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Janus on the Roads: Extreme Temperature and Traffic Accidents

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Climate change is increasingly shaping daily life by amplifying the frequency and severity of extreme weather events such as heatwaves, cold spells, hurricanes, heavy rainfall, and wildfires. While prior research has largely focused on the direct economic and health impacts of such events, their effects on everyday behavior—and the resulting societal risks—remain underexplored. This study examines whether weather-induced stress and compromised attention, both of which can result from extreme temperatures, contribute to increased traffic accident rates. Drawing on panel fixed effects and vector error correction models applied to South Korean data from 2005 to 2023, we find that both extreme heat and cold weather are significantly associated with higher accident incidence. This relationship has intensified in recent years, particularly among young and prime-age adults, coinciding with growing climate volatility. Our findings reveal important behavioral and public safety dimensions of climate change and underscore the need for integrated climate adaptation policies. Such policies should address not only physical health risks but also the more subtle disruptions to daily functioning and the vulnerability of public transport systems, offering important implications for automobile insurers.

Keywords: Climate Change, Extreme Temperature, Traffic Accidents, Behavioral Responses, Automobile Insurance
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I. Introduction

Climate change has emerged as a major threat to human well-being, with extreme temperatures—both unusually hot and cold—and natural disasters such as wildfires, hurricanes, and heavy rainfall posing substantial health and economic risks. High temperatures have been linked to increases in cardiovascular disease (Khraishah et al., 2022; Liu et al., 2022; Yin & Wang, 2017), respiratory symptoms (Anderson et al., 2013; Bernstein & Rice, 2013; Lin et al., 2009), sudden heart attacks (Kang et al., 2016), and hypertension (Kang et al., 2020; Zhou et al., 2023), while extreme cold poses dangers particularly in regions ill-prepared for cold spells. Moreover, natural disasters can generate secondary health impacts by displacing populations, disrupting access to education (Kousky, 2016; Rush, 2018) and healthcare (Kousky, 2016; Nashwan et al., 2023), and exposing individuals to toxic pollutants (Binder & Sanderson, 1987; Young et al., 2004), including hazardous gases (Baxter et al., 1989; Duclos et al., 1990; Gribble, 1994). Beyond adverse health outcomes, climate-induced economic disruptions—such as infrastructure failures, machine malfunctions, and large-scale damage caused by natural disasters—are also intensifying (Botzen et al., 2019; Kadri et al., 2014). In response, an extensive body of literature has emerged quantifying the direct health and economic consequences of climate change.

However, despite considerable research on the direct effects of climate change on health and economic outcomes, relatively few studies have examined the relationship between temperature extremes and traffic accidents. Recent evidence from Iran suggests that both heat waves and cold spells are associated with increases in accident incidence (Eltemasi & Behtooiey, 2024). In Europe, temperature has been identified as a key

determinant of traffic accidents in Finland (Perrels et al., 2015), while unusually high temperatures have been linked to rising accident rates in Poland (Pińskwar et al., 2023). In South Korea, a study using data from Busan Metropolitan City finds that daily mean temperatures above 24 °C are associated with a significant increase in traffic accidents (Lee et al., 2015).

Despite these findings, important gaps remain in the literature. First, most existing studies do not account for the long-term dynamics linking climate change, increasing temperature variability, and evolving traffic safety risks. Longitudinal analyses spanning several years – ideally more than a decade – are needed to assess whether the effects of extreme temperatures on road safety have intensified in parallel with growing climate volatility. Second, country-specific differences in climatic conditions and road infrastructure standards suggest that the impact of temperature extremes on traffic accidents is likely to vary regionally, particularly between developed and developing countries. Third, populations accustomed to persistently hot or cold climates may exhibit distinct patterns of vulnerability and behavioral adaptation.

This study examines the effects of extreme temperatures on traffic accidents in South Korea over the period from 2005 to 2023. Using panel fixed effects and vector error correction models, we find that increases in both average maximum and minimum temperatures are significantly associated with a rise in traffic accidents. Notably, these effects are more pronounced in recent years, suggesting that climate change is intensifying the frequency of weather-related traffic incidents. The rise in accidents is primarily driven by young and prime-age adults, indicating heightened vulnerability among the working-age population. Furthermore, we observe seasonal variation: during summer, higher average maximum temperatures are linked to more accidents, while in winter, lower average minimum temperatures are associated with

increased accident rates. These findings indicate that as climate change amplifies seasonal temperature extremes, the burden of weather-related traffic accidents is likely to grow, underscoring the need for targeted mitigation and adaptation strategies.

