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# Decomposing Climate Risks in Stock Markets

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**Decomposing Climate Risks in Stock Markets**
**Prepared by Yuanchen Yang, Chengyu Huang, Yuchen Zhang**

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**ABSTRACT:** Climate change poses an unprecedented challenge to the world economy and the global financial system. This paper sets out to understand and quantify the impact of climate mitigation, with a focus on climate-related news, which represents an important information source that investors use to revise their subjective assessments of climate risks. Using full-text data from *Financial Times* from January 2005 to March 2022, we develop machine learning-based indicators to measure risks from climate mitigation, and the direction of the risk is identified through manual labels. The documented risk premium indicates that climate mitigation news has been partially priced in the Canadian stock market. More specifically, stock prices react positively to market-wide climate-favorable news but they do not react negatively to climate-unfavorable news. The results are robust to different model specifications and across equity markets.

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WORKING PAPERS

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# Contents

# 1. Introduction

The world's climate is changing. There is general scientific consensus that increased greenhouse gas concentrations are attributable to human activities (IPCC, 2021). The average global surface temperature could rise by 3-6 degrees Celsius by 2100 without immediate action to slow the pace of global warming (OECD, 2021). With increasing global surface temperature, the likelihood and intensity of natural disasters will also increase.

Climate change is an existential threat. While countries broadly agree on reaching net-zero emissions by mid-century to avoid the most adverse climate change scenarios, uncertainties surround the transition toward a low-carbon economy. If governments, firms, and households fail to check temperature rise and mitigate climate change, disorderly adjustments in asset prices would occur, with possible disruption to the proper functioning of the financial system and potential spillovers to other sectors of the economy.

This paper sets out to examine how the market views and prices climate mitigation policies, with a focus on the Canadian economy. It is widely recognized that risks of climate changes can be divided into two types: physical risks and transition risks (IMF, 2022). The former refers to the risks stemming from severe climate events, such as floods, droughts, wildfires, etc., whereas the latter results from policy changes, technological advances, and market shifts in the process of adjusting to a low-carbon economy. Of different types of transition risks, policy change is the one that has attracted the most attention. With the net-zero pledge constantly calling for more mitigation actions, it would be important to understand the effectiveness of existing mitigation policies, and in particular, whether current policies provide adequate incentives to steer agents' behavior towards lower carbon emissions. One of the channels for policies to shape agents' behavior is through price adjustments in financial markets.

Assessing the impact of mitigation policies is particularly relevant to Canada, which is among the world's top carbon emitters and faces a major transformation as the world moves away from fossil fuels. (Government of Canada, 2020; Environment and Climate Change Canada, 2022) The government is pushing for stronger climate policies at both the federal and provincial levels, with profound implications for its oil and gas sector. Prime Minister Trudeau announced during the United Nations Climate Change Conference in Glasgow that Canada will be the first major oil-producing economy to cap and reduce pollution from the oil and gas sector to net zero by 2050. Facing a hard path to decarbonize, the sector will need to continue to adapt, in order to spur innovation and preserve jobs. However, it is not yet well understood how the sector will respond to market and governmental regulatory pressure for green transition.

The key challenge to analyzing market responses to climate mitigation is to develop a time series that adequately captures risks from implementing mitigation policies. One approach is to leverage the fact that policy events that potentially signify shifts in climate policies are often covered by newspapers. In fact, news may even serve as the primary source of information for investors to formulate their subjective probabilities of climate risks. Studying the responsiveness of share prices to news coverage of climate policies offers important advantages over performing event studies around major climate-policy events. (Bhattacharya et al., 2009; Cahan et al., 2009) In particular, an event-study methodology would not allow the unexpected components of policy shocks to be easily disentangled, nor would it allow measurement of the intensity of, or sentiment towards, these shocks. On the contrary, news text, which has increasingly been used in financial economics research, captures unexpected new information that is just acquired by investors and foretells changes in future investment opportunities. News articles encompass diverse narratives and are timely and focused on the risks most pertinent to the market, and in the spirit of canonical asset pricing, news coverage may serve as the best of all publicly available signals. (Huang et al., 2019; Barkema et al., 2021)

We propose a novel, machine learning-based method to investigate how market-wide climate mitigation risks are priced in Canadian stocks. We use state-of-the-art Natural Language Processing model to perform textual analysis of news on climate mitigation policies that appeared in *Financial Times* over 2005-2022. Risks from mitigation are identified through a combination of detailed narrative analysis and supervised learning algorithms. A set of asset pricing models are applied to Canadian oil and gas companies listed in the S&P TSX composite index to examine whether model-generated climate risk factors are associated with positive/negative risk premia. Finally, we explore whether Canadian firms are more sensitive to news on climate mitigation by comparing them with representative US and EU firms.

Our results provide evidence that stock prices of oil and gas companies incorporate information about climate mitigation policies. To avoid neutralizing positive and negative news labels, we generate two climate news indices, with one signaling positive news for climate mitigation and thus lower transition risk, and the other symbolizing negative news for climate mitigation and thus higher transition risk. We hypothesize that an increase in the positive (negative) climate factor signals stricter (lighter) mitigation policies, and thus should be bad (good) news for oil and gas companies. In response to such a negative (positive) shock, investors would sell (buy) oil and gas stocks, thus decreasing (increasing) their prices and increasing (decreasing) their returns. Consequently, we should observe a statistically significant coefficient on the climate risk factor. The results confirm our hypothesis, indicating that firms have started to incorporate climate factors in their portfolio construction.

The responses of stocks in the oil and gas sector to positive and negative news about mitigation policies are asymmetrical. While there is a significantly positive coefficient associated with climate-unfavorable news among the group of oil and gas companies, we find that the sensitivity tied to climate-favorable is negative but statistically insignificant. In other words, an ease in climate mitigation constitutes a favorable shock to oil and gas companies but tighter mitigation policies do not necessarily signal a negative shock. The results are robust to various asset pricing models, including market model, Fama-French three factor model, Fama-French five factor model, Carhart four factor model.

Canadian firms are slightly more sensitive to both climate favorable and unfavorable news than US and EU firms. The efficiency and extent of asset pricing could vary across markets. We conduct a cross-country comparison by performing the same set of exercises on US and EU companies. In the baseline model, we find that the coefficients on the climate risk factor of US and EU companies are slightly smaller in magnitude, relative to that of Canadian companies. Overall, US and EU oil and gas companies also respond to climate policy news, but with different degrees of sensitivity from those based in Canada.

Our study makes an original contribution to the literature. First, we exploit news data to establish a novel indicator of market-wide climate risks. Previously, Engle et al. (2020) relied on news data to measure climate risks and design hedging strategies. Building on their work, Faccini et al. (2021) further disentangled different dimensions of climate risks using a narrative method. Our paper combines the merits of both studies. We present evidence on what types of climate risks are priced, enabled by a novel method that combines manual labeling and machine learning algorithms. Second, we document to what extent oil and gas sector stocks are exposed to climate risks, demonstrating how traditional asset pricing approaches can inform climate finance. In addition, we perform cross-country comparison on climate risk pricing, which offers important insights into which markets are more exposed to climate policy risks.

Taken together, using machine learning-based news measures, we show that news on climate mitigation has been partially priced in the stocks of Canadian oil and gas companies. An ease in mitigation policies represents a positive shock to their stock prices but stronger mitigation policies does not necessarily lead to negative price effects. These findings suggest that climate mitigation risks captured by news coverage have limited, asymmetric impact on stock valuations.

The rest of the paper is organized as follows. Section 2 reviews the literature on climate risk and asset pricing. Section 3 introduces our methodology and data. Section 4 presents and discusses our results. Section 5 provides robustness checks, and Section 6 concludes.

