends; ; 'Investments' is capital expenditure divided by total assets; 'LOG size' is the log of the market capitalization; 'Book-to-market ratio' is total shareholders equity divided by market capitalization; 'Revenue growth' is the revenue at year *t* minus revenue at year *t-1*, divided by the market capitalization; 'Growth in Earnings per Share ' is the EPS in year *t* minus EPS in year *t-1*, divided by the stock price; 'Return Momentum' is the average excess return over the past 12 months; 'Return Volatility' is the standard deviation of the excess return over the past 12 months. **Panel D** reports the monthly returns on the Fama and French factors. 'Mkt-RF' is the return on the value-weighted market portfolio minus the risk-free rate; 'SMB' is the return on a portfolio long in stocks of small firms and short in stocks of large firms; 'HML' is the return on a portfolio long in value stocks and short in growth stocks; 'RMW' is the return on a portfolio long in stocks of firms with robust profitability and short in stocks of firms with weak profitability; 'CMA' is the return on a portfolio long in stocks of firms with conservative investments and short in stocks of firms with aggressive investments.

	Mean	Std. Dev.	min	p5	Median	p95	max
Panel A: Water use and drought variables							
LOG Water Use	12.282	2.919	.306	8.036	12.058	17.817	22.639
Water Use Change (in %, winsorized at 2.5%)	.070	.402	-.713	-.456	.013	.808	1.733
Water Use Intensity (winsorized at 2.5%)	32,327.67	121,179.8	29.226	49.02	902.119	200,821.5	666,425.5
Fraction Negative Trend	.651	.329	.000	.000	.700	1.000	1.000
Fraction Severe	.088	.189	.000	.000	.000	.500	1.000
Fraction Extreme	.070	.172	.000	.000	.000	.403	1.000
Panel B: Market efficiency and political stability variables							
Market Efficiency	-.064	.169	-.856	-.482	.000	.000	.000
Political Instability Rank	54.171	20.239	.473	16.190	58.859	84.433	100
Panel C: Return and firm fundamentals							
ROA (winsorized at 2.5%)	.004	.005	-.009	-.004	.003	.014	.018
ROE (winsorized at 2.5%)	.009	.012	-.029	-.013	.009	.030	.040
ROA Growth (in %, winsorized at 2.5%)	.351	82.170	-1,938.88	-2.164	-.047	1.770	9,802.865

ROA Growth (in %, winsorized at 2.5%)	.055	81.241	-1,941.66	-2.281	-.049	1.728	95,47.941
Excess Return (winsorized at 1%)	.763	9.672	-26.802	-14.737	.418	17.226	32.588
Investments (winsorized at 2.5%)	.004	.003	.0003	.0005	.003	.011	.014
LOG Size (winsorized at 2.5%)	8.981	2.496	4.643	5.149	8.745	13.675	15.356
Book-to-Market Ratio (winsorized at 2.5%)	.710	.602	.035	.097	.536	2.040	2.837
Revenue (winsorized at 5%)	6042.586	15,759.03	11.679	11.916	389.083	65,149.12	65,149.12
Revenue growth (winsorized at 2.5%)	.109	2.299	-.999	-.180	.045	.390	265.930
Earnings per Share (winsorized at 2.5%)	1.853	6.535	-.307	-.067	.072	10.502	37.000
Growth in Earnings per Share (winsorized at 5%)	.0001	.015	-.102	-.012	.0003	.011	.108
Return Momentum (winsorized at 2.5%)	.995	3.331	-6.636	-4.840	.939	7.067	9.430
Return Volatility (winsorized at 2.5%)	9.045	4.688	2.932	3.540	7.860	19.279	23.435
Panel D: Fama-French 5 factor returns							
Mkt-RF	.725	3.951	-17.230	-7.680	1.060	6.820	11.350
SMB	.024	2.442	-4.790	-3.740	.150	3.800	6.940
HML	-.137	2.521	-11.120	-3.670	-.360	4.070	8.220
RMW	.227	1.565	-3.930	-2.330	.290	2.940	4.940
CMA	.012	1.476	-3.350	-2.420	-.050	2.410	3.780

3.6 Empirical method

I follow Hong et al. in their approach to first estimate any potential effects on profitability and then proceed to measure any potential effects on stock returns. I determine the effects on profitability using a pooled OLS regression, using clustered standard errors to allow for heteroskedasticity. The main analysis is on the relation between water scarcity and stock returns. Following Bolton & Kacperczyk, I conduct a two-step analysis to test the formulated hypotheses. First, I run a cross-sectional Fama-MacBeth regression on all the firms per month to determine whether firms with a higher water scarcity risk exposure generate higher returns than firms with a lower such exposure. Second, I regress the return premium on the five Fama & French factors in a time-series to assess whether common risk factors can explain the premium, or whether, alternatively, a significant alpha remains. Due to the inclusion of several interaction terms, this approach is more appropriate than the widely used portfolio sorting method. One of the main drawback of portfolio sorts is that it does not allow for the inclusion of many control variables, while the inclusion of an interaction terms requires at least the inclusion of the main variables of the interaction term separately. The Fama-MacBeth approach, does allow for the unlimited inclusion of control variables and is, as such, the more appropriate method. To account for heteroskedasticity and autocorrelation in the regressions, I cluster the standard errors at the firm- and year-month-level in the cross-sectional regression and use Newey-West adjusted standard errors with 12-month lags in the time-series regression.

The interaction term between water use and drought exposure is the independent variable of interest and is computed by interacting the 12-month lagged water use variable with the 1-month lagged drought variable. Water use data is generally published once a year, while drought data is made available every month, allowing for a faster adoption of the latter in the stock price. The firm fundamentals that serve as control variables are lagged by 12 months as well, with the exception of the book-to-market ratio, market beta, return momentum and return volatility, which are updated more frequently and are therefore lagged by only 1 month.