We make several important contributions to the existing literature. First, by analyzing a long time span from 2005 to 2023, we assess whether the magnitude of temperature-related traffic accidents has increased over time, thereby capturing the growing influence of climate change on road safety. Second, through the application of a time-series vector error correction model, we identify the age groups most vulnerable to extreme temperatures. Given that most traffic accident datasets lack age-specific information, our findings offer valuable insights for the design of targeted policy interventions, particularly for the working-age population. Third, we highlight substantial seasonal heterogeneity in temperature effects: increases in maximum temperatures are strongly associated with higher accident rates during the summer, while decreases in minimum temperatures significantly correlate with accident incidence in winter. Since South Korea experiences sharp seasonal variation in temperature alongside generally well-developed transport infrastructure, our findings suggest that even countries with robust road systems require season-specific traffic safety policies tailored to their climatic conditions.

II. Data and Methodology

Our empirical analysis draws on five publicly available datasets from three distinct South Korean institutions. First, we utilize monthly, province-level traffic accident data from 2005 to 2023, obtained from the Korean Statistical Information Service.[1] For the time-series analysis by demographic groups, we additionally employ monthly traffic accident data disaggregated by age group over the same period, also provided by the Korean Statistical Information Service.[2] Unfortunately, the data do not include a breakdown by cause of accident. Second, we incorporate weather data from the Korea Meteorological Administration, which includes monthly average maximum temperature, average minimum temperature, and precipitation at the measuring-station level from 2005 to 2023.[3] Lastly, regional characteristics such as gross regional domestic product (GRDP) and population are sourced from Statistics Korea.[4] All datasets are publicly available for research purposes.

In our main empirical analysis, we employ a panel fixed effects model to estimate the association between extreme temperatures and traffic accidents, as specified in Equation (1):

1) Information on number of monthly provincial level traffic accidents can be found at: https://kosis.kr/statHtml/statHtml.do?orgId=132&tblId=DT_V_MOTA_016&conn_path=I3 [last accessed on July 17, 2025].
2) Information on number of monthly traffic accidents by age groups can be found at: https://kosis.kr/statHtml/statHtml.do?orgId=132&tblId=DT_V_MOTA_021&conn_path=I3 [last accessed on July 17, 2025].
3) Information on monthly weather can be found at: https://data.kma.go.kr/data/grnd/selectAsosRltmList.do?pgmNo=36 [last accessed on July 17, 2025].
4) Information on gross regional domestic product can be found at: https://www.index.go.kr/unity/potal/main/EachDtlPageDetail.do?idx_cd=1008 [last accessed on July 17, 2025] and regional (provincial-level) population can be found at https://www.index.go.kr/unity/potal/indicator/IndexInfo.do?cdNo=210&idxCd=F0002 [last accessed on July 17, 2025].

$$Accidents_{ytr} = \beta_0 + \beta_1 Temp + \beta_2 \mathrm{Pr}ecipitation + \theta^T Regional\ \ Covariates + \mu_y + \vartheta_r + \ \mu_y^T\ \vartheta_r + \ \pi_t + \ \epsilon_{ytr} \quad (1)$$

In Equation (1), ***Accidents*** denotes the number of traffic accidents occurring in year (***y***), month (***t***), and region (***r***). ***Temp*** refers to either the monthly regional average maximum temperature (***MaxTemp***) or average minimum temperature (***MinTemp***), depending on the model specification. ***Precipitation*** is the total monthly precipitation at the regional level. In the baseline model, we control for ***Regional Covariates***, specifically GRDP and regional population. Additionally, as an optional explanatory variables, on top of base-line as an optional explanatory variables, on top of base-line covariates, we control for car registration numbers, the number of heavy rainfall days per region per month, and the maximum monthly snow depth per region. The terms μ and ν denote year and region (province) fixed effects, respectively. The interaction term $\mu^T\nu$ captures year-varying regional fixed effects. Finally, π accounts for month fixed effects to control for seasonality. This model allows us to estimate the effect of extreme temperatures on traffic accidents while controlling for precipitation, regional heterogeneity, and temporal variations at both yearly and monthly levels. Descriptive statistics for the data underlying these panel regressions are shown in Table 1.

〈Table 1〉 Descriptive Statistics for Panel Analysis

Variable	Obs	Mean	Min	Max	Definition
Accidents	3,648	1127.78	219	5392	Monthly regional total number of accidents
		(1001.14)			
MaxTemp	3,648	18.556	-3.4	34.4	Monthly regional average maximum temperature (oC)
		(8.981)			
MinTemp	3,648	9.095	-14.14	25.93	Monthly regional average minimum temperature (oC)
		(9.661)			
Precipitation	3,648	112.325	0	1131	Monthly regional total precipitation (mm)
		(123.402)			
HeavyRain	3,648	0.701	0	4	Days with heavy rain per month (110mm or over)
		(0.318)			
SnowDepth	3,648	0.938	0	41.9	Maximum snow depth
		(3.072)			
Population	3,648	3142.48	542	13781	Regional population (thousand persons)
		(3130.89)			
GRDP	3,648	104172.6	9038	593556	Gross regional domestic product (billion won)
		(117391.5)			
Cars	3,648	1,276,229	213,310	6,525,098	Number of car registration by month
		(1,146,291)			

Note: standard deviations are shown in parentheses.