# 2. Literature Review

## 2.1 Classification of Climate Risks

It is common to classify climate risks into physical risk and transition risk. The former is defined as risks arising from physical impact of climate change, whereas the latter refers to risks resulting from policy, technology, legal, and market changes that occur during the move to a low-carbon economy. (IMF, 2022)

The impacts of climate risk drivers, whether physical risk or transition risk, on economies and financial markets may vary widely depending on geolocations and become increasingly hard to predict. Physical risk drivers can be further classified into acute risks associated with extreme weather events (Network , 2019), and chronic risks related to gradual climate shifts (McKinsey Global Institute, 2020). It has been estimated that natural disasters, most of which climatological, led to roughly $5.2 trillion losses from 1980s to 2018 (Munich Re, 2020).

Transition risk drivers are global, although the specific nature of each risk driver may vary by economy. Various stress test results indicate that the losses for financial institutions in the event of a disorderly energy transition could be sizeable. While banks and the non-bank financial sector have been affected by, and have therefore closely monitored, these forms of changes linked to climate transition, the synchronous nature of transition-related changes have the potential to result in a scale of impact that is much greater than previously anticipated. (Netherlands Bank, 2018)

In this study, we focus on climate transition risk, particularly the risk from mitigation policies, hoping to shed light on the effect of changing policies, legislation, and regulation as society and industry work to reduce their reliance on carbon and impact on the climate.

## 2.2 Measurement of Climate Risks

Understanding climate risks forms the basis for developing appropriate climate strategies. While conventional risk assessment tools may serve as a starting point for climate-related risk measurement, climate risk drivers have unique features that challenges the direct incorporation of these risks into existing framework. Most notably, the most severe consequences of climate risks are projected to materialize in 30 to 80 years. The exceedingly long simulation horizons and the resulting uncertainties associated with climate modeling necessitate granular and sometimes innovative measurement methodologies.

The assessment of climate-related risks by banks and supervisors has focused on mapping short-term transition risk drivers into portfolios, by capturing the carbon intensity of portfolio exposures, creating internal climate risk scores or ratings, etc. While carbon intensity constitutes a straightforward measurement of an entity's carbon footprint, it proves challenging to track indirect emissions that occur in a firm's value chain and in a product's life cycle.

Since 2014, interest in climate-related financial risks has been boosted by the development of ESG ratings (Halbritter and Dorfleitner, 2015). ESG—short for Environmental, Social, and Governance—has risen to become an increasingly important part of investment decisions. However, controversies are also rising related to ESG rating standards, data sources, and possible greenwashing. ESG rating standards are vastly different across agencies, and can therefore result in an inconsistent measure of performance. Companies, on the other hand, are selectively transparent about what they report, which masks relevant environmental risks and calls into question the reliability of such ratings to guide investment decisions. Moreover, ESG investing is increasingly considered as a mere branding exercise designed to benefit polluting businesses which claim to be in green transition but devote insignificant and opaque spending to clean technologies.

Another possible approach to climate risk assessment is through event analysis. Speaking of transition risk, especially which stems from policy changes, one might naturally think of major climate-related events. For example, various international summits, COP25, COP26. One would imagine that surrounding these events, there are likely changes in the probability of climate risk scenarios. However, using event study alone does not allow us to identify the direction of change. While it is likely that with the agreement stricken at international summits, or the passage of carbon emissions bill, we should see a fall in transition risk, but too aggressive policy changes or failure to deliver the mitigation commitments could also increase transition risks.

Taken together, gaps remain in the measurement and use of climate-related risks. Most existing measures rely on performance indicators derived from ESG scores, which have been marked by increasing controversies due to the lack of transparency around their methodologies and data sources, the misuse of ESG for greenwashing, potential conflict of interests, etc. (Mishra, 2022) In comparison, measures based on carbon footprint should have an advantage, but such information is not widely available at the firm level. The fact that investors demand future carbon trajectories rather than just current carbon emissions added to the difficulty of using carbon intensity to quantify climate risks (Yang, 2021). Taken together, climate risk assessment methodologies have not yet reached maturity.

### 2.3 Climate Risks and Asset Prices

There is a rapidly growing literature examining the effects of climate risks on financial markets and asset prices. To bring climate risk into asset pricing models, one must estimate the fundamental value of assets under various climate change scenarios. However, this assessment is complicated by the uncertainty about the future evolution of the climate, the future path of the economy, and the potential interaction between the climate and the economy. Given the geographical diversity of risk exposures, the nonlinearity of risk distribution, and the fact that historical experience could provide little guidance for future risk calibration, each source of uncertainty can make a huge difference effect on equilibrium prices and risk premia.

Recent evidence has shown that stock market has started to price climate risks (Engle et al., 2020; Faccini et al., 2021). While the literature on climate change and asset pricing have taken different directions, studies have invariably shown that climate change could lead to a relative discount of climate-vulnerable assets. In some cases, the movement in prices consistent with what one might expect, whereas in other cases, market seems to under- or over-react before returning to rational levels.

For our purposes, we focus on the equity market reactions to climate-related risks. Hong, Li, and Xu (2016) demonstrate that a portfolio that shorts food-sector stocks in drought-stricken countries and longs food-sector stocks in drought-free countries would have produced a 9.2 percent annualized return from 1985 to 2015. Since the premium is larger for drought-affected countries where there was not much history of droughts prior to 1980, the authors conclude that climate surprises are driving this premium.

Bansal, Kiku, and Ochoa (2016) develop a temperature-augmented long-run risk model to examine how infinitely lived rational agents capitalize long-term climate risk into forward-looking asset prices (Dell et al., 2012; Severen et al., 2018). Built on Epstein-Zin preferences, their model simultaneously matches the projected temperature path, the observed consumption growth trajectory, the discount rate implied by the risk-free rate, and the negative elasticity of stock prices to temperature changes. The results suggest a significant social cost of carbon and motivate early action to mitigate global warming. It is worth noting that they assume certain sectoral portfolios, including mining, oil and gas extraction, construction, transportation, and utilities, to have a high sensitivity to climate-related risk, whereas those with a low sensitivity are manufacturing, wholesale, retail trade, services, and communications.

Karp and Rezai (2017) adopt an overlapping generations (OLG) modeling approach, trying to disentangle people's incentives to tackle climate change. People might reduce carbon emissions to protect themselves, their wealth, or future generations from climate damage. Based on an overlapping generations climate model with endogenous asset price and investment levels, their findings suggest that asset markets capitalize the future effects of climate policy, regardless of people's concern for future generations. Climate policy can exert subtle distributional effects across the currently living generations, and markets can lead self-interested agents to undertake significant abatement efforts. A small policy change that raises the price of capital increases old agents' welfare and in the meantime, increases welfare of young agents with a high intertemporal elasticity of substitution.

Pankrantz, Bauer, and Derwall (2019) demonstrate that extremely high temperature events negatively affect both revenues and operating income in ways that market analysts did not anticipate. They create firm-specific measures of heat exposure and link it to firm financials, analyst forecasts, and earnings announcement returns of a cross-country sample of 4,400 listed firms from 1995 to 2017. By estimating the impact of randomly distributed variation in the number of days on which firms were exposed to extremely high temperatures, the authors find that increasing exposure to heat reduces revenues and operating income. Moreover, the deviation of analyst estimates from actual performance indicators as well as the abnormal returns around earnings announcements becomes more negative with the increase of heat exposure at the firms' locations. The study lends evidence that investors do not anticipate the economic implications of heat as a first-order climate physical risk.

