How do temperature shocks affect tax revenue from international trade? New evidence from provincial panel analysis in Vietnam

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This study offers new insights into the impact of temperature shocks on international trade activity in Vietnam using tax revenue as a proxy. Temperature shocks reveal deviations in climate variables from the historical norms in relation to human activities, enabling us to examine the way people adapt to climate change. It is likely a superior proxy compared to conventional approaches that either create temperature bins or standardise measurements. The research findings indicate that while the temporary effect of temperature shocks significantly reduces tax revenue from international trade, the permanent effect is nearly six times as great as the temporary effect. The results also reveal that the shock is more pronounced in areas with prominent foreign direct investment companies, and less so in regions with more favourable temperature conditions, indicating heterogeneous effects. The increased energy costs associated with higher temperatures in manufacturing processes potentially leading to long-term vulnerability may explain the findings. Accordingly, we propose several policy implications for fostering sustainable growth in Vietnam amidst rising temperatures.

Keywords:
temperature shock,
international trade,
climate adaptation,
energy cost,
sustainable growth

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Introduction

Rising temperatures are an inevitable, irreversible process that increasingly impacts all aspects of socio-economic life (Hsiang et al. 2017, Watts et al. 2021). Despite growing consensus regarding the escalating costs associated with this phenomenon, governmental actions, particularly in developing countries, tend to be less than urgent (Bhattacharya et al. 2023). Governments' sluggish response is often attributed to bureaucratic inefficiencies, a lack of awareness regarding the severity of the issue, a lack of financial resources necessary to implement such programmes (Bhattacharya et al. 2023, Neufeldt et al. 2021) or some combination of these factors.

Although environmental scientists and economists often lead advocacy efforts against climate change, they frequently fail to elicit significant concern from governments and policymakers, apart from the allocation of limited funding for environmental activities (Grossman 2024, Vaidyanathan 2022). The classical environmental Kuznets curve theory remains a significant reference point for developing countries, which posits that economic growth in the early stages of development will eventually lead to a cleaner environment in later stages (Ahmad et al. 2021, Stern 1998). While United Nations climate change summits strive to reach consensus on climate action among nations, they have yet to effectively address the long-term financial challenges faced by poorer nations, where poverty and inequality are pressing issues (Cevik–Jalles 2022, Georgieva et al. 2022, Nishio 2021).

This discussion leads us to consider how climate change, specifically rising temperatures, affects government tax revenue from import and export activity. This approach not only directly assesses the impact of rising temperatures on government budgets (and the reasonable expectation that action must be taken) but also examines the implications for sectors that will significantly expand in the context of growing global trade. In other words, we estimate the short- and long-term impact of temperature shocks on government tax revenue, which are expected to become more damaging unless nations cease expanding their engagement in global trade. Ideally, governments should invest the funds anticipated to be lost due to climate change to mitigate its ongoing effects.

We select Vietnam as a typical case study for three reasons. First, Vietnam is one of the most vulnerable countries in the fight against climate change, characterised by a wide longitudinal range that results in diverse climatic conditions. Our panel data design using 63 provinces as the units of analysis captures various climate patterns spanning latitudes from 8°30' to 23°30' north and maintains homogeneity in the units of analysis (e.g. scale, traditional culture and human values). This approach minimizes the influence of unobserved non-climatic factors that could affect the relationship under examination (Van Le et al. 2022).

Second, with an increasingly vital role in Vietnam's economic growth [1], the contribution of increased international trade to GDP rose significantly from 23% in 1986 to 184% in 2022 [2]. This trend has accompanied a notable decline in domestic tax revenue, particularly from crude oil, which fell from 25.9% of total revenue in 2000 to just 4.3% in 2022 (GSO 2024), as well as recent inefficiencies in expenditure and budget allocation between cities (Van Le–Tran 2024b). Consequently, tax revenue from import and export activity has become a crucial resource [3], making it an opportune moment for environmental policy advocates to establish connections between budget allocations and climate change mitigation efforts.

Third, from an econometric perspective, local governments in Vietnam function as ‘independent laboratories’, maintaining relatively autonomous trade policies from the central government (Van Le–Tran 2022, Van Le et al. 2022). This autonomy facilitates the determination of causal effects. In other words, despite limitations regarding data representativeness, Vietnam can provide valuable insights that align with our objective of effectively communicating with policymakers about the necessity of adapting to climate change.

This study offers two main contributions. First, it presents fresh evidence on the short- and long-term effects of rising temperatures on tax revenue from import and export activity in Vietnam employing an enhanced measure of temperature shock using deviations of climate variables from their historical norms for human activity as highlighted by Kahn et al. (2021). By examining government revenue directly, we can derive policy implications in the context of climate change and increasing global trade more easily. Second, we investigate the heterogeneous effects of rising temperatures on various outcomes within different contexts, while proposing possible mechanisms for these effects. Consequently, this research is a bridge connecting government actions and scholarly efforts to mitigate the effects of climate change.

The remainder of this paper is organised as follows. First, an overview of the relevant literature is provided, then the empirical approach and data used are described, following with the presentation of the baseline findings. Finally, future research directions are concluded and proposed.

Literature review

We begin by examining Vietnam’s fiscal structure through the composition of budget revenue from export–import activities, followed by a review of plausible channels through which temperature shocks could affect these components, narrowing the literature review with a more focused scope. We then turn to global evidence on temperature shocks and trade, with attention to transmission mechanisms and human adaptation, returning to the Vietnamese context to compare observations and formulate our hypotheses.

Vietnamese context

The study begins with several observations about the circumstances in Vietnam to clarify the context and explain how rising temperatures may affect import and export activity. Focusing on the contribution of international trade, the budgetary revenue from import–export activity accounted for approximately 21.96% to 24.05% of total revenue from 2018 to 2022. Structurally, the foreign direct investment (FDI) sector constituted 68.7% of the country’s total import–export activity in 2023, amounting to approximately 468.2 billion US dollars. Electronic equipment, computers and components, which represent 21.3% of the total import–export activity, dominate this sector and primarily originate from major foreign companies operating in Vietnam such as Samsung, LG Electronics and Intel Vietnam (GSO 2024). The second largest segment comprises agricultural, forestry and fishery processing activities.

Notably, the value added from the operations of these companies in Vietnam is not particularly significant. For example, Intel Vietnam is estimated to contribute added value of only about 3% of the total production value in the country (FUV 2017). Nevertheless, the tax revenue generated from these activities remains higher than the combined revenue from FDI and state-owned enterprises (4.57% of GDP compared with 4.4% of GDP) (GSO 2024). It is likely that Vietnam's import–export activities are substantially influenced by major foreign corporations involved in the production of electronic devices and components. Contrary to what might be expected in a developing country, the primary import–export activity does not predominantly arise from the agricultural sector, which is more susceptible to the adverse effects of climate change due to its lower resilience. This observation aligns with findings presented in Appendix Panel B of Figure A1, which indicate that regions with the highest tax import–export revenue are situated near large corporations such as Samsung (in Thái Nguyên and Bắc Ninh), Intel Vietnam (in Hải Phòng) and various industrial zones (in Bình Dương), and their proximity to the two largest cities of Hà Nội and Hồ Chí Minh City.

Affecting climatic conditions, Vietnam's geography is characterised by a lengthy coastline exceeding 3,000 kilometres and spanning a wide range of latitudes, resulting in diverse climatic conditions throughout the country. The Annamite Range (Trường Sơn) in the west functions as a barrier against the hot, dry winds from Laos, resulting in temperature and humidity variations across different regions. This geographical diversity produces distinct climates from north to south, marked by significant seasonal changes and varying rainfall patterns. In Appendix Panel A of Figure A1 illustrates the trend of increased temperatures, which are particularly evident in the more extreme conditions of Hà Tĩnh and Nghệ An, with higher temperatures observed in the southern regions. Rising temperatures over the past two decades have significantly disrupted Vietnam's electricity supply, affecting import–export activities. Frequent power outages – resulting from depleted hydroelectric reservoirs and peak-hour overloads in industrial zones [4] – have substantially increased costs and unpredictability for businesses (Hoang Duc–Do Ba 2017).

Rising temperatures affect agriculture, which is a crucial input for the processing industry, which is the second largest contributor to import–export activity, particularly in the Mekong Delta region (VCCI–FUV 2022). For example, Anh et al. (2023) use time-series data from 1990 to 2019, demonstrating that a 1% increase in average temperature corresponds to approximately a 3% decrease in agricultural production. Also noteworthy is that the agricultural sector accounts for over 20% of Vietnam's GDP and has employed around 60% of the workforce over the past two decades. Observations in Vietnam further reveal significant shifts in land use (Rutten et al. 2014), which are likely to impose considerable costs and uncertainty for import–export enterprises.