4. Results and discussions

4.1 Effect on profitability

In line with the hypothesis and with the findings by Hong et al., I find that an increased exposure to drought is related to a decrease in profitability. While Hong et al. only measure the effect of long-term increasing drought trends – akin to my 'Fraction Negative Trend' variable – I find a similar negative relation between drought and profitability for current states of severe and extreme drought. Hong et al. have further found that these negative profitability effects have been consistently not anticipated by the market, leading to lower returns for firms with a higher drought risk, as opposed to what the classic risk-return trade off would suggest. In the next section, I continue with a similar question, but rather than estimating the relation between drought and return, I estimate the effect that water use has on the relation between drought and return.

Table 3

This table presents the results of the robustness check for the effect of drought on profitability. It shows the relation between monthly exposure to the three different drought metrics and the return on assets (ROA), converted to monthly amounts.. The variable definitions can be found in table 2. The results are generated using a pooled OLS regression, with standard errors clustered at the firm and year-month level.

	(1) Trend	(2) Severe	(3) Extreme
Fraction Negative Trend	-.0002***		
	(0.000)		
Fraction Severe		-.0004***	
		(.0001)	
Fraction Extreme			-.0004***
			(.0001)
Investments (winsorized at 2.5%	.1499***	.1504***	.1502***
	(.0044)	(.0044)	(.0044)
Leverage (winsorized at 2.5%)	-.0092***	-.0092***	-.0092***
	(.0001)	(.0001)	(.0001)
LOG Size (winsorized at 2.5%)	.0004***	.0004***	.0004***
	(0.0000)	(0.000)	(0.0000)
Total Assets (winsorized at 2.5%)	0.0000**	0.0000**	0.0000**
	(0.0000)	(0.0000)	(0.0000)
Capital Expenditures (winsorized at 2.5%)	0.0000***	0.0000***	0.0000***
	(0.000)	(0.0000)	(0.0000)
Constant	.0066***	.0065***	.0065***
	(.0002)	(.0002)	(.0002)
Observations	151,343	151,343	151,343
R-squared	.1884	.1886	.1885
Year-Month Dummy	YES	YES	YES
Industry Dummy	YES	YES	YES

*Standard errors are in parentheses *** p<.01, ** p<.05, * p<.1*

4.2 Effect on return

4.2.1 Cross-sectional regression

This section presents the results of the cross-sectional regression of excess returns on the interaction between corporate water use and drought. Table 4 presents the results of the interaction of the three metrics of water use with the drought metric for long-term drought exposure – the fraction of subsidiaries in areas of increasing drought over the past 100 years. The interaction is related to a significant return premium for all three water metrics and is robust to the inclusion of industry-fixed effect, with the exception of water use change. In all regressions, I control for time-fixed effects and a set of firm fundamentals. Standard errors are clustered at the firm- and year-month-level to allow for heteroskedasticity within the clusters.

The results in Table X suggest that, given a certain fraction of subsidiaries located in areas of increasing drought over the past 100 years, investors require a premium for firms with a higher level of water use, a bigger positive change in water use or are more water intense. There is, however, a difference in the premium investors require for the different water use metrics. A one unit increase in the log water use, seems related to a monthly premium of 0.0835%, significant at the 1% level, and an annual premium of slightly over 1% per year. Converted back from logarithmic units to cubic meters of water, however, investors seem to require an annual premium of only 0.01% per year for every 1% increase in water use. These results are hardly economically significant. The effect of water change on stock returns in a situation of drought seems slightly larger, but is still economically rather insignificant with almost 0.5% per year for each percentage increase in water use. However, it is relevant to note that the average change in water use is 7% a year, amounting to an annual premium of 3.5%, assuming a linear relation. The effect is significant at the 10% level, but disappears after inclusion of industry-fixed effects. The interaction effect of drought with water intensity on stock returns is highly significant with and without inclusion of industry-fixed effects. Investors require a monthly premium of 0.000007% for each cubic meter increase in water per $ 1 million of revenue. While the effect per cubic meter is small, there is a large standard deviation in water intensity and a one standard deviation increase of water intensity would generate a monthly premium of 0.8483%, amounting to an annual premium of over 10%. The results of the cross-sectional regression on the interaction between fraction of subsidiaries in negative drought-trending areas and the three metrics of water use are presented in table 4 below.

Table 4

This table shows the interaction effect of increasing long-term drought and the corporate level of water use (in LOG), the change in water use, and the water intensity. Drought variables are lagged by 1 month, and water variables are lagged by 12 months. The variable definitions can be found in table 2. The results are generated using a pooled OLS regression, with standard errors clustered at the firm and year-month level. The coefficients on the interaction terms have been adjusted to non-standardized coefficients and can be interpreted as monthly percentage contributions to the firm's excess stock return. The control variables are left in their standardized form.

	(1) Level	(2) Change	(3) Intensity	(4) Level	(5) Change	(6) Intensity
Fraction Negative Trend x LOG Water Use Level	.0835*** (.0915)			.0626*		
Fraction Negative Trend x Water Use Change		.0041* (.0917)			.0028 (.0929)	
Fraction Negative Trend x Water Use Intensity			.000007*** (.0353)			.000007*** (.0355)
Fraction Negative Trend, standardized	-.0639 (.0591)	-.0888* (.0532)	-.1497*** (.0437)	-.0651 (.0636)	-.0915* (.0541)	-.1481*** (.0446)