Since the number of traffic accidents by age group is only available as a national monthly time-series, we primarily employ a vector error correction model (VECM) to assess the relative contributions of young adults, prime-age adults, and older adults to temperature-related traffic accidents. Descriptive statistics for the time-series variables are shown in Table 2.

〈Table 2〉 Descriptive Statistics for Time-series Analysis

Variable	Obs	Mean	Min	Max	Definition
Total Accidents	228	17426.1	12005	21015	Monthly total number of accidents
		(1623.07)			
Young Adult	228	3348.26	2031	4413	Monthly accidents caused by individuals under 30
Accidents		(524.711)			
Adult Accidents	228	11427.7	7047	14396	Monthly accidents caused by individuals aged 30 - 59
		(1529.96)			
Senior Accidents	228	2845.17	633	5545	Monthly accidents caused by individuals aged 60 plus
		(1297.62)			
MaxTemp	228	18.409	0.523	32.036	Monthly average of daily maximum temperatures (oC)
		(8.905)			
MinTemp	228	8.332	-9.808	23.723	Monthly average of daily minimum temperatures (oC)
		(9.565)			
Precipitation	228	111.814	4.511	624.12	Monthly total precipitation (mm)
		(107.019)			

Note: standard deviations are shown in parentheses.

Before estimating the VECM, we assess the stationary of the variables using Augmented Dickey-Fuller (ADF) unit root tests. The regression equation used in these tests is as follows:

$$\Delta Y_t = \alpha + \beta_1 t + \beta_2 Y_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta Y_{t-i} + e_t \quad (2)$$

where Y represents the seven different variables of interest. We test the null hypotheses of unit roots (β_2=0) using MacKinnon (1991) critical values. As reported in Table 3, all variables are stationary in levels except for our measures of accidents caused by seniors, which is trend-stationary.[5)]

5) In a typical VECM analysis, variables should be either level stationary or trend stationary. Accordingly, using the levels of all variables - including *Senior Accidents* - is appropriate. Furthermore, we verify that all eigenvalues of the

〈Table 3〉 Unit Root Tests (Augmented Dickey Fuller Test)

Variable	Constant	Trend	Variable	Constant	Trend
Total Accidents	-7.156***	-7.304***	MaxTemp	-4.474***	-4.438***
Young Adult Accidents	-4.143***	-6.435***	MinTemp	-4.345***	-4.314***
Adult Accidents	-4.578***	-6.876***	Precipitation	-8.457***	-8.438***
Senior Accidents	-1.610	-6.443***			

Note: *, **, *** denote statistical significance at the 10%, 5%, and 1% level, respectively. Critical values of based on MacKinnon (1991).

Next, we determine the optimal lag length for the VECM analysis. To do so, we estimate a number of Vector Autoregression (VAR) model in levels using our monthly data and evaluate alternative lag structures using model selection criteria. Specifically, we rely on the Final Prediction Error (FPE) and the Hannan-Quinn Information Criterion (HQIC) to identify the most appropriate number of lags. Equation (3) presents the level VAR model employed in this step.

$$\begin{bmatrix} Accidents_t^j \\ Temp_t^l \\ \Pr ecipitation_t \end{bmatrix} = \begin{bmatrix} \alpha_1^{j,l} \\ \alpha_2^{j,l} \\ \alpha_3^{j,l} \end{bmatrix} + \sum_{i=1}^{k} A_{t-i}^{j,l} \begin{bmatrix} Accidents_{t-i}^j \\ Temp_{t-i}^l \\ \Pr ecipitation_{t-i} \end{bmatrix} + \begin{bmatrix} u_{1,t}^{j,l} \\ u_{2,t}^{j,l} \\ u_{3,t}^{j,l} \end{bmatrix} \quad (3)$$

Accidents denotes one of four dependent variables: the total number of traffic accidents (***Total Accidents***), accidents involving young adults (***Young Adult Accidents***), prime-age adults (***Adult Accidents***), or seniors (***Senior Accidents***). ***Temp*** refers to either the average maximum temperature (***MaxTemp***) or the average minimum temperature (***MinTemp***). Accordingly, we estimate four

estimated VECM lie within or on the unit circle, confirming the model's stability. Measured eigenvalues are available from the authors upon request.

variants (based on the four age groups) for each of the two VAR model specifications (one specification includes ***MaxTemp*** and the other ***MinTemp).*** Table 4 reports the optimal lag lengths selected using the FPE and the HQIC, following the estimation of all four variants across the two level VAR model specifications.