Kumar, Xin, and Zhang (2019) add to the evidence that stock returns are sensitive to abnormal temperature changes. Exploiting a new measure of firm-level temperature sensitivity, the authors find significant overpricing on stocks with high temperature sensitivity. More specifically, a trading strategy that exploits this information generates an annualized risk-adjusted return of 4.22% during the 1968-2020 sample period. Meanwhile, these firms have lower future profitability, riskier corporate policies, and lower average returns. The authors note that the mispricing could be driven by institutional investors who have lower portfolio weights in firms with high temperature sensitivities and by sell-side equity analysts who issue forecast that are less accurate for these firms. In other words, financial markets under-react to firm-specific information about climate change, thus leading to predictable patterns in stock returns.

Other studies have looked at equity-based financial metrics instead of pure price measures. Chava (2014) concludes that stocks associated with substantial emissions and climate change concerns have a higher cost of equity and debt capital. The author uses the implied cost of capital imputed from analysts' earnings to formulate estimates. El Ghoul et al. (2016) use cross-country data to show that manufacturing firms across 30 countries that invest in corporate environmental responsibility have a lower cost of equity capital. Ginglinger and Moreau (2021) examine the impact of climate risk on capital structure. Relying on novel data that measure forward-looking physical climate risk at the firm level, the study finds that firms faced with greater climate risk have lower leverage due to both demand effect (a reduction in their optimal leverage) and supply effect (a reduced willingness on the part of lenders to fund them).

However, one compelling critique comes from the governor of the Bank of England, Mark Carney, who points out that we cannot rely on current actors, whose decision horizons are likely to be less affected by climate change, to act commensurate with the interests of future generations on climate issues (Carney, 2015). Compared with physical risk, transition risk is less studied in the literature, partly because the measurement of climate transition risk proves harder and less straightforward, partly due to the fact that climate transition risk varies substantially across time and by country, by industry, and even by firm.

More recently, researchers have taken up the challenge to examine transition risks in asset prices. Several studies have emerged, supporting the hypothesis that investors price in at least some transition risk. According to the Blackrock Investment Institute (2016), climate transition risk, among other risks, has yet to be fully priced into asset values.

Engle et al. (2020) use standard tool of asset pricing to build portfolios that are hedged against innovations in climate change news. Despite growing controversies surrounding their methodology and use of ESG scores, they demonstrate how asset pricing approaches can inform or even develop new topics in climate finance.

Faccini et al. (2021) builds on Engle’s work. They further disentangled climate risks into risk from natural disasters, from global warning, from international summits, and from US policy change. They showed that only the risk of government intervention is priced.

Our paper sets out to fill the gap. We develop news-based measures to measure transition risk. More specifically, we focus on transition risk from implementing climate mitigation policies, which is defined as the monthly count of news articles related to climate mitigation policies, standardized by the total number of monthly published news articles. The rationale for this assumption, common in the literature, is that investors’ attention is limited, they will easily be influenced by what they read, especially by news with intense media exposure. or estimating the prospect of more stringent climate regulation. Using news not only allows us to quantify the intensity of shock; the fact that news comes at a much higher frequency also enables us to capture any event or sentiment change that might move the market. (Dougal et al., 2012; Wan et al., 2021)

# 3. Methodology and Data

## 3.1 Pre-Processing News Text Data

To begin with, we retrieve full-text news data from *Financial Times* news API. The database is updated in real time since January 2005 and our sample period starts from January 2005 and ends in March 2022. A total of 923,862 unique English news articles are collected which comes in json format with an average of about 4500 news monthly. Then, we conducted standard text data preprocessing steps including lower case and lemmatization with Part of Speech Tagging, [1] which reduce words to their base form based on their grammatical positions in sentences.

All these procedures are performed using Python's Natural Language Toolkit (NLTK), which contains text processing libraries for tokenization, parsing, classification, lemmatization, tagging, and semantic reasoning. Cleaned data file stores news in paragraph format with news publish date information, title, and processed full text.

## 3.2 Climate Policy Identification

In this study, we are interested in news texts on climate transition risk, and in particular risk that arises from policy changes that follow economic and societal shifts toward a low-carbon and more climate-friendly future. To focus on news texts on climate change policies, we create a glossary of climate policy terms that can be used to exclude irrelevant texts from the whole sample through keyword search.

To construct our list of filtering terms, we first collect climate change white papers from official sources such as the Intergovernmental Panel on Climate Change (IPCC), the Environmental Protection Agency (EPA), and National Oceanic and Atmospheric Association (NOAA) which is part of the United States Department of Commerce. Given the unique features of news articles, we complement these authoritative texts with climate glossaries from news media, most notably BBC, Wall Street Journal, and Bloomberg. Based on this corpus of authoritative texts, we compile our own list of climate change keywords. It is worth noting that, to avoid introducing noise into the dataset, we exclude general terms such as "climate" and "environment" which can also appear in irrelevant word combinations such as "business climate" and "business environment". Instead, we use more specific word combinations such as "climate change", "climate transition", etc.

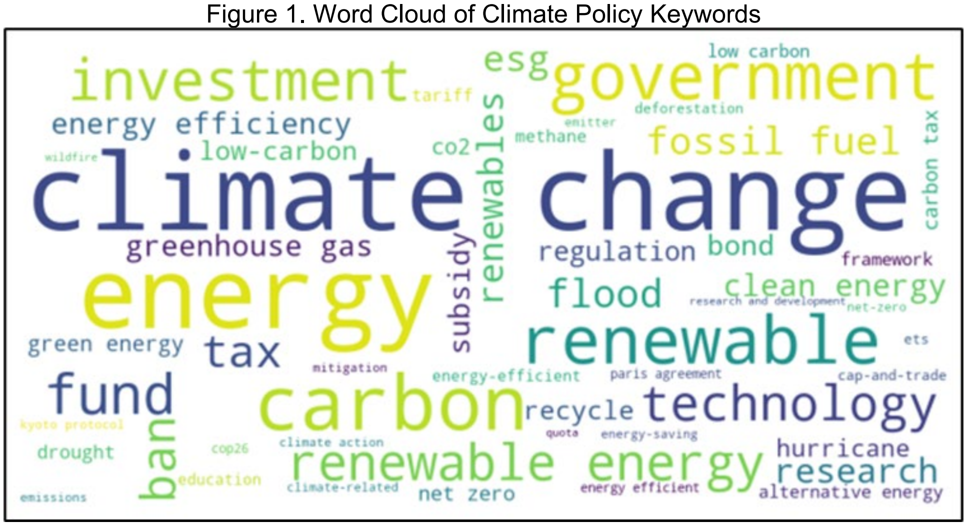
To further limit the sample to texts on climate change policies, we extract keywords on climate policy instruments from IPCC, OECD, IMF, World Bank, International Organization for Standardization (ISO), as well as academic and policy literature (e.g., Gupta et al., 2007; Gorlach, 2013; World Bank, 2017, 2021; Michaelowa, et al., 2018; Penasco et al., 2021; USGS, 2022). The policy instruments to tackle climate change are categorized into two types—market-based instruments and non-market-based instruments—at the most aggregate level. More specifically, market-based instruments refer to policies that work through price adjustments so that the external costs of production or consumption are incorporated. Examples of market-based instruments include carbon taxes, emissions trading, international carbon price floor, etc. On the contrary, non-market-based instruments work by encouraging or discouraging certain behavior through non-

[1] The paragraphs are lemmatized with pos tag which return the words to base form by considering their grammatical positions in sentences.

monetary incentives, or by imposing obligations. Typical non-market-based instruments are mandatory/voluntary emissions disclosure, clean technology support, and command-and-control regulations.

In Figure 1, we summarize the list of climate change and policy keywords in the form of a word cloud. The sizes of words or word combinations are proportional to their TF-IDF scores[2] in the corpus.