LOG Water Use Level, standardized	-.3300*** (.0701)			-.2927*** (.0801)		
Water Use Change, standardized		-.2229*** (.0720)			-.1753** (.0735)	
Water Use Intensity, standardized			-.0315 (.0325)			.0177 (.0433)
Investments, standardized	-.1004** (.0414)	-.1535*** (.0406)	-.1213*** (.0388)	-.1338*** (.0439)	-.1508*** (.0430)	-.1273*** (.0411)
LOG Size, standardized	-.0985** (.0422)	-.1635*** (.0409)	-.1352*** (.0397)	-.1022** (.0439)	-.1641*** (.0429)	-.1381*** (.0414)
Book-to-Market Ratio, standardized	.5061*** (.0506)	.4378*** (.0499)	.4896*** (.0495)	.5290*** (.0518)	.4562*** (.0513)	.5033*** (.0507)
Return on Equity, standardized	.2891*** (.0503)	.3576*** (.0514)	.3624*** (.0492)	.2903*** (.0508)	.3606*** (.0519)	.3699*** (.0496)
Market Beta, standardized	-.0426 (.0922)	-.0640 (.0979)	-.0842 (.0901)	-.0349 (.0933)	-.0432 (.0992)	-.0684 (.0909)
Revenue Growth, standardized	.0064 (.3703)	-.0301* (.0162)	-.0246 (.0163)	-.0375 (.3732)	-.0282* (.0163)	-.0247 (.0163)
EPS Growth, standardized	.5378*** (.0616)	.4522*** (.0629)	.4559*** (.0618)	.5401*** (.0616)	.4563*** (.0629)	.4578*** (.0618)
Return Momentum, standardized	.3370*** (.0593)	.2265*** (.0620)	.3097*** (.0599)	.3178*** (.0595)	.2129*** (.0622)	.2955*** (.0600)
Return Volatility, standardized	-.0118 (.05816)	-.0147 (.0597)	.0001 (.0578)	-.0131 (.0600)	.0019 (.0614)	.0170 (.0594)
Observations	60,579	56,879	61,021	60,579	56,879	61.021
R-squared	.1825	.1883	.1853	.1832	.1889	.1859
Year-Month Dummy	YES	YES	YES	YES	YES	YES
Industry Dummy	NO	NO	NO	YES	YES	YES

*Standard errors are in parentheses   *** p<.01, ** p<.05, * p<.1*

4.2.2 Time-series regression

To determine whether the return premium found in the cross-sectional regressions can be explained by common risk factors, I regress the premium on the Fama-French 5 factors. The results are presented in table 5 and suggest that, even after controlling for Market, SMB, HML, RMW and CMA-factors, a significant water risk premium remains for water use levels and water intensity. Column 1, 3, and 5 present the coefficients of the intercept-only model for comparison to the intercepts remaining after controlling for the factors in columns 2, 4, and 6. The results suggest that investors require a risk-adjusted annual premium of 0.7925% for every log increase in water use of companies located in areas that have seen increasing drought and a premium of 0.0006% for every cubic meter increase in water used per 1 million USD in revenue. The argument brought in the previous section still holds that while the effect of 1 cubic meter of water increase is economically insignificant, the effect on returns becomes economically significant when larger units – more aligned with actual business practices – are used to measure water intensity.

Table 5

This table presents the results of the time-series regressions of the return premia on the Fama-French 5 factors. Columns 1, 2 and 3 present the return premium in the intercept-only model, and columns 2, 4, and 6 present the remaining premium after adjusting for the risk factors. The variable definitions can be found in table 2.

	(1) Level	(2) Level	(3) Change	(4) Change	(5) Intensity	(6) Intensity
MktRF		.0002		-.0001		-0.000007
		(.0125)		(.0005)		(0.000009)
SMB		.0139		.0017*		0.000008
		(.013)		(.0009)		(0.000001)
HML		.0059		-.0008		0.000002
		(.0124)		(.0012)		(0.000001)
RMW		.0196		0		-0.000007
		(.0282)		(.0019)		(0.000003)
CMA		.0305		0		0.000003**
		(.0275)		(.0034)		(0.000001)
Constant	.0719**	.0658*	.0034*	.0032	0.000007**	0.000005**
	(.0362)	(.0355)	(.0018)	(.0028)	(0.000002)	(0.000003)
Observations	133	133	121	121	133	133
Year-Month Dummy	YES	YES	YES	YES	YES	YES

*Standard errors are in parentheses *** p<.01, ** p<.05, * p<.1*

Similar regressions on the interaction with short-term drought exposure – the fraction of subsidiaries in current severe or extreme drought – do not yield significant results. For brevity, the output tables of those regressions are not presented, but remain available upon request. The difference in significance among interactions with long-term drought and short-term drought exposure seems to suggest that investors perceive a gradual increase in drought over time to be more risky than a current state of drought. One explanation might lie in the fact that a current drought does not immediately lead to water shortage, because groundwater can be tapped when basins run dry. In areas of increasing drought over longer periods, water users might have already been dependent on groundwater for a long time, thus depleting the last source of water and exposing themselves to a real risk of running out of water. An alternative explanation for investors not perceiving current states of severe or extreme droughts as risky enough to require a premium is that, contrary to the previous argument, there is actually a risk, but investors misprice it. This could happen when investors are simply more aware of long-term drought trend than of currently ongoing droughts, because some areas are commonly known to be dry, whereas the current state of drought at a particular location might escape the investor's attention.

All in all, the results provide support for hypothesis 2 on the positive relation between water scarcity risk exposure and stock returns, but not across all metrics of drought an water use. Investors only seem to require a premium related to water use levels and water use intensity if the production facilities of the companies are located in areas that have seen increasing drought in the past 100 years. The same level of water use or water use intensity in areas of current severe or extreme drought do not seem to warrant a return premium.

4.2.3 Moderating effect of market efficiency

For stock prices and returns to react to news on drought and water use, financial markets must be efficient. The expectation that more efficient markets are better able to disseminate such information and affect stock prices is captured in hypothesis 3. To test whether stronger market efficiency indeed coincides with a larger return premium on water scarcity risk, I rerun the Fama-MacBeth regressions as in the previous section, with the inclusion of a three-way interaction term. The three-way interaction term is computed from the two-way interaction terms of the previous regression and the market efficiency variable. Its coefficient should capture any effect of market efficiency on the return premium resulting from water scarcity risk. I run separate cross-sectional regressions to measure the effect of market efficiency on the interaction of drought and water use, drought and water use change, and drought and water use intensity. Table 6 present the results for the three-way interactions of market efficiency, the log water use level and each of the three drought metrics.