〈Table 4〉 Optimal Lags after Levels VAR

	Total Accidents		Young Adult Accidents		Adult Accidents		Senior Accidents	
Model	FPE	HQIC	FPE	HQIC	FPE	HQIC	FPE	HQIC
MaxTemp	13	13	13	13	13	13	12	12
MinTemp	13	13	13	13	13	13	12	12

Note: Both the Final Prediction Error (FPE) and the Hannan and Quinn Information Criterion (HQIC) suggest an optimal lag length of thirteen (i.e., k = 13) in both the MaxTemp and MinTemp specifications for three variants of the level VAR model presented in equation (2): *Total Accidents, Young Adult Accidents*, and *Adult Accidents*. For the *Senior Accidents* variant, the suggested optimal lag is twelve (i.e., k = 12) in both model specifications.

According to Table 4, the optimal number of lags for ***Total Accidents, Young Adult Accidents***, and ***Adult Accidents*** is 13 in both the ***MaxTemp*** and ***MinTemp*** model specifications, while the optimal lag length for ***Senior Accidents*** is 12.

To test for cointegration among the variables and to determine the final specification of the VECM, we apply Johansen's method (Johansen, 1991), using the optimal lags reported in Table 4. We primarily use the trace test (λ trace), which relies on likelihood ratio statistics to assess the significance of the estimated canonical correlations. Table 5 presents the results of the Johansen cointegration tests.

〈Table 5〉 Rank of Co-integration by Model Specifications

H0: Rank=r	5%	λtrace			
		Total Accidents	Young Adult Accidents	Adult Accidents	Senior Accidents
MaxTemp Specification					
r=0	29.68	32.50	31.57	31.17	42.57
r=1	15.41	13.61*	11.65*	14.17*	13.12*
r〈=2	3.76	1.22	0.01	0.36	0.38
MinTemp Specification					
r=0	29.68	38.16	33.80	34.82	51.54
r=1	15.41	14.47*	13.40*	14.13*	16.8637
r〈=2	3.76	1.33	0.01	0.56	0.26*

Note: columns labeled '5%' report the critical values at the 5% significance level. * indicates that the null hypothesis of r cointegrating vectors is not rejected at the 5% level.

In general, the number of cointegrating relationships is found to be one across all model specifications and accident variants, with the exception of the ***Senior Accidents*** variant under the ***MinTemp*** specification, where two cointegrating vectors are identified (r=2). Once the optimal lag lengths and the number of cointegrating relationships are determined, we proceed to estimate the VECM equations, as specified in Equations (4), (5), and (6) below:

$$\triangle Accidents_t^j = \alpha_{1,0} + \sum_{i=1}^{k} \alpha_{1,i} \triangle Accidents_{t-i}^j + \sum_{i=1}^{k} b_{1,i} \triangle Temp_{t-i}^l + \sum_{i=1}^{k} c_{1,i} \triangle \mathrm{Precipitation}_{t-i} + \theta_{Accidents}^T ECT_{t-1} + u_{1,t} \quad (4)$$

$$\triangle Temp_t^l = \alpha_{2,0} + \sum_{i=1}^{k} \alpha_{2,i} \triangle Accidents_{t-i}^j + \sum_{i=1}^{k} b_{2,i} \triangle Temp_{t-i}^l + \sum_{i=1}^{k} c_{2,i} \triangle \mathrm{Precipitation}_{t-i} + \theta_{Temp}^T ECT_{t-1} + u_{2,t} \quad (5)$$

$$\triangle \mathrm{Precipitation}_t = \alpha_{3,0} + \sum_{i=1}^{k} \alpha_{3,i} \triangle Accidents_{1,t-i} + \sum_{i=1}^{k} b_{3,i} \triangle Temp_{t-i}^{l} + \sum_{i=1}^{k} c_{3,i} \triangle \mathrm{Precipitation}_{t-i} + \theta_{\mathrm{Precipitation}}^{T} ECT_{t-1} + u_{3,t} \quad (6)$$

Here, ECT denotes the vector of error correction terms. The coefficients $\theta_{Accidents}$, θ_{Temp}, and $\theta_{Precipitation}$, commonly referred to as speed-of-adjustment parameters, indicate how quickly the system of cointegrated variables (Accidents, Temperature, and Precipitation) returns to its long-run equilibrium following short-term deviations. As such, these coefficients provide insight into the long-run dynamics among the cointegrated variables and the dependent variable (Bell & Rousseau, 2001; Cho, 2023; Zestos & Tao, 2002).