Figure 1. Word Cloud of Climate Policy Keywords




*Sources: IPCC, EPA, NOAA, OECD, IMF, World Bank, ISO, and author calculations.*

Clearly, “climate change” is the most salient keyword, showing the theme of our study. Since we aim at measuring climate transition risk that stems from policy changes, terms such as “government”, “regulation”, and “tax” also appear with high frequency.

Our filtering standard is to include news paragraphs that contain at least one word or word combination from the climate change keyword list, and at least one from the list of policy instruments. We end up with a total of 3.7 million news paragraphs and an average of 17.6 thousand paragraphs per month from January 2005 to March 2022.

### 3.3 Generating Training Data for Climate Transition Risk Identification

Having obtained the sample of news paragraphs on climate change policies, our next goal is to identify whether each paragraph signals an increase or decrease in climate transition risk, a task that is impossible to be accomplished by manpower due to the pure number of paragraphs awaiting analysis. We need machine learning algorithms to perform the task.

Ideally, machine learning models could help us classify all news paragraphs into predefined groups—the group of news paragraphs whose content flags an increase in climate transition risk and the group of paragraphs that announce a decrease in climate transition risk. However, to reliably tell whether a piece of news signifies a rise or drop in transition risk has always been a challenge, because assessing the risk is not only subjective, as the

[2] TF-IDF score is a numerical statistic that is intended to reflect how important a word is to a document in a collection or corpus. For more details, please refer to [TF-IDF Wiki](#).

same climate policy may be good news for some industries whereas bad news for others, but also requires considerable expertise. Therefore, the process of text classification cannot be entirely automated.

To solve this problem, we follow the supervised learning approach with customized data labels. To label the news data with relatively high confidence, we conduct a detailed narrative analysis to dissect the news content. As the first step, we randomly select roughly 800 representative paragraphs that spread across the sample period, which constitute a restricted sample. A group of four researchers then read through 50 paragraphs and agree on the labeling criteria. The general rule is that we label the paragraphs based on whether the content implies stricter mitigation policies or lighter mitigation policies, and label it as climate favorable or unfavorable.[3] Examples of manually labelled news paragraphs are presented in the appendix to help illustrate our labeling criteria.

The rest of the restricted sample is then split into $C_4^2$, or six portions. Each researcher labels three portions independently, so that each portion is being labelled by two researchers. If the two researchers give the same label, we accept the label as it is. If they disagree, we would introduce a third researcher and take the majority vote.

In this way, we obtain about 800 labeled news paragraphs, which will be used by machine learning models to understand the context and make predictions.,

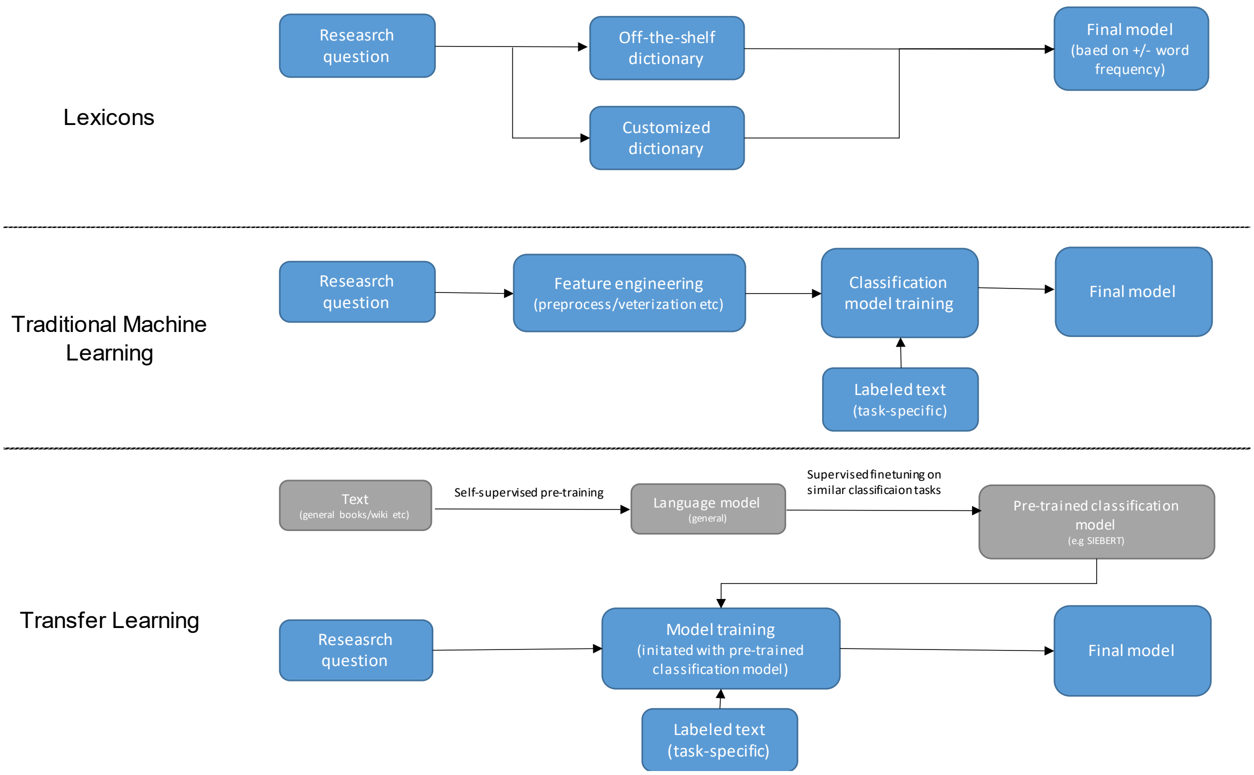
### 3.4 Applying Machine Learning Algorithms

We use the 800 labeled news paragraphs to teach the machine learning model to label the remaining sample for us. These 800 paragraphs are divided into training set (500), validation set (150), and test set (150) three splits that are commonly used in different stages of the creation of a machine learning model. The test data set used to provide an unbiased evaluation of a final model fit on the training data set. As it is never used in training process, it is also called a holdout data set.

In the case of text classification, parameters refer to configuration variables that capture features of the text such as the length of a paragraph, the relationship between the first and last word. They are tailored to a specific task and adjusted as the model learns. The model training process is achieved by supervised learning through optimization methods such as stochastic gradient descent. The model then produces a result, for each paragraph—favorable or unfavorable—and compares the result with our label, which is the answer key. Based on the result of the comparison, the model parameters are adjusted and optimized until the accuracy rate stabilizes.

[3] If the content of the title and the content of the text point to different directions of change in climate transition risk, the direction of the title dominates.

Figure 2. Sentiment Classification Strategies Compared[4]




More specifically, we followed the more recent transfer learning strategy for our task as shown in Figure 2. We adopted a transformer based deep learning model architecture (Vaswani et al. 2017) which demonstrated state-of-the-art performance for text classification tasks. We initiate our model weights from SIEBERT ("Sentiment in English"). It is an open-source model checkpoint initialized from RoBERTa-large, then fine-tuned and evaluated on 15 text classification data sets. It is a popular pretrained model for general purpose text classification tasks (Hartmann et al. 2022). We further finetuned the model on our customized training data.

We conducted a small scale hyperparameter tuning on our training and validation split. As our training data is relatively small, we did not go for the set of hyperparameters that maximize the accuracy in validation split. Instead, we chose a set of hyperparameters that yield similar accuracy in both training and validation split. Finally, we evaluated our model in the test split and achieved 70% accuracy.
This is a decent performance given that the average accuracy rate yielded by human raters is a little over 80%.