Table 6
This table shows the three-way interaction effect of market efficiency, water use (in LOG) and the three metrics of drought. Drought variables are lagged by 1 month, and water variables are lagged by 12 months. The variable definitions can be found in table 2. The results are generated using a pooled OLS regression, with standard errors clustered at the firm and year-month level. The coefficients on the interaction terms have been adjusted to non-standardized coefficients and can be interpreted as monthly percentage contributions to the firm's excess stock return. The control variables are left in their standardized form.

	(1)	(2)	(3)	(4)	(5)	(6)
Fraction Neg. Trend x LOG Water Use Level X Market Efficiency	.2019 (.5411)			.2101 (.5404)		
Fraction Severe x LOG Water Use Level x Market Efficiency		-.3631 (.4543)			-.3393 (.4555)	
Fraction Extreme x LOG Water Use Level x Market Efficiency			.0822 (.4547)			.1039 (.4540)
Fraction Neg. Trend x LOG Water Use Level, standardized	.2615*** (.0988)			.2015** (.1025)		
Fraction Severe x LOG Water Use Level, standardized		.0088 (.0692)			.0589 (.0711)	
Fraction Extreme x LOG Water Use Level, standardized			.0059 (.0706)			.0579 (.0727)
Fraction Neg. Trend x Market Efficiency, standardized	.1833 (.3376)			.1665 (.3378)		
Fraction Severe x Market Efficiency, standardized		-.3059 (.3821)			-.2943 (.3824)	
Fraction Extreme x Market Efficiency, standardized			.23597 (.4266)			.2400 (.4270)
LOG Water Use Level x Market Efficiency, standardized	.2909 (.3906)	-.0970 (.3137)	.0172 (.3184)	.2986 (.3903)	-.0679 (.3136)	.0396 (.3185)
Fraction Neg. Trend, standardized	-.0797 (.0645)			-.0801 (.0689)		
Fraction Severe, standardized		.0010 (.0671)			-.0210 (.0680)	

Fraction Extreme, standardized			.0089 (.0654)			-.0132 (.0665)
LOG Water Use Level, standardized	-.3542*** (.0748)	-.0314 (.0595)	-.0575 (.0604)	-.3172*** (.0840)	-.0740 (.0640)	-.0798 (.0645)
Market Efficiency, standardized	-11.3764*** (1.1560)	-12.6316** (1.1522)	-12.0652*** (1.1623)	-11.4799*** (1.1546)	-12.6487*** (1.1507)	-12.0955*** (1.1599)
Investments, standardized	-.1009** (.0414)	-.0724* (.0392)	-.0539 (.0390)	-.1341*** (.0438)	-.0591 (.0419)	-.0481 (.0419)
LOG Size, standardized	-.0982** (.0422)	-.1044* (.0435)	-.0920** (.0435)	-.1019** (.04389)	-.0932** (.0447)	-.0851* (.04483)
Book-to-Market Ratio, standardized	.5055*** (.0506)	.4787*** (.0527)	.4938*** (.0527)	.5284*** (.05187)	.5124*** (.0545)	.5293*** (.05428)
Return on Equity, standardize	.2902*** (.0503)	.3436*** (.0458)	.3174*** (.0456)	.2914*** (.0508)	.3424*** (.0460)	.3180*** (.0458)
Market Beta, standardized	-.0406 (.0923)	-.0462 (.0888)	-.0346 (.0880)	-.0329 (.0933)	-.0560 (.0895)	-.05074 (.0886)
Revenue Growth, standardized	.0048 (.3706)	-.0369** (.0187)	-.0249 (.0164)	-.0380 (.3735)	-.0343* (.0187)	-.0225 (.0165)
EPS Growth, standardized	.5394*** (.0616)	.4396*** (.0548)	.4617*** (.0535)	.5416*** (.0617)	.4427*** (.0548)	.4683*** (.0535)
Return Momentum, standardized	.3355*** (.0594)	.3311*** (.0579)	.2722*** (.0575)	.3163*** (.0595)	.3207*** (.05809)	.2610*** (.0576)
Return Volatility, standardized	-.0115 (.0581)	-.0538 (.0564)	-.1142** (.0563)	-.0126 (.0600)	-.0573 (.0577)	-.1146** (.0575)
Observations	60,579	63,788	64,621	60,579	63,788	64,621
R-squared	.1825	.1693	.1691	.1832	.1698	.1696
Year-Month Dummy	YES	YES	YES	YES	YES	YES
Industry Dummy	NO	NO	NO	YES	YES	YES

*Standard errors are in parentheses *** p<.01, ** p<.05, * p<.1*

The results show no significant effect of market efficiency on the interaction between water use levels and drought exposure, suggesting that the effect of water use levels on the stock return at given levels of drought is not larger or smaller during periods in which the market is more efficient. The output tables of the regressions on the interaction with the other two water use metrics – the change in water use and the water intensity – show similar insignificant results. For brevity, the output tables of those regressions are not presented, but remain available upon request. The results might seem somewhat surprising, but it must be noted that the findings do not suggest that market efficiency does not significant affect stock returns; they merely suggest that market efficiency does not significantly affect the stock returns beyond the effect of the interaction between water use and drought that has already been accounted for. All in all, the findings do not provide support for hypothesis 3.