We argue that Vietnam's import–export sector is heavily shaped by major foreign corporations producing electronic devices and components, activities less vulnerable to climate shocks due to their indoor nature, indicating a potentially different transmission mechanism. However, the country's fragmented geography and reliance on hydropower make the national grid vulnerable, particularly during the dry season and peak production periods. In contrast, agriculture – a key input for the processing industry, the second largest contributor to trade – is far more exposed to temperature shocks.

Mechanism and adaptation

The mechanisms and empirical evidence for the impact of rising temperatures on global import and export activities are relatively extensive, featuring various research designs. Three mechanisms can be briefly outlined as follows. First, increased temperatures can negatively influence agricultural productivity, resulting in diminished output in climate-sensitive sectors, and subsequently affecting export volumes. Compelling evidence for this is provided by Kalkuhl–Wenz (2020), who demonstrate that temperature significantly affects productivity. Their analysis predicts that a 3.5°C increase in global mean surface temperature by the century's end may lead to a 7%–14% reduction in global output by 2100, with the most severe effects experienced in poorer and tropical regions. Furthermore, Kotz et al. (2021) find that a one-degree increase in temperature variability corresponds to an average 5% reduction in regional growth rates, with the greatest vulnerability occurring in low-latitude, low-income areas, where declines can reach up to 12%.

Second, higher temperatures can disrupt transportation networks due to extreme weather events, affecting supply chains and raising costs. Studies by Addoum et al. (2023), Burke et al. (2015) and Dell et al. (2012) illustrate the negative effects of extreme temperatures on economic output and consequent trade, noting that 'extreme temperatures significantly impact earnings in over 40% of industries'. Investigations by Koetse–Rietveld (2009), Perkins–Neumayer (2014) and Schlenker–Roberts (2008) demonstrate that climate change is likely to exacerbate trade imbalances, particularly for developing countries that depend on agriculture. Jones–Olken (2010) find that a 1°C increase in temperature reduces export growth in poorer nations by between 2.0% and 5.7%.

Third, it is highly likely that climate change may heterogeneously disrupt trade patterns, affect labour productivity and alter comparative advantages among countries. Graff Zivin–Neidell (2014) observe that outdoor labour supply shifts to cooler hours during heatwaves, emphasising that regions accustomed to higher temperatures may adapt more effectively, benefitting from physiological adjustments and technological advancements that facilitate coping with the heat. Kahn et al. (2021) argue that resource reallocation over time becomes increasingly challenging, potentially complicating efforts to adapt.

In line with Somanathan et al. (2021), who link hotter years to lower economic output in developing countries – partially via reduced labour productivity – evidence from Indian factories shows that high-temperature days reduce productivity and increase absenteeism, lowering annual production by 2% per 1°C rise. Colmer (2021) highlights structural adjustments to temperature shocks such as labour shifts from agriculture to manufacturing, while Hsiang et al. (2017) document wide-ranging socio-economic impacts of climate change. For Vietnam, a highly climate-vulnerable country, empirical evidence on temperature effects in trade remains limited. Existing studies broadly address small and medium-sized enterprises' (SMEs') innovation and exports (Alam et al. 2022) or specific agricultural products like rice (Kontgis et al. 2019, Le 2016), often relying on RCP-based forecasts that may over- or understate the urgency for policy response.

Empirical studies in Vietnam remain limited compared with global evidence. Yuen et al. (2021) employ a systems approach in the Red and Mekong River Deltas, offering nuanced insights into complex environmental challenges. Using half a century of historical data, Jones–Olken (2010) estimate substantial adverse effects of major temperature shocks on textile yarn and fabrics (−9.44%), rubber manufacturers (−10.79%) and leather (−12.81%). Baronchelli–Ricciuti (2022) find that higher minimum temperatures in June reduce rice production, although SMEs and rice production contribute less to tax revenue than implied in previous chapter. The limited weight of domestic evidence may reflect unaccounted adaptation or heterogeneous impacts. Adaptation is documented in energy-intensive industries, where firms improve processes to cut energy use (Hoang Duc–Do Ba 2017), and in product-switching strategies observed even before World Trade Organisation accession (Adger et al. 2001). Ito et al. (2022) further highlight the socio-cultural dimensions of adaptation in vulnerable regions.

In developing countries, climate change adaptation often involves reallocating labour from more minor to larger plants and increased labour market concentration, reducing energy costs per unit, improving managerial capacity and enhancing access to finance (Ponticelli et al. 2023). While this pattern is less evident in Vietnam, the export–import sector benefits from cheaper media tools (McElwee 2010) and improved transparency regarding power outages, which enables better planning. Forecasts to 2030 suggest that industry, which includes much of the export–import sector, is likely to adapt more effectively than agriculture (Rutten et al. 2014). Therefore, we propose the following hypotheses:

H1: In Vietnam, where the FDI sector accounts for two-thirds of export volume, temperature shocks may affect export–import activities mainly through electricity consumption channels.

H2a: Limited evidence for temperature shock impacts in Vietnam may reflect unaccounted pre-existing human adaptation.

Furthermore, studies examine the heterogeneous effects of rising temperatures across different contexts. For example, Jones–Olken (2010) highlight the diverse effects across export products, particularly noting detrimental impacts on Vietnam's consumer goods and agricultural exports, while machinery and electronics industries are less affected. Jacob et al. (2018) find that a 1.5°C increase in temperature might create a more favourable environment for summer and spring/autumn tourism in much of Western Europe, while this warming trend might negatively affect regions like Spain and Cyprus, where overnight stays could decline by 8% and 2%, respectively (Scott et al. 2012). For indoor manufacturing activities, the United States Occupational Safety and Health Administration suggests that the ideal office temperature ranges between 68°F and 76°F degrees (20°C–24.4°C), with humidity levels between 20% and 60% [5]. Moreover, it is likely that changes in average temperatures may not significantly affect indoor manufacturing activities (e.g. electronic component assembly) unless they increase electricity costs (Schlenker–Roberts 2008). Therefore, we propose the following hypothesis:

H2b: Limited evidence for temperature shock impacts in Vietnam may be due to heterogeneous effects arising from the country's diverse climatic and geographical conditions.

In summary, while global theoretical and empirical evidence indicates the clear effect of rising temperatures on declining import–export activities, we observe relatively limited evidence in Vietnam despite the country's high vulnerability to climate change. Previous literature suggests that this may be due to companies' climate change adaptation strategies, the heterogeneous effects of the relationship under varying conditions or both. The first explanation implies a need for more precise temperature shock measurement, while the latter emphasises the necessity of addressing these heterogeneities.

Empirical strategy and data

Measuring temperature shocks

Building on the first implication, which highlights the need for more accurate temperature shock measurement, we now present an empirical approach for their estimation. Conventional methods primarily depend on several key techniques such as the use of average temperature, standardisation and the creation of temperature bins, with model specifications typically favouring either linear or quadratic functions (Taraz 2018). This approach assumes that a 1°C (or one standard deviation or one bin) increase in hotter regions has an effect similar to the same increase in cooler regions. In other words, this approach presupposes homogeneous effects of temperature shocks on outcomes but does not differentiate between hot and cold shocks. Notably, this approach neglects the potential for population adaptation in response to temperature changes. For example, categorising temperatures into bins assumes that the impact of varying (typically increasing) temperature ranges differs across outcomes, which can produce misleading results due to the manipulation of bin definitions or the general upwards trend in global temperatures. Notably, these methods may not even qualify as exogenous shocks in economic growth models as past outcomes (e.g. economic growth) could influence future temperatures through feedback effects (Kahn et al. 2021).

To address these limitations, Kahn et al. (2021) propose a superior approach to conceptualise temperature shocks by measuring climate variables' deviations from respective historical norms due to human activity. The authors suggest calculating a temperature shock as follows:

$$Temperature\ Shock_{it} = |\mathcal{T}_{it} - \mathcal{T}^*_{i,t-1}| \qquad (*)$$

where $\mathcal{T}^*_{i,t-1} = m^{-1}\sum_{s=1}^{m}\mathcal{T}_{i,t-s}$ represents province i's historical norm in a given period of time. To determine the historical norms for province i, the authors calculate the moving averages of temperature over the past m years, where m is a large enough number to ensure that the variations in the historical norms for each year are small. We set m to 10 and $m = 15$ and $m = 20$ to perform robustness tests to assess the local population's climate change adaptive capacity. Therefore, the exposure to shock arises from either the current year's temperature exceeding the average in the preceding m years (heat shock) or the current year's temperature falling below its historical norm (cold shock).[1] A temperature shock value approaching zero indicates that the average temperature shows no surprising swing relative to m years ago. In this way, the approach can relax the assumptions discussed earlier, while at the same time asserting that climate variables only influence outcomes when they deviate from historical norms. Such norms are considered technologically neutral, implying that if climate variables remain close to their historical norms, they are not expected to affect outcomes. Kahn et al. (2021: p. 3) state that "*by using deviations of climate variables from their respective historical norms, while allowing for nonlinearity, we avoid the econometric pitfalls associated with the use of trended variables, such as temperature, in output growth equations*".