Finally, we examine the effects of extreme temperatures on traffic accidents during the summer and winter seasons. To this end, we return to the panel fixed effects model, restricting the sample to the months of July and August for summer, and January and February for winter. This seasonal analysis enables us to isolate and compare the distinct effects of average maximum and minimum temperatures within each period. Estimations are conducted using the model presented in Equation (7).

$$Accidents_{ytr} = \beta_0 + \beta_1 Temp + \beta_2 \mathrm{Precipitation} + \theta^T Regional\ \ Covariates + \mu_y + \vartheta_r + \pi_t + \epsilon_{ytr} \quad (7)$$

In this analysis, we do not include year-varying regional fixed effects ($\mu^T \nu$) due to the limited number of observations available in each seasonal subsample.

Ⅲ. Results

Table 6 presents the regression results based on the panel fixed effects model. The first two panels report estimates using the monthly average maximum temperature: Model 1 does not control for the optional explanatory variables (i.e. car registration numbers, days with heavy rain, and maximum snow depth), whereas Model 2 does. The remaining two panels present results using the monthly average minimum temperature; again, Models 1 and 2 correspond to the exclusion and inclusion of optional controls, respectively. Columns (2) and (3) report results from subsample analyses, where Column (2) restricts the sample to the period from 2005 to 2013, and Column (3) covers the period from 2014 to 2023.[6)]

6) The cutoff between 2013 and 2014 is chosen for convenience as a midpoint partition to compare earlier and later subsamples. The results are robust to shifting the dividing line to 2014/15. We do not claim that this cutoff represents a structural break.

〈Table 6〉 Panel Fixed Effect Results

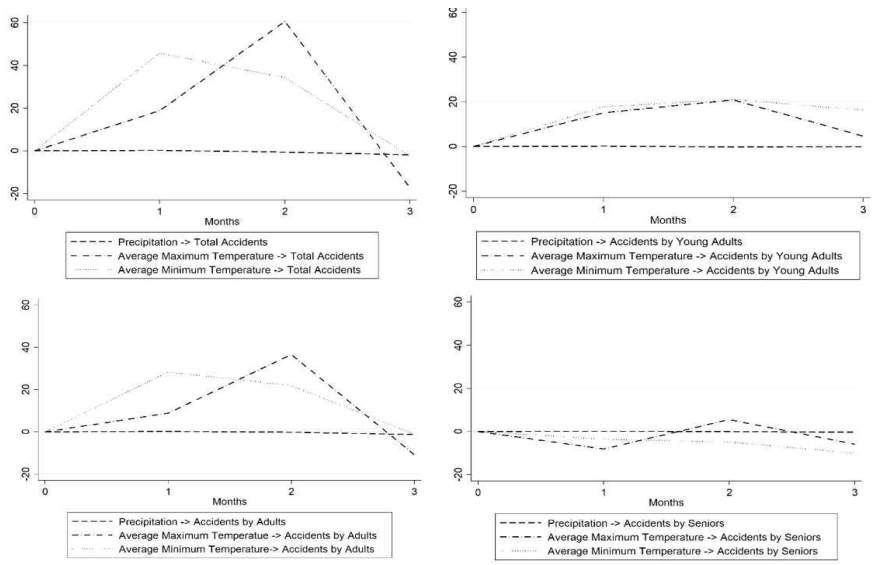
Variable	Total	2005-2013	2014-2023
Model 1			
MaxTemp	6.613	5.907	7.313
	(1.298)***	(1.921)***	(1.697)***
P>|t|	0.000	0.003	0.000
Observations	3,648	1,728	1,920
Clusters(Year-Region)	304	144	160
Model 2			
MaxTemp	6.357	5.389	7.657
	(1.250)***	(1.831)***	(1.682)***
P>|t|	0.000	0.004	0.000
Observations	3,648	1,728	1,920
Clusters(Year-Region)	304	144	160
Year F.E.	Yes	Yes	Yes
Monthly F.E.	Yes	Yes	Yes
Regional F.E.	Yes	Yes	Yes
Year-Regional F.E	Yes	Yes	Yes
Model 1			
MinTemp	4.379	3.770	4.821
	(1.328)***	(1.839)**	(1.927)**
P>|t|	0.001	0.042	0.013
Observations	3,648	1,728	1,920
Clusters(Year-Region)	304	144	160
Model 2			
MinTemp	4.085	3.719	4.582
	(1.314)***	(1.783)**	(1.912)**
P>|t|	0.002	0.039	0.018
Observations	3,648	1,728	1,920
Clusters(Year-Region)	304	144	160
Year F.E.	Yes	Yes	Yes
Monthly F.E.	Yes	Yes	Yes
Regional F.E.	Yes	Yes	Yes
Year-Regional F.E	Yes	Yes	Yes

Notes: clustered standard errors are reported in parentheses. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Both monthly average maximum and minimum temperatures are positively and significantly associated with the number of traffic accidents. Notably, this result holds regardless of whether new car registrations, heavy rains, and snow depths are included as a control variable, reinforcing that the observed effect is not merely a reflection of traffic volume. Moreover, the estimated effects are more pronounced in the later period from 2014 to 2023, suggesting a potential intensification of temperature-related traffic risks over time. This pattern may reflect the increased frequency of extreme temperature events due to climate change, as well as a general upward trend in maximum temperatures observed in recent years.