4.2.4 Moderating effect of political instability

Using a similar approach as the one in the previous section, I test the moderating effect of political instability on the effect of water scarcity risk using three-way interaction effects. I rerun the Fama-MacBeth cross-sectional regression and interpret the coefficient of the three-way interaction terms as the contribution of political instability to the return premium of the two-way interaction effect between drought and water use. Table X presents the three-way interactions computed from the political instability variable, water use levels (in LOG) and the three metrics of drought exposure. The results show positive, but insignificant coefficients, and thus provide no support for hypothesis 2. The regressions including the remaining two water use metrics – the change in water use and the water use intensity – provide similar insignificant results. For brevity, the output tables of those regressions are not presented, but remain available upon request. The reason for the absence of significant effects might be related to the mispricing of risk by investors or the absence or immateriality of the risk itself. When the position is held that political instability complicates access to water, following the argumentation outlined in section 2.4, then the absence of an effect on the return premium might be due to mispricing by investors. Alternatively, political instability might simply not materially increase water scarcity risk beyond the risk already captured by the interaction of drought and water use. The cases in which access to water was indeed obstructed due to political instability – such as the blockages of water dams by the so-called Islamic State – might be perceived to be too rare by investors to have a significant effect on the cross-section of stock returns.

Table 7

This table shows the three-way interaction effect of political instability, water use (in LOG) and the three metrics of drought. Drought variables are lagged by 1 month, and water variables are lagged by 12 months. The variable definitions can be found in table 2. The results are generated using a pooled OLS regression, with standard errors clustered at the firm and year-month level. The coefficients on the interaction terms have been adjusted to non-standardized coefficients and can be interpreted as monthly percentage contributions to the firm's excess stock return. The control variables are left in their standardized form.

	(1)	(2)	(3)	(4)	(5)	(6)
Fraction Neg. Trend x LOG Water Use Level x Political Instability	.0027 (.0044)			.0025 (.0044)		
Fraction Severe x LOG Water Use Level x Political Instability		.0012 (.0029)			.0012 (.0029)	
Fraction Extreme x LOG Water Use Level x Political Instability			.0020 (.0034)			.0021 (.0034)
Fraction Neg. Trend x LOG Water Use Level, standardized	.3867 (.2575)			.3175 (.2614)		
Fraction Severe x LOG Water Use Level, standardized		.0949 (.1735)			.1441 (.1747)	
Fraction Extreme x LOG Water Use Level, standardized			.0991 (.2083)			.1515 (.2100)
Fraction Neg. Trend x Political Instability, standardized	.0026 (.0026)			.0035 (.0026)		
Fraction Severe x Political Instability, standardized		.00081 (.0030)			.0012 (.0031)	
Fraction Extreme x Political Instability, standardized			-.0044 (.0033)			-.0043 (.0034)
LOG Water Use Level x Political Instability, standardized	-.0034 (.0038)	-.0038 (.0030)	-.0002 (.0029)	-.0044 (.0038)	-.0044 (.0030)	-.0008 (.0029)
Fraction Neg. Trend	-.2085 (.1620)			-.2625 (.1660)		
Fraction Severe, standardized		-.0682 (.1827)			-.1140 (.1843)	
Fraction Extreme, standardized			.2604 (.1991)			.2293 (.2010)

LOG Water Use Level, standardized	-.1334 (.2268)	.1827 (.1841)	-.0366 (.1809)	-.0400 (.2353)	.1772 (.1848)	-.0293 (.1819)
Political Instability	.0005 (.0024)	-.0027 (.0022)	.0003 (.002)	.0015 (.0025)	-.0023 (.0023)	.0005 (.0023)
Investments, standardized	-.1056** (.0416)	-.0771** (.0393)	-.0563 (.0392)	-.1405*** (.0439)	-.0644 (.0420)	-.0524 (.0420)
LOG Size, standardized	-.1007** (.0435)	-.1158** (.0450)	-.0809* (.0448)	-.1036** (.0454)	-.1012** (.0466)	-.0713 (.0465)
Book-to-market ratio, standardized	.5020*** (.0511)	.4690*** (.0535)	.4953*** (.0534)	.5253*** (.0521)	.5042*** (.0551)	.5303*** (.0548)
Return on Equity, standardized	.2880*** (.0505)	.3404*** (.0460)	.3152*** (.0457)	.2905*** (.0511)	.3399*** (.0462)	.3165*** (.0459)
Market Beta, standardized	-.0390 (.0922)	-.0409 (.0887)	-.0335 (.0880)	-.0308 (.0933)	-.0508 (.0894)	-.0486 (.0886)
Revenue Growth, standardized	-.0148 (.3706)	-.0407** (.0188)	-.0263 (.0167)	-.0554 (.3736)	-.0384** (.0188)	-.0244 (.0168)
EPS Growth, standardized	.5371*** (.0616)	.4381*** (.0549)	.4611*** (.0535)	.5392*** (.0616)	.4414*** (.0548)	.4677*** (.0535)
Return Momentum, standardized	.3327*** (.0593)	.3293*** (.0579)	.2695*** (.0575)	.3128*** (.0595)	.3188*** (.0580)	.2575*** (.0575)
Return Volatility, standardized	-.0139 (.0589)	-.0626 (.0569)	-.1176** (.0567)	-.0126 (.0608)	-.0657 (.0583)	-.1176** (.05812)
Observations	60,579	63,788	64,621	60,579	63,788	64,621
R-squared	.1826	.1693	.1692	.1833	.1698	.1698
Year-Month Dummy	YES	YES	YES	YES	YES	YES
Industry Dummy	NO	NO	NO	YES	YES	YES

*Standard errors are in parentheses *** p<.01, ** p<.05, * p<.1*

4.3 Robustness checks

The findings for hypothesis 1 on the effect of drought on profitability are robust at the substitution of ROA as a dependent variable with the growth in ROA, the ROE or the growth in ROE. In other words, a significant negative relation exists between drought and the level of profitability, and drought and the change in profitability. To test the robustness of the return premium on water scarcity risk, I have substituted company-level water use metrics by the average water use of the industry the company belongs to, whereby I use the 2-digit NAICS code as the industry classification. Given that industry water use metrics are more easily available than company-specific water use metrics, I had expected the interaction of industry water use with drought to be stronger than that of company-level water use, but the regression returns insignificant results. This suggests that investors do assess water scarcity exposure on a per company basis.