Econometric model

Next, with the above calculation, capturing the new temperature variable is more likely to ensure it functions as an exogenous variable. By ruling out the relative

[1] However, distinguishing between heat and cold shocks should be approached with considerable caution as it may introduce opportunities for data manipulation, which could subsequently produce spurious results.

possibility of adaptation, this approach also helps avoid the econometric pitfalls associated with using trended variables in output tax equations. Thus, the empirical model is estimated as follows.

$$Y_{i,t} = \varphi_i + \sum_{\tau=0}^{T} \delta_\tau X_{i,t-\tau} + Z'\beta + \lambda t + u_{i,t}, \quad (1)$$

where $Y_{i,t}$ represents the tax revenue from province i's export–import activity in year t. To ensure that this variable is a good proxy for international trade activity, we assume that the government's tax practices is not affected by temperature shocks (a). $X_{i,t-\tau}$ denotes a temperature shock in year $t-\tau$, where $\tau\ (=0,\dots,T)$ indicates the lagged impact. φ accounts for time-invariant unobservable factors (e.g. historical, cultural and geographical characteristics) influencing the outcome. λ and u respectively represent time fixed effects (FEs) and the error term. Z is a vector of control variables, selected on the basis of previous research (Van Le–Tran 2022, Van Le et al. 2022). This includes a set of climate background variables (i.e. average temperature and rainfall), a set of market background controls (i.e. FDI inflow, industrial index, high-quality labour ratio and private sector labour share) and a set of macroeconomic background controls (i.e. urbanisation rate, GDP per capita, institutional quality proxied by the provincial competitiveness index [PCI]).

Theoretically, determining the value of τ involves considering how a temperature shock affects the province's import–export activity over time. Technically, Jordà (2005) provides straightforward evidence regarding independent variable magnitude and lagged effects on outcomes by examining how the dependent variable responds to the shock triggered across different time frames. Notably, the flexibility and simplicity of this approach enable a nuanced understanding of how temporary temperature shocks can influence international trade patterns over extended periods. Assuming that the impact of temperature shock on the outcome extends to the third year, equation (1) becomes the following:

$$Y_{i,t} = \varphi_i + \delta_0 X_{i,t} + \delta_1 X_{i,t-1} + \delta_2 X_{i,t-2} + \delta_3 X_{i,t-3} + Z'\beta + \lambda t + u_{i,t} \quad (2)$$

The cumulative effect, known as long-run propensity (LRP), is the sum of parameters δ, $LRP = \theta = \delta_0 + \delta_1 + \delta_2 + \delta_3$. Substituting $\delta_0 = \theta - \delta_1 + \delta_2 + \delta_3$ into equation (2) and simplifying, we obtain the following:

$$Y_{i,t} = \varphi_i + \theta X_{i,t} + \delta_1(X_{i,t-1} - X_{i,t}) + \delta_2(X_{i,t-2} - X_{i,t}) + \delta_3(X_{i,t-3} - X_{i,t}) + Z'\beta + \lambda t + u_{i,t} \quad (3)$$

Therefore, to estimate the LRP, we perform the transformed regression of Y onto X_t, $(X_{t-1} - X_t), (X_{t-2} - X_t)$ and $(X_{t-3} - X_t)$. Then, $\theta = LRP, se(\theta) = se(LRP)$, and the confidence interval for θ is the confidence interval for LRP.

Building on the second implication regarding the heterogeneous effects of temperature shocks on trade activities, we consider the following specification:

$$Y_{i,t} = \varphi_i + \theta_0 X_{i,t} + \theta_1 (M_i . X_{i,t}) + \sum_{j=1}^{3} \delta_j (X_{i,t-j} - X_{i,t}) + Z'\beta + \lambda t + u_{i,t}, \quad (4)$$

where M_i denotes the moderator, which may include groups of provinces characterised by energy-intensive industries, stable power infrastructure, favourable climatic conditions or a high FDI share. If our hypothesis holds, given the state of the national power grid during 2010–2019, we expect provinces with energy-intensive industries and low power infrastructure to be more adversely affected by temperature shocks and vice versa. Similarly, areas exposed to higher temperatures are expected to include provinces with high FDI shares and those with unfavourable climatic conditions.

Data

The data for this study were obtained from three main sources. First, Vietnam's General Statistics Office provides a wide range of macroeconomic variables for all 63 provinces, spanning from 2010 to 2019, and is commonly used as the primary source for sub-national indicators (Van Le–Tran 2022, Van Le et al. 2022). Previous authors note that the relatively independent nature of local governments in policy implementation enables the use of cross-province units to determine causal effects between macroeconomic variables. Temperature data were collected for the period 2002–2019 to compute the moving average according to equation (*) (see also Kahn et al. 2021).

Second, tax revenue data were manually collected from the Public Disclosure of the State Budget Portal, Ministry of Finance (MOF) Vietnam, which undergoes verification by MOF staff. Accordingly, every 18 months after the end of each fiscal year, the provincial councils of these 63 provinces/cities approve and disclose financial statements detailing total revenue, total expenditure and budget balances. The dataset includes tax revenue from (i) export–import activity, (ii) oil and raw materials, (iii) domestic sources and (iv) others. While we focus on tax revenue from export–import activity as the dependent variable, additional regressions are conducted using other proxies as placebo tests for whether government behaviour is affected by temperature shocks (a).

Third, we use data from Vietnam's PCI, which measures local governments' governance quality. Key indicators include (i) low market entry costs, (ii) minimal unofficial costs and (iii) efficient administrative procedures for inspections, controls and regulation implementation. This index was collected to analyse the impact of natural resources on institutional quality. We also draw data from the Vietnam Provincial Governance and public administration performance index (PAPI) [6], which, in contrast to assessing institutional quality from the business perspective, measures and benchmarks citizens' experiences and perceptions of local governments' performance, policy implementation and service delivery quality. This can subsequently be used to advocate for more effective and responsive governance.

Table 1

Descriptive statistics

Variables	Units	MEAN	SD
	2010		
Revenues from trade tax on logarithm	million VND	11.220	4.580
Temperature (z-score)	z-score	0.030	0.970
Rainfall (z-score)	z-score	−0.040	1.060
Temperature shock (10-year moving average)	(authors' calculation)	0.210	0.210
Temperature shock (15-year moving average)		0.277	0.171
Temperature shock (20-year moving average)		0.311	0.174
Electric tools usage ratio	%	95.670	6.500
Temperature	C degree	25.383	2.021
FDI involvement	million US$	203.440	494.230
Industrial index	GSO calculation	*	*
Labour quality ratio	[0,1]	0.570	0.040
Private sector labour share	[0,1]	0.840	0.110
Urbanisation ratio	[0,1]	0.250	0.160
GDP in logarithm	thousand billion VND	3.170	0.890
PCI in logarithm	[0,100]	4.060	0.080
PCI: *entry costs*	[0,10]	6.650	0.710
PCI: *access to land*	[0,10]	6.060	1.180
PCI: *transparency*	[0,10]	5.740	0.780
PCI: *time costs*	[0,10]	6.310	0.950
PCI: *informal charges*	[0,10]	6.350	0.800
PCI: *policy bias*	[0,10]	5.680	0.990
PCI: *proactivity*	[0,10]	5.250	1.290
PCI: *labour policy*	[0,10]	5.290	0.600
PCI: *law & order*	[0,10]	4.930	1.020
Control of corruption in the public sector	[0,10]	*	*
Public administrative procedures	[0,10]	*	*
Public service delivery	[0,10]	*	*

(Table continues on the next page.)