Next, we examine which age groups contribute most to traffic accidents associated with extreme temperatures. Following the estimation of the VECM, we compute impulse response functions (IRFs) to assess the dynamic effects of monthly regional precipitation, average maximum temperature, and average minimum temperature on total traffic accidents, as well as on accidents caused by young adults, prime-age adults, and older adults. Figure 1 summarizes the resulting IRFs.

Figure 1: VECM Regression Results Using Impulse Response Functions



A one standard deviation increase in average maximum temperature leads to an estimated 20 additional traffic accidents in the current month and approximately 60 more in the following month, resulting in a cumulative total of around 80 temperature-induced accidents. This effect dissipates after two months, which aligns with the typical three-month seasonal cycle and thus limits the persistence of temperature-related impacts. Of the 80 additional accidents, roughly 30 are caused by young adults and 50 are caused by prime-age adults, implying that young adults account for approximately 38% of the temperature-induced accidents, while prime-age adults account for 62%. A similar pattern is observed for average minimum temperature. Although the effect of minimum temperature peaks in the current month rather than the following month, the total number of additional accidents also reaches approximately 80, with 62% attributed to prime-age adults and 38% to young adults. The contribution from older adults remains negligible in both cases.

Table 7 presents the estimated associations between monthly average maximum and minimum temperatures and traffic accidents during the summer and winter seasons, distinguishing between Models 1 and 2. Results from both the panel fixed effects model and the VECM analysis suggest that increases in either temperature measure are associated with higher traffic accident rates. However, these effects may vary seasonally. To examine potential seasonal heterogeneity, we return to the panel fixed effects framework, restricting the sample to the months of July and August for summer, and January and February for winter.

Table 7: Summer and Winter Panel Regression Results

Variable	July and August		January and February	
Model 1				
MaxTemp	16.440		0.682	
	(4.010)***		(5.910)	
P>|t|	0.000		0.908	
MinTemp		4.583		-11.690
		(4.960)		(4.687)**
P>|t|		0.356		0.013
Observations	608	608	608	608
Clusters	304	304	304	304
Model 2				
MaxTemp	15.274		-0.057	
	(4.026)***		(5.818)	
P>|t|	0.000		0.992	
MinTemp		6.636		-12.485
		(4.628)		(4.627)***
P>|t|		0.153		0.007
Observations	608	608	608	608
Clusters	304	304	304	304
Year F.E.	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes
Regional F.E.	Yes	Yes	Yes	Yes

Notes: clustered standard errors are reported in parentheses. *, **, *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

As shown in Table 7 and Figure 1, increases in temperature are generally associated with a rise in traffic accidents. However, the direction and significance of this relationship vary by season. During the summer months, increases in average maximum temperature are significantly associated with higher traffic accident rates, whereas average minimum temperature shows no meaningful effect. In contrast, during the winter season, this pattern is reversed: average maximum temperature is not significantly associated with traffic accidents, but decreases in average minimum temperature are linked to an increase in accidents. As before, these results remain robust to the

inclusion of new car registrations, days with heavy rain, and maximum snow depth as control variables.

Our findings suggest that, although higher temperatures are generally correlated with increased traffic accident risk, the relationship is not uniform across seasons. In periods characterized by frequent extreme weather—such as extreme heat in summer and extreme cold in winter—the observed effects are driven specifically by the relevant seasonal extreme. Thus, it is not temperature increases per se, but rather exposure to season-specific temperature extremes that underlies the observed associations.

Ⅳ. Discussion

Our findings demonstrate a robust association between extreme temperatures and traffic accident rates in South Korea, with the magnitude of this relationship becoming more pronounced in recent years (see Table 6). Both average maximum and minimum temperatures are positively associated with accident incidence, but seasonal analysis reveals important asymmetries. Specifically, during the summer months, only increases in average maximum temperature significantly raise accident rates, while average minimum temperature has no discernible effect. In contrast, during winter, it is the decline in average minimum temperature—not maximum temperature—that is significantly linked to increased accident frequency (see Table 7). Impulse response analysis further indicates that a one standard deviation increase in either average maximum or minimum temperature can lead to approximately 80 additional accidents, primarily caused by prime-age and young adult drivers, with minimal contribution from older adults (see Figure 1).