As the final step, we apply the model to the rest of the news data through model inference, and obtain the labels of all climate policy-related paragraphs. In this way, we get the number of climate favorable news paragraphs and the number of unfavorable news paragraphs, which, after being scaled by the total number of news paragraphs, become our climate news factors.

[4] Figure modified based on Hartmann et al. 2022 (Fig. 2).

### 3.5 Collecting Stock Price Data

The subjects of study are all Canadian oil and gas companies in the Standard and Poor's (S&P) TSX index, as well as representative U.S. and EU companies.

Stock price data is gathered from the Bloomberg Terminal. We collect company name, index membership, industry classification, monthly stock price, absolute $CO_2$ emissions, and total GHG emissions data for all the constituents of the following stock indices: S&P TSX, S&P Europe, S&P SIOP, S&P SIOS, S&P Utilities, S&P Steel, S&P Metals, and Cement, which are benchmark Canadian index, European index, oil and gas exploration and production select industry index, oil and gas equipment select industry index, utilities, steel, metals, and cement industries' indices, respectively.

Variables on $CO_2$ and GHG emissions are dropped due to the large number of missing values. The final dataset spans over 19 years from January 2004 to March 2022, covering 1751 companies.

Our factor construction method closely follows that of Fama and French (1992, 1993). Information on market premium, size premium, and value premium, which are traditionally considered to be able to capture cross-sectional return variations, along with the risk-free rate, can be found in the official website of University of Chicago professor Kenneth French. Since we are interested in cross-market comparisons, we gather 3 asset pricing factors for the North American market and the European market. We also retrieve 2 additional factors, cash earning to price ratio and dividend yield ratio, alongside the momentum factor for use in robustness checks.

### 3.6 Correlating Climate Factor with Stock Price

Risk premium is calculated using a set of asset pricing models. In the baseline model, we estimate the following equation

$$r_{i,t} - r_{f,t} = \alpha_i + \beta_i C_t + \gamma_i X_t + \varepsilon_{i,t} \tag{1}$$

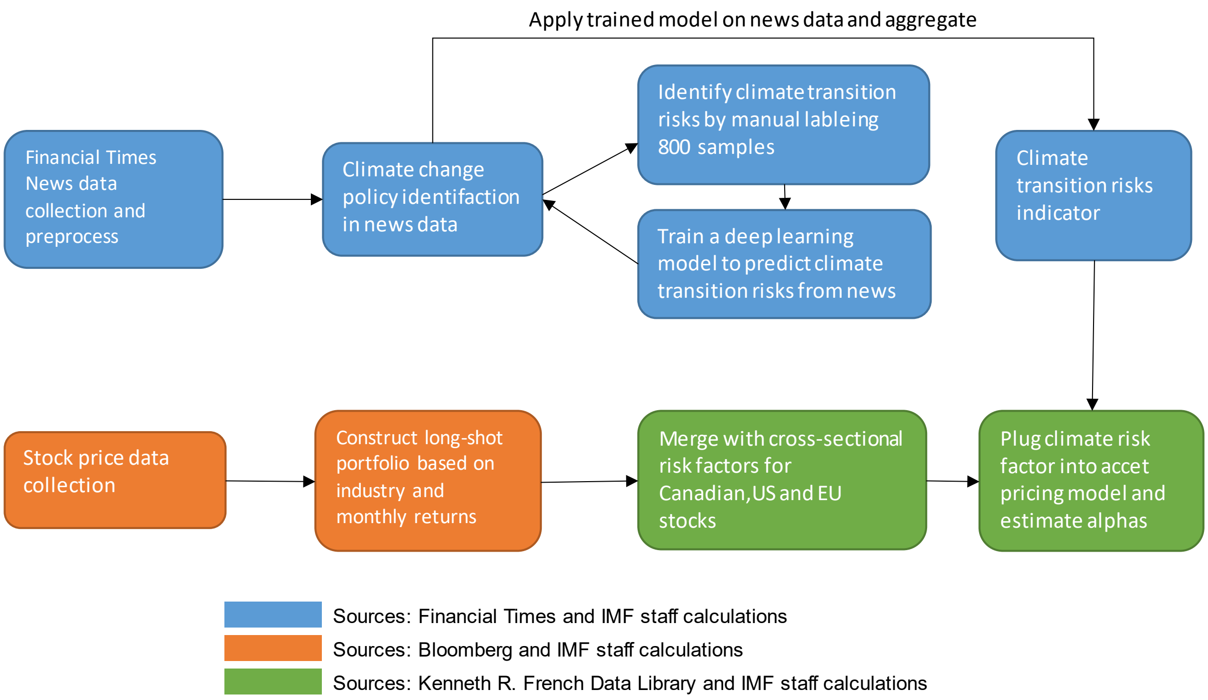
where $r_{i,t}$ is the monthly return on stock $i$, $r_{f,t}$ is the monthly risk−free return, $C_t$ is the news−based climate news factor, $X_t$ is a vector of factors that have been found to explain the performance of stock returns, and $\varepsilon_{i,t}$ is the error term. The overlapping months between the news data and the stock data are from January 2005 to March 2022, leading to a time series of 206 monthly returns. The significance and magnitude of $\beta_i$ are of interest to our study. If we observe a statistically significant $\beta_i$ , it means that our novel climate risk factor can explain the variations in stock returns.

We also investigate whether the climate news factor is relevant for investors by creating long-short portfolios. As opposed to regression-based asset pricing tests, portfolio sorting represents a non-parametric approach to testing for the relevance of asset pricing factors.

We begin by sorting stocks based on the sensitivity of each stock's returns to the model-generated climate news factor. We then create a long-short portfolio that mimics the trading behavior of buying stocks with the largest climate sensitivities, or betas, and selling the stocks with the lowest climate sensitivities. The abnormal return of the mimic portfolio, if any, is estimated using equation (1). The significance and magnitude of $\alpha_i$ are of interest to our study. If the long-short portfolio yields statistically significant returns when other risk factors are controlled, it indicates that the climate news factor is priced by the investors.

The helicopter view of our methodology is presented in the flow chart below.

Figure 3. Research Methodology Flowchart



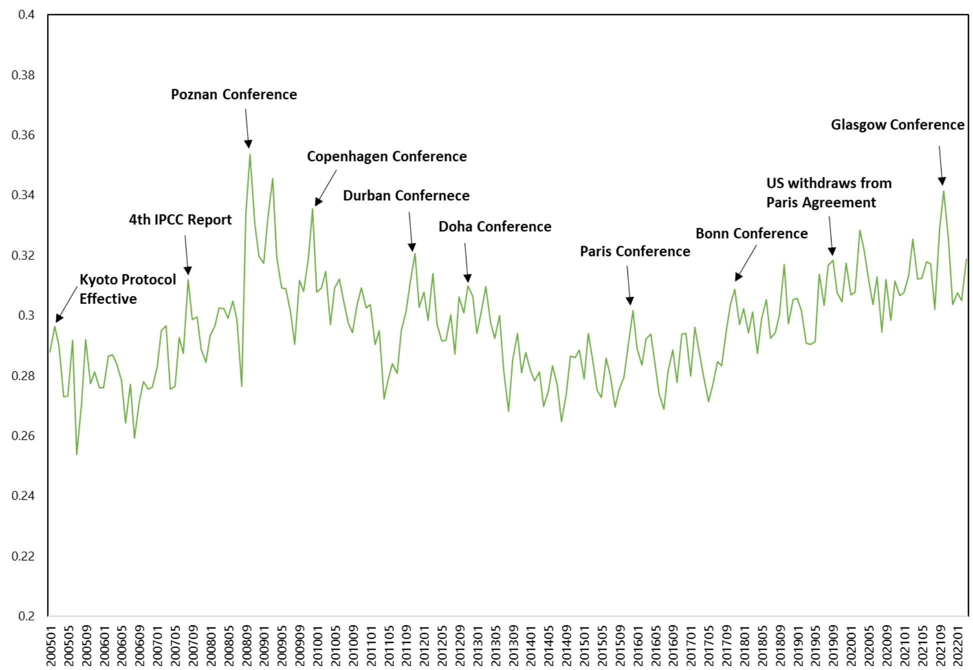

Given our focus on the oil and gas sector, in an alternative approach, we sort all companies based on their industry classification on the assumption that oil and gas companies are more sensitive to climate transition risks. The companies in the sample are thus divided into two groups—the group of oil and gas companies and the rest. Our long-short portfolio is then constructed by longing the stocks of oil and gas companies and shorting in the stocks of non-oil and gas companies. If we observe significant abnormal returns on the climate news factor after controlling for other risk factors, this suggests that climate risk is relevant for investors in the stock market.