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Variables	Units	MEAN	SD
2016			
Revenues from trade tax on logarithm	million VND	12.170	4.270
Temperature (z-score)	z-score	0.090	0.990
Rainfall (z-score)	z-score	0.250	1.050
Temperature shock (10-year moving average)	(authors' calculation)	0.300	0.210
Temperature shock (15-year moving average)		0.406	0.254
Temperature shock (20-year moving average)		0.446	0.271
Electric tools usage ratio	%	98.050	4.030
Temperature	C degree	25.503	2.064
FDI involvement	million US$	236.54	435.68
Industrial index	GSO calculation	110.97	22.600
Labour quality ratio	[0,1]	0.620	0.280
Private sector labour share	[0,1]	0.910	0.080
Urbanisation ratio	[0,1]	0.290	0.180
GDP in logarithm	thousand billion VND	3.630	0.900
PCI in logarithm	[0,100]	4.070	0.050
PCI: *entry costs*	[0,10]	8.500	0.350
PCI: *access to land*	[0,10]	5.770	0.560
PCI: *transparency*	[0,10]	6.240	0.380
PCI: *time costs*	[0,10]	6.580	0.700
PCI: *informal charges*	[0,10]	5.330	0.680
PCI: *policy bias*	[0,10]	5.490	0.550
PCI: *proactivity*	[0,10]	4.880	0.670
PCI: *labour policy*	[0,10]	6.000	0.790
PCI: *law & order*	[0,10]	5.460	0.800
Control of corruption in the public sector	[0,10]	5.900	0.560
Public administrative procedures	[0,10]	7.110	0.230
Public service delivery	[0,10]	7.020	0.350

(Table continues on the next page.)

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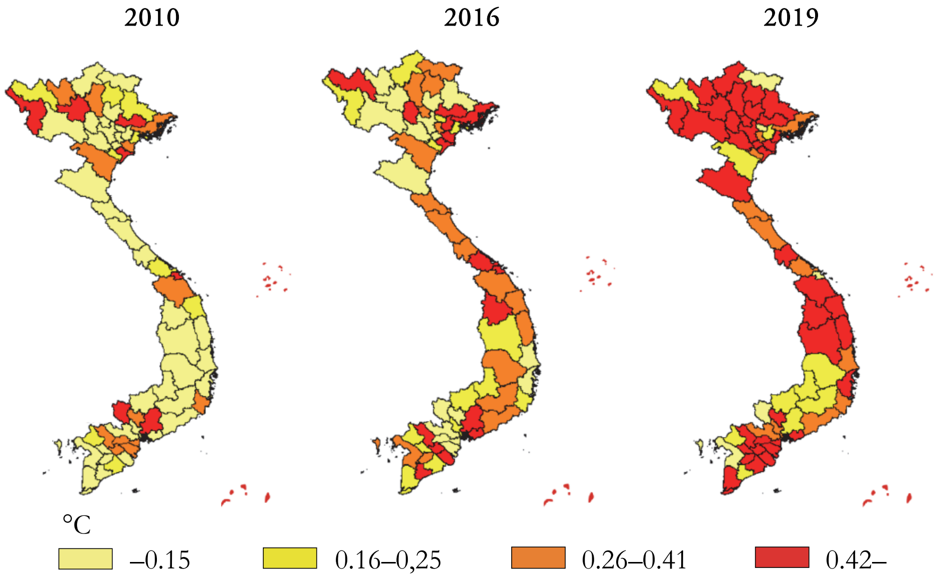
Variables	Units	MEAN	SD
	2019		
Revenues from trade tax on logarithm	million VND	12.960	3.870
Temperature (z-score)	z-score	0.290	0.900
Rainfall (z-score)	z-score	−0.300	1.060
Temperature shock (10-year moving average)	(authors' calculation)	0.640	0.440
Temperature shock (15-year moving average)		0.758	0.444
Temperature shock (20-year moving average)		0.789	0.450
Electric tools usage ratio	%	98.610	2.860
Temperature	C degree	25.916	1.886
FDI involvement	million US$	247.60	438.93
Industrial index	GSO calculation	110.340	10.660
Labour quality ratio	[0,1]	0.620	0.280
Private sector labour share	[0,1]	0.940	0.070
Urbanisation ratio	[0,1]	0.300	0.180
GDP in logarithm	thousand billion VND	3.870	0.900
PCI in logarithm	[0,100]	4.180	0.040
PCI: *entry costs*	[0,10]	7.320	0.600
PCI: *access to land*	[0,10]	6.860	0.560
PCI: *transparency*	[0,10]	6.680	0.270
PCI: *time costs*	[0,10]	6.930	0.800
PCI: *informal charges*	[0,10]	6.240	0.710
PCI: *policy bias*	[0,10]	6.380	0.630
PCI: *proactivity*	[0,10]	6.220	0.580
PCI: *labour policy*	[0,10]	6.680	0.630
PCI: *law & order*	[0,10]	6.630	0.640
Control of corruption in the public sector	[0,10]	6.780	0.480
Public administrative procedures	[0,10]	7.340	0.190
Public service delivery	[0,10]	7.240	0.260

Note: * indicates that the data are unavailable.

Descriptive statistics are presented in Table 1. Notably, when we analyse temperature shock using equation (*), the differing responses are illustrated in Figure 1. It is evident that the northern regions (which have cooler temperatures) show significant changes in temperature compared to the historical data, whereas southern regions with typically higher temperatures exhibit little variation, except in areas with FDI such as Bình Dương and Hồ Chí Minh City. On average, the 2019 data indicate that temperatures in these provinces have risen by 0.64°C compared with a decade earlier.

Figure 1

Evolution of temperature shocks in Vietnam



Notes: temperature shock represents climate variables' deviations from the respective historical norms for human activity, $\text{Temperature Shock}_{it} = |\mathcal{T}_{it} - \mathcal{T}^{*}_{i,t-1}|$, where $\mathcal{T}^{*}_{i,t-1} = 10^{-1}\sum_{s=1}^{10}\mathcal{T}_{i,t-s}$. The maps illustrate clear intensification of temperature shocks over time, with more provinces shifting into higher shock categories by 2019 compared with 2010. Notably, the central and southern regions show the most pronounced increases, highlighting potential hotspots for climate vulnerability and economic impact.

Results

Baseline results

Table 2 presents the baseline results, using a measure that captures deviations from historical temperature norms rather than average temperature (see Appendix Table A1 for results using average temperature).[2] Notably, Vietnam's geographical makeup, with its extensive longitude and long eastern coastline and the Hoàng Liên Sơn mountain range to the west, has facilitated differing adaptive capacities in localities in response to temperature increases. Therefore, a simple comparison of average temperatures will be less meaningful. We refer to marked temperature changes compared with the province's historical average as a 'true' temperature shock,

[2] In Appendix Table A1 presents the results from the conventional approach, defining temperature shocks as increases in standardized average temperature or its logarithm. While coefficients in columns (1) and (4) are positive and significant, the results are not robust across other specifications. This likely reflects the inadequacy of standardized average temperature as a shock measure in high-resilience areas, given its failure to capture adaptability and the endogeneity arising from the historical concentration of export firms in hotter southern provinces (Hsiang et al. 2017, Ramey 2016).

while the historical average is considered the initial norm or climate background for the remainder of the study. Column (1) of Table 2 reveals a significant finding, i.e. a true temperature shock has a negative impact on tax revenue from export and import trade activity. This result is further confirmed in the subsequent columns that control for more temperature shock lagged effects remain consistent with earlier studies (Dell et al. 2012, Deryugina–Hsiang 2014, Hsiang–Jina 2014, Jones–Olken 2010), validating H2a.

Next, we employ the impulse response of outcomes preceding the occurrence of a temperature shock to explore the long-term effects (Jordà 2005). The findings are illustrated in Figure 2, indicating that the impact of a temperature shock will affect export–import activity across provinces in Vietnam for approximately three years, and may peak in the third year. While the current measurement focuses on comparing temperature shocks to their asymmetric norm (either heat or cold shocks), we also expand the investigation by conducting separate regression analyses for hotter and cooler shocks, as detailed in Appendix Table A2. This result implies that a hotter temperature shock will have a more negative impact than a cold shock, on average. The remainder of our analysis solely focuses on the effects in absolute values for simplification and to maintain maximum transparency as distinguishing between heat and cold shocks would require splitting the sample.