5. Conclusion

5.1 Summary

I have designed and performed this study with the aim of answering the question 'Do investors care about water scarcity risk?' The answer seems affirmative, but under a set of conditions. To understand the context in which investor respond to water scarcity, I found it relevant to first assess whether one of the two components of water scarcity – namely, drought – is already affecting firm profitability. Indeed, the evidence shows that firms with a relatively large fraction of their production subsidiaries in areas of increasing drought over the past 100 years or with a current severe or extreme drought ongoing generate lower profitability than firms with a relatively smaller fraction of their production subsidiaries in such dry places.

Upon closure reflection of the mechanisms of drought's impact on profitability, it must be concluded that not all companies will be equally affected by circumstances of drought; companies that need more water would naturally be more vulnerable to the negative profitability effects of a drought than companies that need little water. The expectation of large water users being affected be drought more than small water users should lead investors to require higher return for large water users in areas of drought than for small water users. The results of a set of cross-sectional Fama-MacBeth regressions, indeed, suggest the existence of a 'water scarcity premium' for large water users with production facilities at locations that have gotten increasingly drier over the past 100 years. The premium remains significant after controlling for the Fama-French 5 risk factors. These findings provide evidence for the general 'doing good but not well' hypothesis as put forward by Statman and Glushkov (2009). The findings become insignificant for large water users in areas with a current severe or extreme drought ongoing. Investors might be either underestimating the risk associated with current droughts, or correctly assessing that a current drought might not lead to water scarcity due to potential reserves of groundwater. Market efficiency and political instability in the country of the production facilities do not significantly add to the 'water scarcity premium' anymore.

The findings of this study contribute to the field of physical climate risk research and that of drought risk in particular, as it adds some more insight into the relation between drought and return, specifying that that positive relation is strong for large water users.

5.2 Practical implications

The existence of a risk-adjusted water scarcity premium is relevant for investors aiming to green their portfolio. The finding that stocks of firms with a larger water scarcity risk exposure generate higher returns when production facilities are located in areas of increasing drought has as a result that those stocks cannot be removed from the portfolio without giving up on return. Stocks of the same firms do not generate a premium when located in areas of current severe or extreme drought, so green investors wanting to screen large water users from their portfolio without giving up on return, could remove those large water users with production facilities in current drought areas, but not in areas with a long-term increasing drought trend. Alternatively, green investors can choose to screen out companies with high levels of water use and keep those with a high water intensity, because the economic significance of the prior is considerably lower. Following such an approach to screening, the green investor can increase the water responsibility of their portfolio without sacrificing too much or any return.

An understanding of the current water scarcity premium can furthermore be helpful in understanding the effects of future changes in investors' knowledge of and attitude towards water scarcity risk. While investors seems to currently price in water scarcity risk under certain conditions, it is difficult to assess to what extent the premium is adequate given the risk, because the risk cannot reliably be measured. It is difficult to oversee the financial effects of increasing water risk for similar reasons that it is difficult to oversee the financial effects of other environmental issues; climate issues are new and their development remains contingent on the timing and nature of a potential transition to a more environmentally responsible economy. This study has focused explicitly on the physical risks related to water scarcity – namely the risk that there will not be enough water to satisfy demand of businesses – but it must be noted that the return premium can significantly increase when transition risk start materializing. More specifically, investors are advised to stay informed on governmental initiatives to disincentivize excessive water use by setting higher prices for water or implementing caps, similar to emission reduction policies. Investors should be aware of the current and potential future effects of water scarcity on their investment returns.

5.3 Limitations

This study is performed under a set of assumptions pertaining to the production locations of the sample firms and the water use of those production facilities. First, due to the unavailability of time-series data on the subsidiaries of companies, the production subsidiary locations have been collected for the most recent available year a have been assumed to remain constant over the sample period. This introduces a limitation into the study, because the study does not account for the possibility that a company relocates its production in response to water scarcity at the location. Companies that seem to have a high exposure on account of the drought at their production facilities might actually have moved and reduces their exposure. Second, while drought at the supposed company production location is determined on an extraordinarily fine level, water use data is only available at the company level. In this study, I have implicitly assumed corporate water use to be evenly distributed across the subsidiaries. This is an unrealistic assumption and does not account for the possibility that the company reduces its water use at times of drought at the production location. The assumption of stability of the production facility locations and the even distribution of water use across those locations, both do not account for managerial response to water scarcity risk and might thus incorrectly assign a high water scarcity exposure to companies that have successfully reduces their exposure. A final limitation of this preliminary study into the stock return effects of water scarcity risk, is that the discovered premium might in fact be a premium for another risk that has not been appropriately controlled for. Water scarcity risk is highly correlated with drought risk, which in turn is highly correlated with temperature and precipitation. It is not inconceivable that the premium on stocks of firms that use a lot of water at dry locations might in part be a premium for temperature risk or wildfire risk, although the inclusion of a water metric supports the interpretation of the premium as a water scarcity premium.

5.4 Future research

The field of financial climate research is rapidly evolving, with the effects of many environmental issues still uncertain. Within the field of financial climate research, water scarcity is especially underdeveloped and any research into the effect of water scarcity on firm profitability and returns could add to the literature. In that effort, research designs from other fields of environmental research can be borrowed and applied to water scarcity risk, like I applied the subdivision of water use in levels, changes and intensities from Bolton & Kacperczyk's categorization of emissions. Similarly, the subdivision in scope 1, 2 and 3 emissions can be borrowed from the carbon risk literature and contribute to an understanding of different exposures to water scarcity risk in the entire supply chain, including water used in purchased intermediate goods and water consumed during use of the product by the customer. By applying proving methods from related climate fields where appropriate, the field of water scarcity risk can advance and contribute to developing a common framework for studying the financial effects of climate risks altogether.