# 4. Results and Discussion

## 4.1 Climate News Factor

In Figure 3, we plot the time series of climate policy-related news coverage over the sample horizon, annotated with climate-relevant events.

Figure 4. Intensity of Climate News Coverage

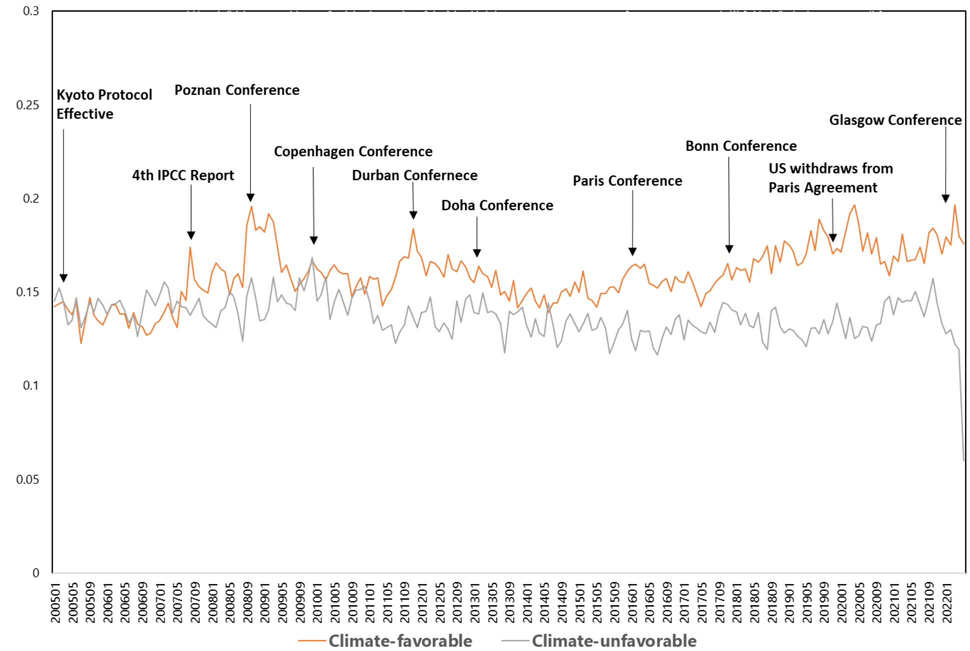



Sources: *Financial Times* and author calculations

The index regularly shows increases around salient climate events, such as world climate summits, the announcement of internationally binding climate accords, and the release of important climate reports.

We further disaggregate the news based on its climate impact and generate two sub-indices—climate favorable news and climate unfavorable news. The time series of the two sub-indices are shown in Figure 4.

Figure 5. Intensity of Climate Favorable and Unfavorable News




Sources: *Financial Times* and author calculations

The indices are the ratios of climate favorable/ unfavorable news over the total number of news paragraphs. As expected, international summits where the political leaders of many countries meet to discuss issues related to climate change in an attempt to reduce global carbon emissions, are associated with tighter mitigation policies, and are climate favorable news by our definition.[5]

It is worth emphasizing that the definition of "news" in our study is not limited to the arrival of new information. Rather, it is extended to include the incremental change in investors' perception of climate risks, which could also move the market. The indicator tracks real-time climate news, and thus reflects current attitudes towards climate events. It may even reflect attitudes that exist prior to the events themselves, given that news coverage often precedes them. However, it has limitations when it comes to capturing the retrospective significance of an event. For example, while the Paris Conference resulted in a landmark agreement with lasting implications for future climate actions, its importance may not necessarily have been appreciated in contemporary news coverage, whereas the significance of the Poznan COP conference may prove to be less consequential when viewed in retrospect.

We further validate the index by conducting manual checks on a randomly selected sample, and the movement of our indicator surrounding this event is also similar to that of other indices in the literature. (e.g. Engle et al., 2020; Faccini et al., 2021). Additional tests to validate the indicator can be found in the robustness check section.

[5] Note that the spike is much more moderate for controversial events, as our index is constructed as the percentage of negative news rather than the raw counts. The movement of our index surrounding this event is similar to that of other indices in the literature. (e.g. Engle et al., 2020; Faccini et al., 2021)

### 4.2 The Effect of Climate Risk on Oil and Gas Companies

We then add the climate news factor to traditional Fama-French three factor model, which includes a market factor, a size factor, and a value factor, and examine whether the climate risk elicited by the news factor is useful for explaining the returns of Canadian oil and gas sector stocks.

We hypothesize that news on tighter mitigation policies, which is defined as climate-favorable news in this study, represents a bad signal to the oil and gas sector. In response to such a negative shock, investors would short sell stocks in the oil and gas sector, thus reducing their prices. As a result, we should observe a negative coefficient on the risk factor.

Conversely, news on lighter mitigation policies, which is labeled as climate unfavorable here, constitutes a relatively good signal to the oil and gas sector. Investors would react by buying stocks in the oil and gas sector, thus boosting their prices. As a result, we should find a positive coefficient on that risk factor.

The results, reported in Table 1, are consistent with our hypothesis. However, only the coefficient on the climate unfavorable factor is statistically significant (Model 2). In terms of economic magnitude, one percentage increase in the factor value is associated with 14 percentage increase in stock returns. The impact of the climate risk factor is much larger than market, size, and value factors.

Table 1. Pricing of Climate News Factor in Canadian Stock Market

| | (1) | (2) |
|---|---|---|
| Climate-favorable | -2.945 | |
| | (4.490) | |
| Climate-unfavorable | | 14.259*** |
| | | (2.174) |
| Mkt-RF | 1.974*** | 2.459*** |
| | (0.247) | (0.267) |
| SMB | 1.827*** | 4.395*** |
| | (0.340) | (0.492) |
| HML | 2.004*** | 4.168*** |
| | (0.187) | (0.430) |
| Constant | 5.289 | -1.973 |
| | (7.476) | (3.096) |
| Observations | 13,861 | 13,861 |
| R-squared | 0.468 | 0.468 |

Sources: Bloomberg, French data library, and author calculations

Investors with long positions in oil and gas assets, one may argue, may perceive any current relaxation of climate mitigation efforts as a postponement of stricter measures in the future. Consequently, it remains uncertain whether the expected returns on fossil fuel assets should rise and incentivize further investment, given that expected returns are typically assessed based on the present value of discounted future returns. Admittedly, investors could be rational and able to price in all policy changes in future periods. However, it has also been widely documented in the literature that investors demonstrate considerable short-termism, pursuing uninformative short-term speculation and neglecting long-run fundamentals (see e.g. Bushee, 1998; Froot et al., 1992; Stein, 1989). Our results lend support to the latter theory.