Table 2

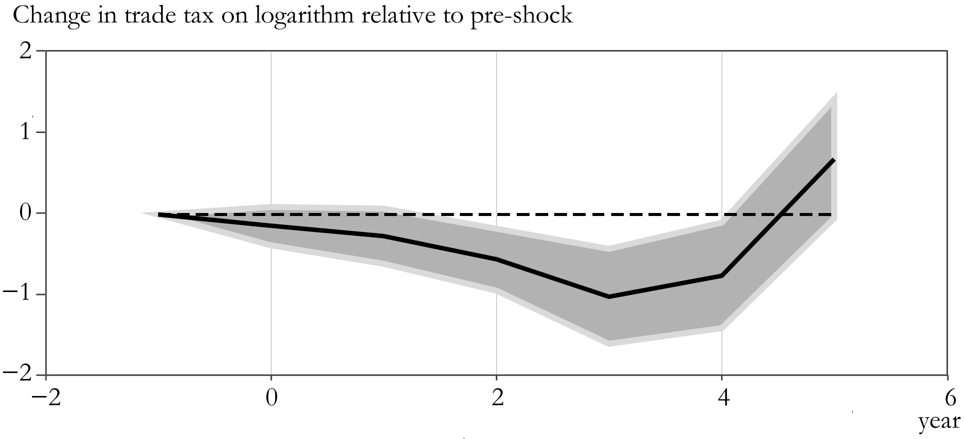
Effect of temperature shocks on tax revenue from export–import activity

Variables	Revenue from import–export activities in logarithm			
	(1)	(2)	(3)	(4)
$Temperature\ Shock_t$	−0.435***	−0.443***	−0.455***	−0.486***
	(0.168)	(0.163)	(0.168)	(0.182)
$Temperature\ Shock_{t-1}$		−0.509***	−0.555***	−0.688***
		(0.169)	(0.165)	(0.177)
$Temperature\ Shock_{t-2}$			−0.609***	−0.756***
			(0.170)	(0.173)
$Temperature\ Shock_{t-3}$				−1.105***
				(0.245)
Year FEs	Yes	Yes	Yes	Yes
Province FEs	Yes	Yes	Yes	Yes
Observations	630	567	504	441
R^2	0.125	0.133	0.148	0.186
Number of provinces	63	63	63	63

Notes: temperature shock represents deviations of climate variables from the respective historical norms for human activity, $Temperature\ Shock_{it} = |\mathcal{T}_{it} - \mathcal{T}^*_{i,t-1}|$, where $\mathcal{T}^*_{i,t-1} = 10^{-1}\sum_{s=1}^{10}\mathcal{T}_{i,t-s}$. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Figure 2

Long-term effects of temperature shock on the outcome: impulse response analysis



Based on the impulse response analysis, we set τ to three and estimate the long-term propensity using equation (3). Table 3 (the baseline result) presents the coefficients of the long-term propensity (θ). These findings remain consistent, even after introducing control variables, including climate background in column (2), industrial development in column (3) and macroeconomic background in column (4). Notably, with regard to magnitude, the temporary effect (Table 2) is approximately 5–7 times smaller than the permanent effect (Table 3). This indicates that studies may underestimate the impact of temperature shocks on economic outcomes if they do not account for long-term effects or consider people's climate change adaptation. As predicted, historic regional temperatures also have a statistically significant positive correlation with the outcome, which can be explained by the fact that multinational enterprises contributing to export and import activity in Vietnam are situated in regions with high temperatures.

To examine how this empirical result is possible (i.e. the long-term impact of a temperature shock is five to seven times greater than its short-term effect), we examine the transmission mechanism using the local projections technique to investigate the effects of temperature shocks on institutional quality through (a) the business perspective (i.e. PCI and its components), (b) citizens' perspective (i.e. PAPI components) and (c) actual reduction in private sector employment. Notably, the role of institutions and private sector development in Vietnam has been widely examined and enjoys substantial consensus (Dang et al. 2025, Luong–Van Le 2024, Van Le–Tran 2024a, Van Le et al. 2022, Van Nguyen et al. 2024). The results in Figure 3 present a broadly consistent picture, confirming that temperature shocks reduce the effectiveness of government interactions with businesses (outcomes 1–10) and citizens (outcomes 11–13) and directly decrease private sector employment (outcome 14), which is determined to be a key driver of development and tax revenue – particularly from the second year after the onset of the temperature shock.

Table 3

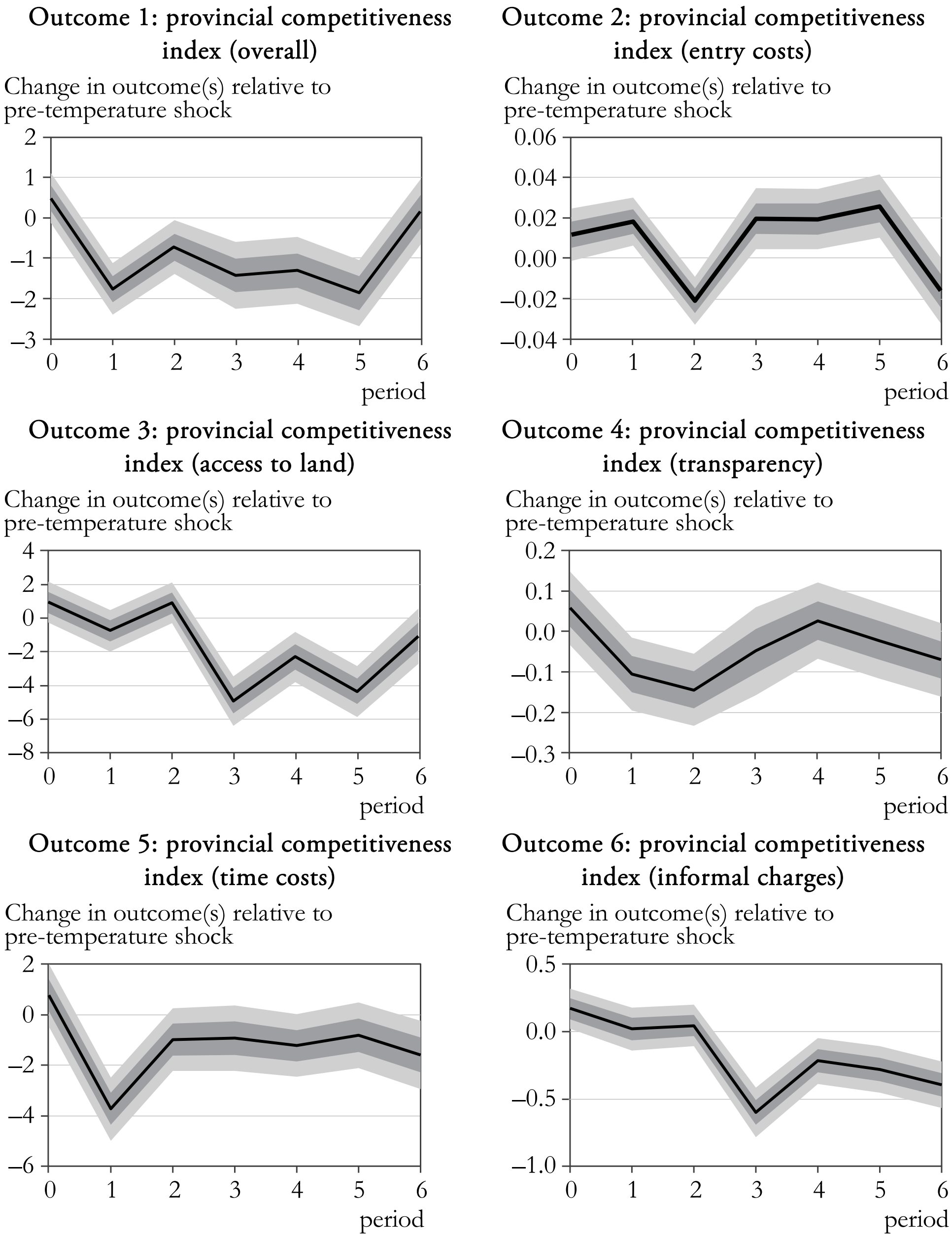
Long-term effect of temperature shocks on tax revenue from export–import activity

Variables	Revenue from import–export activity in logarithm			
	(1)	(2)	(3)	(4)
$Temperature\ Shock\ (LRP - \theta)$	−3.035***	−3.387***	−3.428***	−3.448***
	(0.499)	(0.523)	(0.522)	(0.527)
Historic recorded temperatures		11.124**	11.393**	12.442**
		(4.885)	(4.882)	(4.950)
Rainfall		0.061	0.062	0.055
		(0.433)	(0.435)	(0.435)
FDI in logarithm			−0.000	−0.000
			(0.000)	(0.000)
Industrial index			0.001	0.002
			(0.005)	(0.005)
High-quality labour ratio			−0.285	−1.134
			(0.534)	(1.299)
Private sector labour share			−6.424**	−6.120**
			(2.814)	(2.824)
Urbanisation rate				3.885
				(5.385)
GDP per capita in logarithm				0.369
				(1.301)
PCI				−4.048
				(3.060)
$X_{t-1} - Xt\ (\delta_1)$	5.517***	5.545***	5.585***	5.542***
	(0.930)	(0.931)	(0.931)	(0.935)
$X_{t-2} - Xt\ (\delta_2)$	−4.072***	−4.179***	−4.193***	−4.169***
	(0.783)	(0.783)	(0.783)	(0.785)
$X_{t-3} - Xt\ (\delta_3)$	1.105***	1.151***	1.151***	1.147***
	(0.245)	(0.245)	(0.245)	(0.245)
Year FEs	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R^2	0.186	0.197	0.213	0.219
Number of provinces	63	63	63	63

Notes: the model in this table is estimated in the transformed form according to equation (3); therefore, the coefficient of the temperature shock (θ) reflects the long-term effect, whereas the δ coefficients do not capture the marginal effect of annual temperature changes. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Figure 3