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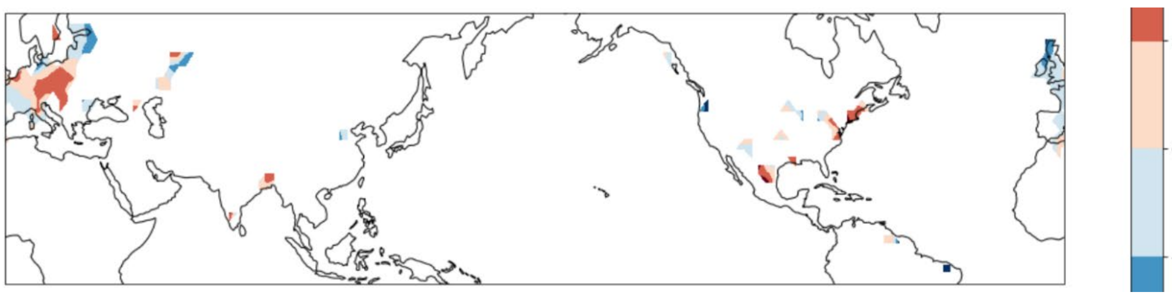
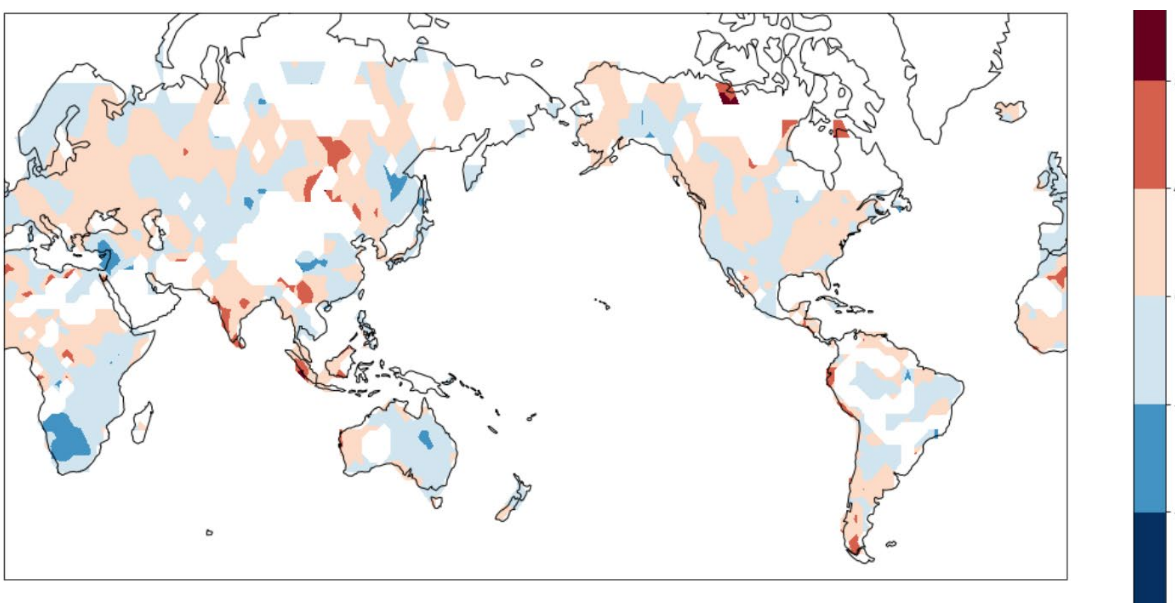
Appendices