### 4.3 Asymmetrical Responses to Climate Favorable and Unfavorable News

The results in Table 1 point to asymmetrical responses of Canadian oil and gas sector stocks to climate favorable and unfavorable news. Our findings from the portfolio sorting approach lend further evidence.

Since an increase in the climate favorable news factor signals stricter mitigation policies, and thus should be bad news for oil and gas companies, in response to such a negative shock, investors would sell oil and gas stocks, thus decreasing their prices and increasing their returns. As a result, the long-short portfolio would yield a positive alpha. In a similar vein, an increase in climate unfavorable news should be associated with a negative alpha. The results in Table 2 confirm our hypothesis, indicating that firms have incentives to manage their climate risk exposure.

Table 2. Portfolio Sorting Analysis of Canadian Stock Market

| **Panel A: Fama-French Three-Factor Model** | | |
|---|---|---|
| Climate-favorable | Climate-unfavorable | Total |
| 0.105 | -0.769*** | -0.875*** |
| (0.157) | (0.107) | (0.177) |
| **Panel B: Market Model** | | |
| Climate-favorable | Climate-unfavorable | Total |
| 0.045 | -0.745*** | -0.882*** |
| (0.157) | (0.109) | (0.179) |

Sources: Bloomberg, French data library, and author calculations

While there is a significantly negative risk premium associated with climate unfavorable news among the group of oil and gas companies, we find that the risk premium tied to climate favorable news is positive but statistically insignificant. In other words, an ease in climate mitigation constitutes a positive shock to oil and gas companies but tighter mitigation policies do not necessarily translate into bad news.

### 4.3 Cross-Country Evidence

While market-wide climate risk is expected to be affect companies across countries, the extent of pricing could vary, depending on the level of exposure to climate change, degree of market efficiency, etc. Canadian firms could be more sensitive to climate risk factors than US and EU firms, due to its higher reliance on the oil and gas sector. We conduct a cross-country comparison by performing the same set of exercises on US and EU companies.

Table 3. Pricing of Climate News Factor in the US Stock Market

| **Panel A: Fama-French Three-Factor Model** | | |
|---|---|---|
| Climate-favorable | Climate-unfavorable | Total |
| 0.087 | -0.692*** | -0.783*** |
| (0.153) | (0.107) | (0.176) |
| **Panel B: Market Model** | | |
| Climate-favorable | Climate-unfavorable | Total |
| 0.149 | -0.713*** | -0.774*** |
| (0.151) | (0.105) | (0.173) |

Sources: Bloomberg, French data library, and author calculations

Table 3 displays the average returns of long-short portfolios made up of companies traded in the US stock market. In the baseline Fama-French Three-Factor model, we find that the average monthly abnormal return of US companies, which stands at 0.69 percentage points, is slightly smaller in magnitude compared with that of Canadian companies, which is estimated to be 0.77 percentage points. Oil and gas sector companies in Canada demonstrate a slightly higher sensitivity to climate-related transition risk than those based in the United States.

Table 4. Pricing of Climate News Factor in the EU Stock Market

| **Panel A: Fama-French Three-Factor Model** | | |
|---|---|---|
| Climate-favorable | Climate-unfavorable | Total |
| 0.131 | -0.715*** | -0.770*** |
| (0.138) | (0.096) | (0.160) |
| **Panel B: Market Model** | | |
| Climate-favorable | Climate-unfavorable | Total |
| 0.120 | -0.741*** | -0.805*** |
| (0.139) | (0.097) | (0.161) |

Sources: Bloomberg, French data library, and author calculations

When we turn to the EU stocks, we find the direction of change is the same as that of the Canadian and US market, though of varying magnitude. EU oil and gas companies react significantly to climate unfavorable news, or news on lighter climate mitigation, whereas their reaction to climate favorable news, or news on stricter climate mitigation, is rather muted. The fact that companies treat climate transition risk similarly regardless of their listing location, could perhaps reflect the global nature of these multinationals and their investor base.

# 5. Robustness Checks

## 5.1 Using Alternative Asset Pricing Models

We have shown from Table 2 to Table 4 that our results are robust to various asset pricing model specifications, including the market model and the Fama-French three factor model. In additional asset pricing tests, we introduce the Fama-French five factor (Fama and French, 2014) and the Carhart four factor (Carhart, 1997).

Table 5. Pricing of Climate News Factor Using Alternative Asset Pricing Models

| **Panel A: Fama-French Five-Factor Model** | | |
|---|---|---|
| Climate-favorable | Climate-unfavorable | Total |
| 0.113 | -0.707*** | -0.781*** |
| (0.210) | (0.152) | (0.248) |
| **Panel B: Carhart Four Factor Model** | | |
| Climate-favorable | Climate-unfavorable | Total |
| 0.124 | -0.723*** | -0.806*** |
| (0.210) | (0.149) | (0.243) |

Sources: Bloomberg, French data library, and author calculations

The Fama-French five factor model is directed at capturing the size, value, profitability, and investment patterns in average stock returns. With the addition of profitability and investment factors, the results remain stable (Table 5, Panel A).

The Carhart four factor model, proposed by Mark Carhart in 1997, adds an extra momentum factor to the Fama-French three factor model. Momentum refers to the speed or velocity of price changes in a stock, which, reflected in the model, is the premium on winners minus losers. Our conclusions remain unchanged after introducing the momentum factor, as shown in Panel B of Table 5.

## 5.2 Using Alternative Climate Risk Measures

Our results are also robust to different definitions of climate risk. In Faccini et al. (2021), the authors believe that an increase in investor attention can be reflected either by an increase in the number of news articles published on climate change, and/or an increase in the proportion of articles devoted to the topic of climate change, within a given number of articles published. Therefore, there is no need for the climate news factor to be standardized by dividing the number of climate policy-related paragraphs by the total number of monthly published news paragraphs.

Following this definition yields similar results (Table 6). An increase in the intensity of climate unfavorable news coverage is associated with significantly negative abnormal returns, i.e., a positive shock. However, it is worth noting that an increase in the coverage of climate favorable news also leads to significant abnormal returns, which highlights the importance of climate policy communication to the public via media outlets, as more information on climate mitigation, whether tighter or looser policy measures, has been positively received by the market.

Table 6. Pricing of Climate News Factor Using Alternative Climate Risk Measures

| Panel A: Fama-French Three-Factor Model | | |
|---|---|---|
| Climate-favorable | Climate-unfavorable | Total |
| -0.352*** | -0.390*** | -0.384*** |
| (0.054) | (0.051) | (0.053) |
| **Panel B: Market Model** | | |
| Climate-favorable | Climate-unfavorable | Total |
| -0.331*** | -0.357*** | -0.355*** |
| (0.057) | (0.055) | (0.057) |

Sources: Bloomberg, French data library, and author calculations

## 5.3 Adopting Different Portfolio Sorting Strategies

In an alternative approach to testing the validity of the climate news factor, we sort stocks in descending order in decile portfolios, based on the magnitude of their estimated climate betas with respect to the factor. A rolling window of daily observations over the past three years is used to estimate climate betas, and the window is rolled forward by one-month at each estimation step. The post-ranking value-weighted portfolio monthly return over the next month is then computed, and the resulting spread portfolio return is calculated as the difference between the return of highest-ranking portfolio with highest climate betas minus the return of the lowest-ranking portfolio with lowest climate betas.