Local projections estimating the long-term effects of temperature shocks on key macroeconomic indicators



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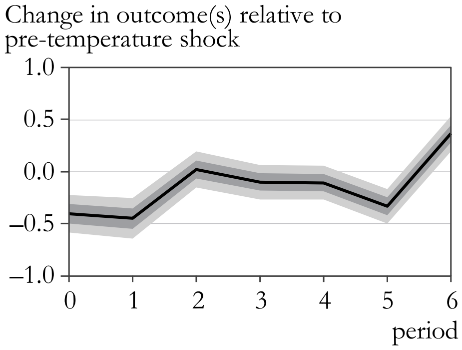
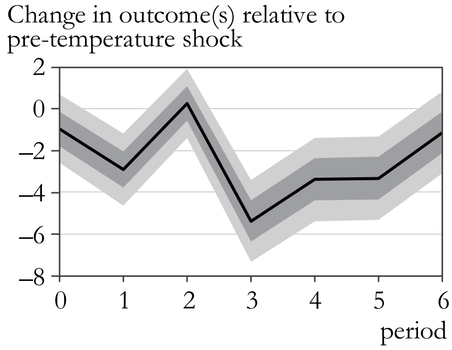
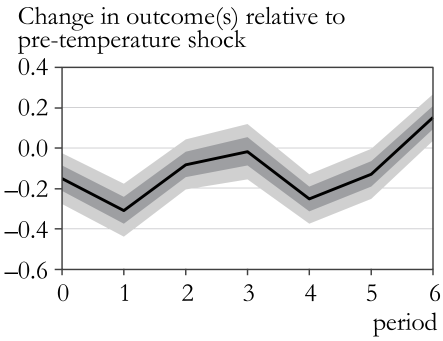
Outcome 7: provincial competitiveness index (policy bias)



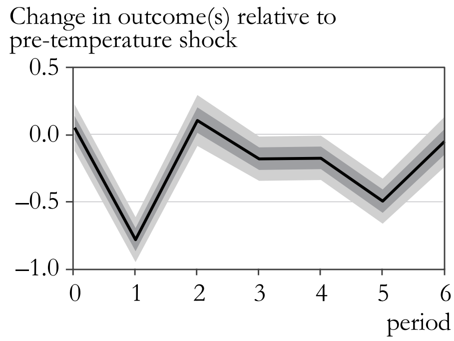
Outcome 8: provincial competitiveness index (proactivity)



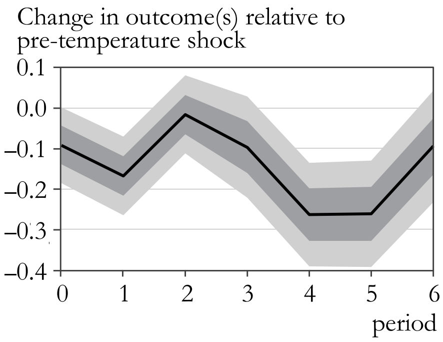
Outcome 9: provincial competitiveness index (labour policy)



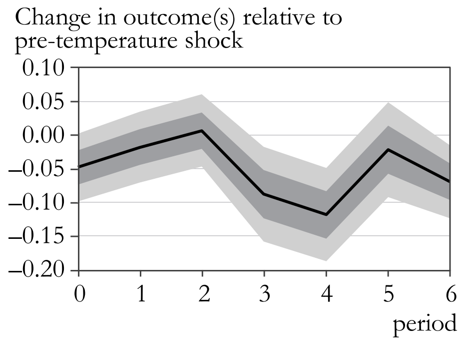
Outcome 10: provincial competitiveness index (law and order)



Outcome 11: control of corruption in the public sector



Outcome 12: public administrative procedure



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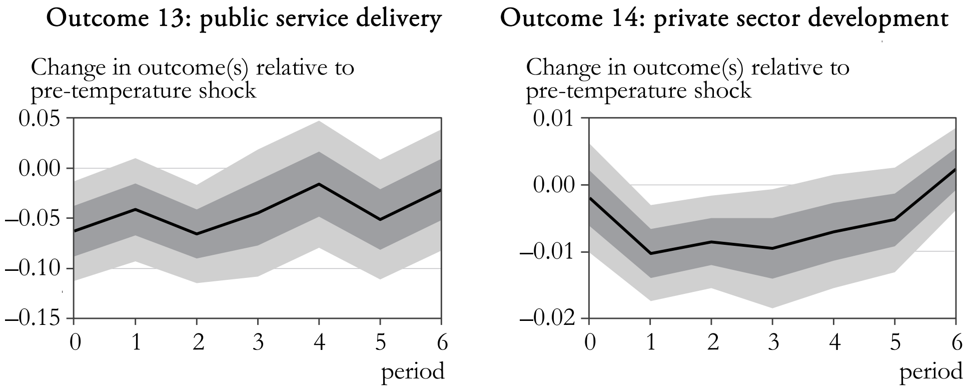

Notes: estimates are presented with 68% and 95% confidence intervals. Outcomes 1–10: PCI sub-indices on economic governance – entry costs, access to land, transparency, time costs, informal charges, policy bias, proactivity, business support services, labour policy and law & order. Outcomes 11–13: PAPI dimensions – control of corruption, public administrative procedures and public service delivery – assessing integrity, administrative efficiency and service quality. Outcome 14: Private sector development, proxied by the share of private sector employment in total labour force, indicating its influence on tax revenue generation and socio-economic growth.

Heterogeneous effects

We next test several hypotheses based on insights from our literature review. First, we examine whether temperature shocks exhibit heterogeneous effects on outcomes, particularly in regions characterised by favourable temperature conditions which are less susceptible to such shocks. In column (1) of Table 4, we investigate this by regressing the interaction between the shock variable and a dummy variable set to one if the average temperature ranges from 20°C–24°C (Fanger 1970). Our findings confirm that temperature shocks have a smaller effect on provinces characterised by favourable temperature conditions. Second, referencing to Hallegatte et al. (2013), climate shocks pose a greater threat to coastal regions, which include 28 of Vietnam's 63 provinces (see in Appendix Table A3). In column (2), the coefficient of the interaction term is statistically insignificant, indicating that it may not necessarily apply to the various types of temperature shock. Third, columns (3) and (4) present the coefficients of interaction between temperature shocks and variables related to the FDI sector. In column (3), we use a dummy variable to denote provinces attracting FDI (value of 1) versus those that do not (value of 0), indicating that the effect of temperature shocks is more pronounced in regions with FDI activity. Furthermore, column (4) demonstrates that greater reliance on FDI activity intensifies the negative impact of temperature shocks on the revenue generated from local export–import activity. These combined findings support H2b.

Table 4

Heterogeneous effects

Variables	Revenue from import–export activity in logarithm			
	(1)	(2)	(3)	(4)
$Temperature\ shock\ (LRP - \theta)$	−3.611***	−3.024***	−3.000***	−2.846***
	(0.599)	(0.500)	(0.502)	(0.507)
$Temp\ shock \times optimal\ conditions$	0.735*			
	(0.425)			
$Temp\ shock \times coastal\ area$		−0.212		
		(0.431)		
$Temp\ shock \times FDI\ zone$			−0.809**	
			(0.391)	
$Temp\ shock \times FDI\ dependence$				−0.852**
				(0.426)
$X_{t-1} - Xt\ (\delta_1)$	5.595***	5.575***	5.563***	5.550***
	(0.929)	(0.939)	(0.933)	(0.928)
$X_{t-2} - Xt\ (\delta_2)$	−4.225***	−4.128***	−4.119***	−4.194***
	(0.786)	(0.792)	(0.786)	(0.784)
$X_{t-3} - Xt\ (\delta_3)$	1.168***	1.124***	1.122***	1.158***
	(0.247)	(0.248)	(0.246)	(0.246)
Year FEs	Yes	Yes	Yes	Yes
Province FEs	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R^2	0.192	0.186	0.187	0.195
Number of provinces	63	63	63	63

Notes: the optimal condition is a dummy variable indicating if the average temperature of a province falls between 20°C and 24°C degrees. The list of coastal zones and provinces experiencing optimal conditions is presented in Appendix Table A3. FDI zones are provinces actively attracting FDI. FDI dependence refers to provinces where the labour force participation rate exceeds the threshold $p(50)$. Additional models with control variables are presented in Appendix Table A4. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Mechanism and robustness tests

This chapter outlines several strategies to ensure the robustness of our analysis. Table 5 includes a dynamic model that accounts for the one-year lagged effects of the dependent variable, improving model specification while maintaining consistent results, albeit with slightly reduced magnitude. Our preliminary surveys and observations indicate that the most significant adaptation in the import–export sector may be attributable to electricity usage and energy consumption. This issue was particularly critical in periods when Vietnam’s hydropower faced significant losses due to droughts affecting reservoirs in 2013 and 2019. Frequent power outages resulted in considerable costs (Hoang Duc–Do Ba 2017). Indeed, increased electricity consumption implies higher manufacturing costs and potential power shortages during peak hours, leading to disruptions in import–export activity (Acaravci–Ozturk 2010, Polemis–Dagoumas 2013).