Figure 1: Plotted maps of PDSI drought data in 1850, 1930 and 2018





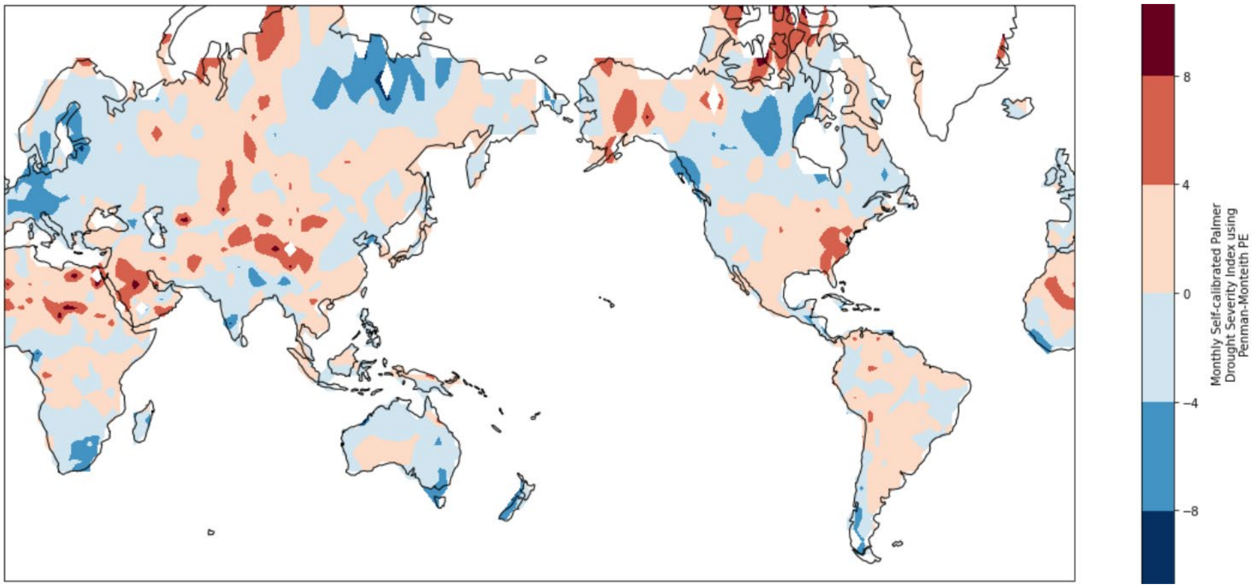


Table 1: List of included industries

NAICS	Description
1100	Agriculture, Forestry, Fishing and Hunting
1110	Crop Production
1111	Oilseed and Grain Farming
1112	Vegetable and Melon Farming
1113	Fruit and Tree Nut Farming
1114	Greenhouse, Nursery, and Floriculture Production
1119	Other Crop Farming
1121	Cattle Ranching and Farming
1122	Hog and Pig Farming
1123	Poultry and Egg Production
1124	Sheep and Goat Farming
1125	Aquaculture
1129	Other Animal Production
1131	Timber Tract Operations
1132	Forest Nurseries and Gathering of Forest Products
1133	Logging
1141	Fishing
1142	Hunting and Trapping
1150	Support Activities for Agriculture and Forestry
1151	Support Activities for Crop Production
1152	Support Activities for Animal Production
1153	Support Activities for Forestry
2110	Oil and Gas Extraction
2111	Oil and Gas Extraction
2120	Mining (except Oil and Gas)
2121	Coal Mining
2122	Metal Ore Mining
2123	Nonmetallic Mineral Mining and Quarrying
2131	Support Activities for Mining
2210	Utilities
2211	Electric Power Generation, Transmission and Distribution
2212	Natural Gas Distribution
2213	Water, Sewage and Other Systems
3111	Animal Food Manufacturing
3112	Grain and Oilseed Milling
3113	Sugar and Confectionery Product

Manufacturing

3114 Fruit and Vegetable Preserving and Specialty Food Manufacturing

3115 Dairy Product Manufacturing

3116 Animal Slaughtering and Processing

3117 Seafood Product Preparation and Packaging

3118 Bakeries and Tortilla Manufacturing

3119 Other Food Manufacturing

3121 Beverage Manufacturing

3122 Tobacco Manufacturing

3130 Textile Mills

3131 Fiber, Yarn, and Thread Mills

3132 Fabric Mills

3133 Textile and Fabric Finishing and Fabric Coating Mills

3141 Textile Furnishings Mills

3149 Other Textile Product Mills

3151 Apparel Knitting Mills

3152 Cut and Sew Apparel Manufacturing

3159 Apparel Accessories and Other Apparel Manufacturing

3161 Leather and Hide Tanning and Finishing

3162 Footwear Manufacturing

3169 Other Leather and Allied Product Manufacturing

3210 Wood Product Manufacturing

3211 Sawmills and Wood Preservation

3212 Veneer, Plywood, and Engineered Wood Product Manufacturing

3219 Other Wood Product Manufacturing

3221 Pulp, Paper, and Paperboard Mills

3222 Converted Paper Product Manufacturing

3231 Printing and Related Support Activities

3241 Petroleum and Coal Products Manufacturing

3250 Chemical Manufacturing

3251 Basic Chemical Manufacturing

3252 Resin, Synthetic Rubber, and Artificial and Synthetic Fibers and Filaments Manufacturing

3253 Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing

3254 Pharmaceutical and Medicine Manufacturing

3255 Paint, Coating, and Adhesive Manufacturing

3256 Soap, Cleaning Compound, and Toilet Preparation Manufacturing

3259 Other Chemical Product and Preparation Manufacturing

3261 Plastics Product Manufacturing

3262 Rubber Product Manufacturing

3270 Nonmetallic Mineral Product Manufacturing

3271 Clay Product and Refractory Manufacturing

3272 Glass and Glass Product Manufacturing

3273 Cement and Concrete Product Manufacturing

3274 Lime and Gypsum Product Manufacturing

3279 Other Nonmetallic Mineral Product Manufacturing

3311 Iron and Steel Mills and Ferroalloy Manufacturing

3312 Steel Product Manufacturing from Purchased Steel

3313 Alumina and Aluminum Production and Processing

3314 Nonferrous Metal (except Aluminum) Production and Processing

3315 Foundries

3320 Fabricated Metal Product Manufacturing

3321 Forging and Stamping

3322 Cutlery and Handtool Manufacturing

3323 Architectural and Structural Metals Manufacturing

3324 Boiler, Tank, and Shipping Container Manufacturing

3325 Hardware Manufacturing

3326 Spring and Wire Product Manufacturing

3327 Machine Shops; Turned Product; and Screw,

	Nut, and Bolt Manufacturing
3328	Coating, Engraving, Heat Treating, and Allied Activities
3329	Other Fabricated Metal Product Manufacturing
3331	Agriculture, Construction, and Mining Machinery Manufacturing
3332	Industrial Machinery Manufacturing
3333	Commercial and Service Industry Machinery Manufacturing
3334	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing
3335	Metalworking Machinery Manufacturing
3336	Engine, Turbine, and Power Transmission Equipment Manufacturing
3339	Other General Purpose Machinery Manufacturing
3341	Computer and Peripheral Equipment Manufacturing
3342	Communications Equipment Manufacturing
3343	Audio and Video Equipment Manufacturing
3344	Semiconductor and Other Electronic Component Manufacturing
3345	Navigational, Measuring, Electromedical, and Control Instruments Manufacturing
3346	Manufacturing and Reproducing Magnetic and Optical Media
3351	Electric Lighting Equipment Manufacturing
3352	Household Appliance Manufacturing
3353	Electrical Equipment Manufacturing
3359	Other Electrical Equipment and Component Manufacturing
3361	Motor Vehicle Manufacturing
3362	Motor Vehicle Body and Trailer Manufacturing
3363	Motor Vehicle Parts Manufacturing
3364	Aerospace Product and Parts Manufacturing
3365	Railroad Rolling Stock Manufacturing
3366	Ship and Boat Building
3369	Other Transportation Equipment Manufacturing
3370	Furniture and Related Product Manufacturing
3371	Household and Institutional Furniture and Kitchen Cabinet Manufacturing
3372	Office Furniture (including Fixtures) Manufacturing
3379	Other Furniture Related Product Manufacturing
3391	Medical Equipment and Supplies Manufacturing
3399	Other Miscellaneous Manufacturing
4832	Inland Water Transportation
5622	Waste Treatment and Disposal
8123	Drycleaning and Laundry Service