Table 7. Pricing of Climate News Factor Using Different Sorting Strategies

| Panel A: Fama-French Three-Factor Model | | |
|---|---|---|
| Climate-favorable | Climate-unfavorable | Total |
| 0.134** | -0.752*** | -0.858* |
| (0.052) | (0.273) | (0.507) |
| **Panel B: Market Model** | | |
| Climate-favorable | Climate-unfavorable | Total |
| 0.133*** | -0.550* | -1.324*** |
| (0.046) | (0.307) | (0.435) |

Sources: Bloomberg, French data library, and author calculations

The baseline model includes Fama-French three factors (Table 7, Panel A). In a series of additional tests, we include only the market factor (Panel B) and divide stocks into quintiles/quartiles/terciles portfolios, the results still hold.

## 5.4 Focusing on Canadian Specific News

While climate change is widely recognized as a market-wide risk (World Economic Forum, 2022) and Canada has been a leading advocate for global climate action (Bloomberg, 2022; Government of Canada, 2022), it would still be worthwhile to explore the price effect of climate-related news that has a special reference to Canada.

Out of the whole sample of climate-related tweets, we picked those on Canada using an array of country identifiers. (Schrodt, 2015) The results of this exercise are presented in Table 8. While the coefficients are consistent with our hypothesis, the magnitudes are significantly larger, indicating stronger effect of Canada-specific news on the domestic market.

Table 8. Pricing of Climate News Factor (Canada-specific) in Canadian Stock Market

| | (1) | (2) |
|---|---|---|
| Climate-favorable | -5.958 | |
| | (9.083) | |
| Climate-unfavorable | | 42.281*** |
| | | (6.446) |
| Mkt-RF | -1.514*** | 3.681*** |
| | (0.556) | (0.381) |
| SMB | 6.034*** | -0.502*** |
| | (0.695) | (0.515) |
| HML | 1.510*** | 1.184*** |
| | (0.177) | (0.187) |
| Constant | 5.564 | -32.278*** |
| | (7.883) | (6.039) |
| Observations | 13,861 | 13,861 |
| R-squared | 0.468 | 0.468 |

Sources: Bloomberg, French data library, and author calculations

5.5 Dropping ESG Tag

ESG, short for Environmental, Social, and Governance, has become a crucial force in investing due to climate change. (OECD, 2020) Despite the fact that incorporating risks associated with climate change and stranded assets stemming from the climate transition is increasingly recognized as a central element to the ESG environmental pillar, several inherent flaws—lack of standardization, subjectivity, data quality concerns, conflicting priorities, greenwashing and impact washing—have rendered the index a less-than-optimal framework for evaluating climate change impacts. (Elmalt et al., 2021; Harvard Business Review, 2022) Therefore, in this subsection, we rerun the climate keyword search without including the ESG tag, and the findings do not qualitatively differ from our main results.

Table 9. Pricing of Climate News Factor (Without ESG) in Canadian Stock Market

| | (1) | (2) |
|---|---|---|
| Climate-favorable | -2.994 | |
| | (4.564) | |
| Climate-unfavorable | | 10.035*** |
| | | (1.530) |
| Mkt-RF | 2.039*** | 2.543*** |
| | (0.248) | (0.272) |
| SMB | 1.740*** | 3.617*** |
| | (0.341) | (0.414) |
| HML | 1.971*** | 3.437*** |
| | (0.185) | (0.332) |
| Constant | 5.435 | -1.329*** |
| | (7.691) | (0.212) |
| Observations | 13,861 | 13,861 |
| R-squared | 0.468 | 0.468 |

Sources: Bloomberg, French data library, and author calculations

5.6 Including “Climate-Benign” Label

The news passages are categorized into two groups: "climate-favorable" and "climate-unfavorable". Nevertheless, this binary classification may be too limited, and it could be beneficial to incorporate a third category, labeled as "climate-benign", to encompass instances where the news does not have a positive nor negative connotation regarding climate policy. Including this additional classification could enhance the accuracy and informativeness of the other two categories and potentially lead to more robust results.

To obtain the “climate-benign” category, we remap the sentiment metric to climate labels. A ratio in sentiment analysis is a score that gauges the confidence interval of negative and positive sentiments conveyed in comments. Typically, this is depicted on a scale ranging from 0 to 1, with the low end of the scale indicating predominantly negative responses and the high end of the scale signifying mainly positive responses.

In previous exercises, we adopt a binary label, which means all sentiment scores higher than or equal to 0.5 are categorized as positive, and those lower than 0.5 are classified as negative. In the new mapping, we introduce a third category, labeling scores higher than 0.8 as positive, lower than 0.2 as negative, and the rest neutral. The neutral labels are also called “climate-benign” labels, suggesting that the news content is neither favorable nor unfavorable to climate. Taking into consideration the new “climate-benign” label does not fundamentally change our results, as shown in Table 10.

Table 10. Pricing of Alternative Climate News Factor in Canadian Stock Market

| | (1) | (2) |
|---|---|---|
| Climate-favorable | -2.892 | |
| | (4.409) | |
| Climate-unfavorable | | 11.028*** |
| | | (1.681) |
| Mkt-RF | 2.057*** | 2.391*** |
| | (0.249) | (0.263) |
| SMB | 1.946*** | 3.747*** |
| | (0.338) | (0.426) |
| HML | 1.992*** | 3.343*** |
| | (0.186) | (0.320) |
| Constant | 4.683 | -1.235*** |
| | (6.585) | (0.197) |
| Observations | 13,861 | 13,861 |
| R-squared | 0.468 | 0.468 |

Sources: Bloomberg, French data library, and author calculations

# 6. Conclusion

While climate change has lagged behind social issues during the Covid-19 crisis, the COP 26 and the green race have recently changed the equation, putting climate risk back on the agenda of investors and even goes beyond ESG investing.

Using state-of-the-art machine learning techniques, we propose a news-based index to measure the intensity of climate mitigation policies. The index proves to be effective in tracking major climate policy events with a relatively high frequency. We convert the index into a climate risk factor and apply it to a set of asset prices models, in order to estimate market response to different types of mitigation policies. The results consistently show that risk from climate mitigation has been reflected in the stocks of Canadian oil and gas companies. An ease in mitigation policies, which should generally be viewed as good news for the oil and gas sector, is associated with an upward movement in their stock prices. However, stronger mitigation policies do not necessarily represent a negative shock. The oil and gas sector experiences a downward correction in stock valuations, but the price fall is not statistically significant. We extend the analysis to US and EU stock markets and find a similar asymmetric response to climate-favorable and -unfavorable news. The sensitivities, however, are smaller than in the Canadian market.

Our findings indicate that climate mitigation policies are relevant for investors and current policies provide right incentives, as reflected in the movement of stock prices in the expected direction. However, mitigation policies captured by media coverage have limited, asymmetric impact on asset valuations. The impact of climate change is far-reaching. (UTZ, 2022) Beyond the oil and gas sector, how the rest of the economy responds to climate change policies could be important avenues for future research.

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# Appendix

Table 1. Sample Labels of News Data

| Publication Date | Title | Text | Label |
|---|---|---|---|
| 2008-08 | more suppliers raise energy bills | another government option, one considered more likely, is to force companies to pay for more carbon emissions permits to cover their power station output. currently most of their emissions permits are free. | Favorable |
| 2015-10 | oil majors to collaborate on cleaner energy | eight big oil and gas groups are to meet in paris next week where they will announce research and development co-operation on cleaner energy, ahead of a un global climate change conference in december, according to the chief executive of total. | Neutral |
| 2018-08 | us auto sector should have been more careful what it wished for | as soon as he was elected, carmakers started urging mr trump to rethink president barack obama's planned vehicle fuel economy and emissions standards for 2022-25. last week, the trump administration set out its proposals for fulfilling that request... | Unfavorable |

PUBLICATIONS

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