One potential explanation for these patterns lies in the age distribution of licensed drivers. As of 2024, 61% of driver's license holders in South Korea are prime-age adults, 26% are seniors, and only 13% are young adults (Korean Statistical Information Service, 2025). Despite their smaller share, young adults account for approximately 38% of temperature-related traffic accidents—nearly three times their representation among drivers. This overrepresentation aligns with previous research suggesting that young adults are 2.6 times more likely to be involved in traffic accidents than other age groups (Korea Broadcasting System, 2015; Seoul Broadcasting System, 2015). While this may partially reflect a greater propensity for risky driving behavior, it is unlikely to be the sole explanation. During periods of extreme temperature—such as heatwaves or cold spells—physiological and psychological stress can affect all age groups; however, young adults may response in a more dismissive or erratic manner (Moustafa et al., 2017; Steinbeis et al., 2012), leading to a disproportionate increase in accident risk.

Another potential explanation involves the structural effects of extreme temperatures on transportation systems. High temperatures can degrade road surfaces, leading to asphalt softening or rutting, which compromises tire grip and vehicle stability. Similarly, extreme cold can create icy road conditions, generate potholes through freeze–thaw cycles, and reduce visibility due to fog or frost. These physical hazards heighten accident risk, particularly when drivers fail to anticipate or adequately adjust to degraded road conditions (Gao et al., 2016; Lee et al., 2014). Moreover, extreme temperatures can impair vehicle performance—for example by causing tire pressure fluctuations, engine overheating in summer, or malfunctions in driver assistance systems during winter—further increasing the likelihood of accidents. Public transportation services and traffic signal operations may also

be disrupted during severe weather events, potentially exacerbating congestion and placing additional strain on individual drivers. These infrastructural and mechanical vulnerabilities represent a critical channel through which climate-induced temperature extremes may elevate traffic accident risks, independent of driver behavior or demographic composition.

The results of this study indicate that traffic accident rates are likely to rise as maximum temperatures continue to increase. Moreover, as climate change intensifies, both the frequency and severity of extreme temperature events are projected to escalate—resulting in more cold days during winter and more hot days during summer, even as average winter temperatures gradually become milder (Jeon & Cho, 2015; Michelfelder & Pilotte, 2022). Under such conditions, the risk of temperature-induced traffic accidents is expected to intensify, driven by increased exposure to season-specific temperature extremes.

Our findings have important implications for the automobile insurance industry, particularly as climate change continues to increase the frequency and severity of extreme temperature events. First, given the observed seasonal and demographic heterogeneity in temperature-related traffic accidents, insurers should reconsider their pricing and risk assessment models to incorporate these dimensions. For instance, accident risks rise with higher average maximum temperatures in summer and with lower average minimum temperatures in winter. Moreover, young drivers—despite representing a smaller share of licensed drivers—are significantly overrepresented in temperature-related accidents. These insights point to the need for more nuanced underwriting approaches that adjust premiums not only by age group but also by seasonal exposure. Insurers might also explore targeted incentives, such as premium discounts for young drivers who complete climate-specific

defensive driving programs.

Second, the study highlights the importance of considering environmental and mechanical risk factors—such as road surface degradation, tire instability, and vehicle system malfunctions—as key contributors to accident risk. Traditional underwriting models primarily emphasize on driver characteristics and driving history, but in the context of increasing climate volatility, insurers should adopt more comprehensive frameworks that also account for environmental and vehicular vulnerability. For example, insurers might implement dynamic pricing or real-time risk adjustments based on weather conditions, vehicle maintenance status, or exposure to high-risk road segments. Integrating telematics and vehicle monitoring systems may further reduce claim incidence by enabling the early detection of maintenance needs or issuing hazard warnings under extreme weather conditions.

Finally, as climate change continues to increase the frequency of temperature-related traffic accidents, insurers should begin considering the long-term financial implications of this trend. In South Korea, where automobile insurance is mandatory, a rise in accidents naturally leads to higher claims, placing pressure on insurers' loss ratios. While this may not pose an immediate threat to solvency, a sustained increase in claims over time may undermine overall profitability. To prepare for this, insurers can explore investment strategies that align with broader climate resilience goals—such as increasing allocations to green bonds or ESG-linked assets—which not only support environmental goals but also demonstrate a proactive approach to emerging climate-related risks.