Qiao et al. (2023) find that greater temperature variations hinder the stabilisation of electricity demand in China. Therefore, in Panel A of Table 6, we examine the effects of both temperature levels and temperature shocks on electricity consumption to investigate the underlying mechanisms. If our hypothesis holds true, it is reasonable to expect that the effect of average temperature and temperature shocks will align with the pattern of the primary outcome variable, meaning that the former would have no statistical significance while the latter would demonstrate a positive and statistically significant effect. Given the lack of province-level data on kilowatt-hour usage, we use the ratio of electric tool usage, based on the assumption that per-device electricity consumption changes linearly over time. Our findings support the hypothesis of temperature adaptation. While the coefficients of average temperature in columns (1)–(3) of Table 6 are statistically significant, those of temperature shocks in columns (4)–(6) are robust, with all lagged shocks statistically and significantly affecting the outcomes.

Due to the absence of provincial electricity consumption data, we examine electricity consumption channel using power tool utilisation rates to capture equipment-level changes, which may not reflect overall industrial electricity use after a temperature shock. As an alternative, we indirectly assess the mechanism through heterogeneity analysis (Panel B, Table 6) based on whether provinces host energy-intensive industries and have well-developed power infrastructure. The results align with expectations, demonstrating that provinces with either stable power infrastructure or lower vulnerability to power shortages (i.e. not energy-intensive industries) experience smaller impacts from temperature shocks. The list of provinces classified by energy intensity and power infrastructure quality is provided in Appendix Table A5, compiled with caution as it is primarily based on the research team's observational experience in Vietnam during 2010–2019, which may involve a degree of subjectivity. These results also support H1.

Concerns arise that (a) the choice of $m = 10$ could be arbitrary, although it is a common practice for samples with limited time periods (Kahn et al. 2021); (b) using tax revenue from export–import activity may not be a suitable proxy, as temperature shocks might influence tax collection practices or government tax policies (expected to decrease with rising temperatures); and (c) the influence of FDI clustering and industrial zoning in hotter areas of Vietnam may introduce possible selection bias.

For concern (a), we re-estimate the benchmark results with $m = 15$ and $m = 20$, as Kahn et al. (2021) suggest when data length is sufficient in a global context. The results, in Table 7 reveal slightly smaller estimated magnitudes but remain consistent in sign and statistical significance. Appendix Table A6 addresses concern (b) by employing alternative tax revenue indicators. If any shock coefficients are statistically significant, it will indicate that our assumption about tax practices that the measured impact reflects changes in tax behaviour rather than export–import activity is incorrect. The results indicate that temperature shocks did not affect government tax practices during the study period.[3] For concern (c), we re-estimate using a sample that excludes the top and bottom 5% of provinces based on average FDI values (see in Appendix Table A7). The results remain consistent in sign and magnitude compared with the benchmark estimates, supporting the plausibility of our exogeneity assumption for the temperature shock variable.

Table 5

Robustness test: dynamic model

Variables	Revenue from import–export activity in logarithm			
	(1)	(2)	(3)	(4)
Dynamic control (Y_{t-1})	0.515***	0.510***	0.500***	0.509***
	(0.051)	(0.051)	(0.052)	(0.052)
$Temperature\ Shock\ (LRP - \theta)$	−1.772***	−2.001***	−2.044***	−2.086***
	(0.459)	(0.485)	(0.488)	(0.489)
$X_{t-1} - Xt\ (\delta_1)$	3.096***	3.202***	3.254***	3.210***
	(0.858)	(0.861)	(0.866)	(0.865)
$X_{t-2} - Xt\ (\delta_2)$	−2.184***	−2.302***	−2.331***	−2.299***
	(0.718)	(0.721)	(0.725)	(0.724)
$X_{t-3} - Xt\ (\delta_3)$	0.576**	0.617***	0.622***	0.616***
	(0.223)	(0.224)	(0.225)	(0.225)
Climate background control	Yes	Yes	Yes	Yes
Market background control	Yes	Yes	Yes	Yes
Economic background control	Yes	Yes	Yes	Yes
Time FEs	Yes	Yes	Yes	Yes
Province FEs	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R^2	0.363	0.368	0.374	0.384
Number of provinces	63	63	63	63

Notes: temperature shock represents deviations of climate variables from the respective historical norms for human activities, $Temperature\ Shock_{it} = |\mathcal{T}_{it} - \mathcal{T}^*_{i,t-1}|$ where $\mathcal{T}^*_{i,t-1} = 10^{-1}\sum_{s=1}^{10}\mathcal{T}_{i,t-s}$. The climate background control includes average temperature and average rainfall. The market background control includes FDI implementation, the industrial index, the high-quality labour ratio and the private sector labour share. The economic background control includes the urbanisation rate, the logarithm of GDP per capita and the provincial competitiveness index (PCI). Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

[3] While it would be preferable to control for each province's export–import volume; however, such data are not currently available for Vietnam.

Table 6

Robustness test: Electricity consumption channel

Panel A: electric tool use

Variable	electric tool usage ratio					
	(1)	(2)	(3)	(4)	(5)	(6)
$SD(Temperature_t)$	0.304	0.343	0.512			
	(0.375)	(0.385)	(0.404)			
$SD(Temperature_{t-1})$		0.522	0.578			
		(0.400)	(0.397)			
$SD(Temperature_{t-2})$			0.622			
			(0.403)			
$Temperature\ Shock_t$				0.591**	0.736***	0.894***
				(0.235)	(0.242)	(0.257)
$Temperature\ Shock_{t-1}$					0.774***	0.894***
					(0.250)	(0.253)
$Temperature\ Shock_{t-2}$						0.714***
						(0.261)
Time FEs	Yes	Yes	Yes	Yes	Yes	Yes
Province FEs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	630	567	504	630	567	504
R^2	0.206	0.186	0.170	0.214	0.209	0.203
Number of provinces	63	63	63	63	63	63

Panel B: heterogeneity: stable power infrastructure and energy-intensive industries

Variables	revenue from import–export activity in logarithm			
	(1)	(2)	(3)	(4)
$Temperature\ Shock\ (TS)$	−3.629***	−3.618***	−2.904***	−2.889***
	(0.557)	(0.559)	(0.501)	(0.504)
$TS \times \mathbb{1}_{\{\text{Stable Power Infrastructure}\}}$	0.881**	0.876**		
	(0.374)	(0.374)		
$TS \times \mathbb{1}_{\{\text{Energy-Intensive Industries}\}}$			−0.926**	−0.932**
			(0.463)	(0.463)
$X_{t-1} - Xt\ (\delta_1)$	5.565***	5.515***	5.557***	5.496***
	(0.925)	(0.930)	(0.927)	(0.932)
$X_{t-2} - Xt\ (\delta_2)$	−4.221***	−4.166***	−4.150***	−4.090***
	(0.781)	(0.783)	(0.781)	(0.783)
$X_{t-3} - Xt\ (\delta_3)$	1.170***	1.154***	1.133***	1.116***
	(0.245)	(0.245)	(0.244)	(0.244)
Climate background control	No	Yes	No	Yes
Market background control	No	Yes	No	Yes
Economic background control	No	Yes	No	Yes
Time FEs	Yes	Yes	Yes	Yes
Province FEs	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R^2	0.198	0.215	0.195	0.212
Number of ID	63	63	63	63

Notes: $\mathbb{1}$ indicates that provinces with the characteristics listed in $\{\ldots\}$ are assigned a value of 1 and 0 otherwise. The list of provinces and the rationale for their grouping are presented in detail in Appendix Table A5. While the classification criteria may be somewhat subjective, based on the research team's experience in observing Vietnam, this approach provides a useful basis for categorisation. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7

Robustness test: alternate temperature shock measures

Variables	Revenue from import and export activity on logarithm			
	(1)	(2)	(3)	(4)
$Temperature\ Shock\ (m = 20)$	−1.279***	−1.511***	−2.204***	−2.185***
	(0.400)	(0.409)	(0.444)	(0.447)
$Temperature\ Shock\ (m = 15)$				
Historic recorded temperatures		9.769***	5.406	5.277
		(3.604)	(4.400)	(4.495)
Rainfall		0.476	−0.192	−0.208
		(0.379)	(0.415)	(0.417)
FDI implicated on logarithm			−0.000	−0.000
			(0.000)	(0.000)
Industrial index			−0.002	−0.002
			(0.005)	(0.005)
High-quality labour ratio			−0.643	−1.337
			(0.511)	(1.150)
Private sector labour share			−3.913	−3.755
			(2.671)	(2.693)
Urbanisation rate				3.328
				(4.699)
GDP per capita on logarithm				0.786
				(1.128)
Provincial competitiveness index (PCI)				−0.363
				(2.315)
$X_{t-1} - Xt\ (\delta_1)$	2.195***	2.196***	3.684***	3.656***
	(0.766)	(0.761)	(0.802)	(0.805)
$X_{t-2} - Xt\ (\delta_2)$	−1.522**	−1.522**	−2.716***	−2.700***
	(0.657)	(0.653)	(0.689)	(0.691)
$X_{t-3} - Xt\ (\delta_3)$	0.387*	0.383*	0.741***	0.739***
	(0.208)	(0.207)	(0.218)	(0.218)
Year FEs	Yes	Yes	Yes	Yes
Province FEs	Yes	Yes	Yes	Yes
Observations	630	630	504	504
R^2	0.132	0.145	0.165	0.167
Number of ID	63	63	63	63

(Table continues on the next page.)