Furthermore, given these projections, a coordinated policy response that bridges environmental and transportation domains is essential. First, transportation and environmental agencies as well as automobile insurers

should jointly develop seasonal risk management frameworks that incorporate real-time weather data, climate forecasts, and road safety indicators to inform dynamic traffic control measures, speed regulations, and public alert systems during periods of extreme temperatures. Second, infrastructure adaptation policies should promote the adoption of climate-resilient materials and design standards—such as permeable, heat-resistant pavements and cold-resilient surface treatments—within national road maintenance and environmental adaptation strategies. Third, urban and regional transportation planning should align with climate mitigation goals by expanding multimodal, low-emission public transport systems that reduce congestion and accident exposure during high-risk periods, while also contributing to lower greenhouse gas emissions. Finally, driver education programs should incorporate content on climate-related risks and defensive driving strategies under extreme temperature conditions, with additional outreach targeting high-risk individuals, particularly young and inexperienced drivers.

This study contributes to the growing body of literature on the relationship between climate change and traffic safety in several important ways. First, by analyzing a long time span from 2005 to 2023, we capture both short-term and long-term dynamics in the relationship between extreme temperatures and traffic accidents. This temporal scope enables us to compare the magnitude of temperature-related accident risks over time, revealing that the effects have become more pronounced in recent years—a trend likely associated with the intensifying impacts of climate change.

Second, our application of a time-series vector error correction model (VECM) allows us to identify the age groups most affected by extreme temperature conditions. Since most traffic accident datasets are not disaggregated by age, our analysis provides rare and valuable insights into

demographic vulnerability, revealing that young and prime-age adults are particularly susceptible to temperature-induced traffic risks. These findings underscore the need for targeted safety interventions and educational campaigns tailored to high-risk demographic groups, especially during periods of extreme weather.

Third, we provide clear evidence of seasonal heterogeneity in the relationship between temperature and traffic accidents. Specifically, we find that increases in average maximum temperature are strongly associated with higher accident rates during the summer months, while decreases in average minimum temperature are significantly linked to accident incidence during the winter. This pattern highlights the importance of considering not only the overall effects of temperature, but also the season-specific impacts of climatic extremes. In the case of South Korea—a country with well-developed road infrastructure and marked seasonal variation—our findings suggest that even advanced transport systems remain vulnerable to the safety risks posed by climate volatility. Accordingly, national and local authorities should consider implementing differentiated, season-specific traffic safety measures that reflect evolving climate risks.

V. Conclusion

In conclusion, this study contributes to a deeper understanding of how environmental stressors—particularly extreme temperatures associated with climate change—interact with behavioral, seasonal, and demographic factors to influence traffic accident risk. Using panel fixed effects and time-series vector error correction models applied to data from 2005 to 2023 in South

Korea, we show that both maximum and minimum temperatures significantly affect accident rates, with more pronounced effects in recent years. Young and prime-age adults are identified as the most vulnerable groups, and the analysis reveals distinct seasonal patterns, with extreme heat in summer and extreme cold in winter emerging as the primary drivers of temperature-induced accidents. These findings underscore the need for integrated, climate-responsive transportation policies that account for seasonal variation, demographic vulnerability, and infrastructural resilience. More broadly, this study offers a framework for future research and policy development at the intersection of climate adaptation and transportation planning, emphasizing the importance of evidence-based strategies to ensure public safety in an increasingly volatile climate.

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초 록

기후변화는 폭염, 한파, 허리케인, 집중호우, 산불 등 극한 기상현상의 빈도와 강도를 증폭시키며 점차 일상생활 전반을 변화시키고 있다. 기존 연구들은 이러한 기상 이변이 초래하는 직접적인 경제 및 건강상의 문제에 주로 초점을 맞춰왔지만, 일상적 행동 변화와 이로 인한 사회적 위험에 대해서는 상대적으로 덜 조명되었다. 본 연구는 극한 기온이 스트레스와 집중력 저하를 유발해 교통사고를 증가시킬 수 있다는 점에 주목하여, 극한 기온과 교통사고 간의 관계를 실증적으로 분석하였다. 2005년부터 2023년까지의 한국 자료를 활용해 패널 고정효과 모형 및 벡터 오차수정모형으로 분석을 수행한 결과, 폭염과 한파 모두 교통사고 발생률 증가와 통계적으로 유의미한 관계를 보였으며, 이는 기후변동성이 심화된 최근일수록 더욱 두드러지게 나타난다. 또한 이러한 영향은 특히 청년층을 포함한 생산연령층에서 더 크게 관찰되었다. 본 연구 결과는 기후변화의 행동적 측면과 공공안전 차원에서의 함의를 제시하며, 자동차 사고와 대중교통 체계의 취약성을 포괄하는 통합적 기후적응 정책의 필요성을 강조한다. 또한 자동차 보험 산업에도 중요한 시사점을 제공한다.

국문색인어: 기후변화, 극한 기온, 교통사고, 행동 반응, 자동차 보험