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Variables	Revenue from import and export activity on logarithm			
	(5)	(6)	(7)	(8)
$Temperature\ Shock\ (m = 20)$				
$Temperature\ Shock\ (m = 15)$	−1.692***	−1.946***	−2.504***	−2.487***
	(0.417)	(0.424)	(0.461)	(0.465)
Historic recorded temperatures		10.640***	5.982	5.941
		(3.544)	(4.270)	(4.364)
Rainfall		0.450	−0.214	−0.228
		(0.376)	(0.413)	(0.414)
FDI implicated on logarithm			−0.000	−0.000
			(0.000)	(0.000)
Industrial index			−0.002	−0.002
			(0.005)	(0.005)
High-quality labour ratio			−0.613	−1.154
			(0.509)	(1.146)
Private sector labour share			−3.985	−3.821
			(2.657)	(2.679)
Urbanisation rate				2.630
				(4.682)
GDP per capita on logarithm				0.861
				(1.122)
Provincial competitiveness index (PCI)				−0.426
				(2.301)
$X_{t-1} - Xt\ (\delta_1)$	2.748***	2.763***	4.045***	4.019***
	(0.789)	(0.784)	(0.834)	(0.837)
$X_{t-2} - Xt\ (\delta_2)$	−1.878***	−1.894***	−2.917***	−2.906***
	(0.673)	(0.669)	(0.712)	(0.713)
$X_{t-3} - Xt\ (\delta_3)$	0.475**	0.475**	0.786***	0.785***
	(0.213)	(0.211)	(0.224)	(0.225)
Year FEs	Yes	Yes	Yes	Yes
Province FEs	Yes	Yes	Yes	Yes
Observations	630	630	504	504
R^2	0.141	0.157	0.174	0.176
Number of ID	63	63	63	63

Notes: temperature shock represents climate variables' deviations from the respective historical norms for human activity. Columns (1)–(4) use a 20-year moving average; columns (5)–(8) use a 15-year moving average. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Conclusions and future research

The mismatch between the limited actions of the Vietnamese government regarding climate change (particularly temperature shocks) and the abundant global literature highlighting its negative impact is unsurprising. This discrepancy may be attributable to the way in which research messages are communicated to policymakers. A more effective communication approach to prompt action might involve demonstrating how climate change directly affects their tax revenue rather than using vague statements about environmental consequences. Our message to policymakers is: Why not use tax revenue to promote to climate change adaptation rather than remaining passive and allowing our resources to erode? Taking action can transform challenges into opportunities, fostering resilience and a sustainable future.

We are surprised that despite the wealth of studies worldwide on the negative consequences of temperature shocks on export–import activity, the weight and extent of empirical evidence in Vietnam remain minimal. Our research fills this gap. We confirm that the temporary impact of temperature shocks on government export–import revenue is immense, while the permanent effects are even higher, approximately five to seven times more. The impact is more pronounced in areas with unfavourable climates and is particularly severe in regions with substantial FDI. The consequences of this environmental impact may mean for these impacts might include increased electricity use to adapt to the shocks.

Comparing our empirical evidence with the broader research landscape in Vietnam, it seems to us that current measurement indicators in empirical studies tend to focus too strongly on average metrics rather than thoroughly examining temperature shocks in relation to study areas' adaptability. This is particularly true for the export–import sector, which can adapt and respond to shocks – beyond averages – in different ways than the agricultural sector can, particularly in geographical regions that have not previously experienced significant temperature shocks. Notably, limited data availability for Vietnam may pose a barrier to constructing better indicators for research.

What remains for policymakers? Awareness of the fiscal impacts of temperature shocks on the government budget must be strengthened. Based on average temperature changes from 2002–2019 and our long-term estimates, each province lost an average of VND 131–149 billion[4] in tax revenue from export–import activities alone, which exceeds many provinces' five-year cumulative environmental protection spending. The impact likely operates through electricity consumption, particularly in the FDI sector, which accounts for 68.7% of Vietnam's import–export value (2023). This fact underscores the necessity of short- and medium-term policies to ensure

[4] Table 3 shows that a 1°C rise in temperature leads to a long-term decline of about 3.0%–3.45% in export–import tax revenue. With revenue of VND 5,500 billion, this equals a loss of VND 167–190 billion, and a 0.789°C increase will incur a loss of about VND 131–149 billion.

energy (i.e. electricity) stability in high temperature shock periods. Ideally, the VND 131–149 billion per province could be invested in green energy (e.g. solar power) development to support the national grid, particularly in industrial zones with higher ambient temperatures. While it is less likely that FDI companies will relocate to more favourable climates, considering the infrastructure and logistics constraints tied to global supply chains, ensuring a stable electricity supply through robust power infrastructure and transparent blackout management strategies are feasible and essential within the government's broader green planning agenda. Ultimately, a long-term strategy that prioritises budget allocation for climate change mitigation and adaptation to temperature shocks should be considered an environmental imperative as well as a matter of fiscal prudence and national prosperity.

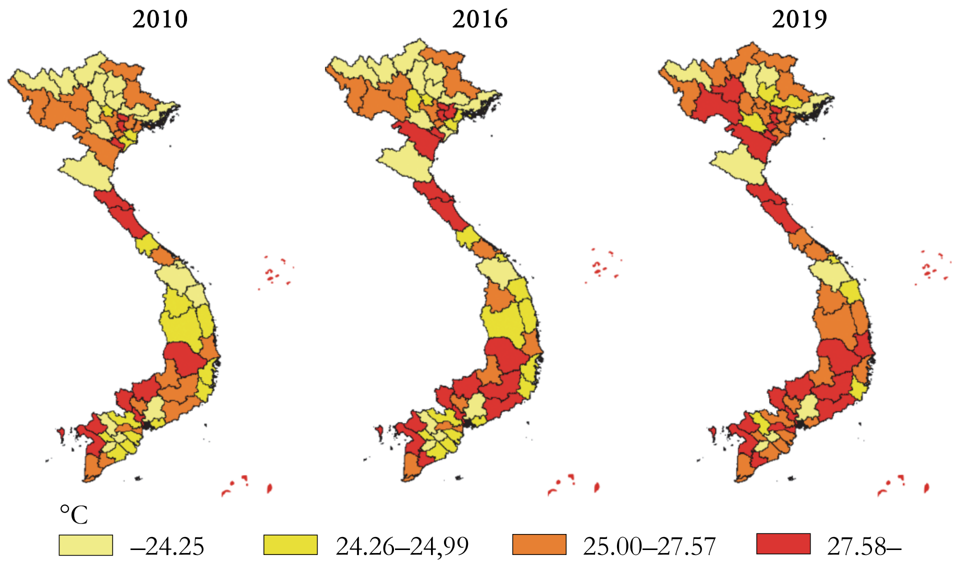
Future research could examine alternative temperature shock indicators such as daily temperature fluctuations or maximum temperatures compared with previous periods. A better design would involve analysing data from more precise geographical grid cells rather than the provincial level, considering that districts and communes within the same province may have differing climatic characteristics. Furthermore, studies should also concentrate on exploring the heterogeneous impacts of temperature shocks under varying conditions, rather than treating them as uniform, which is likely to produce inaccurate results given the population's increased adaptability. Finally, examining the effects of hot versus cold temperature shocks could provide additional insights for future climate change adaptation efforts.

Appendix

Figure A1

Evolution of average temperatures and tax revenue from international trade

Panel A: the evolution of average temperatures in Vietnam



Panel B: evolution of tax revenue from international trade

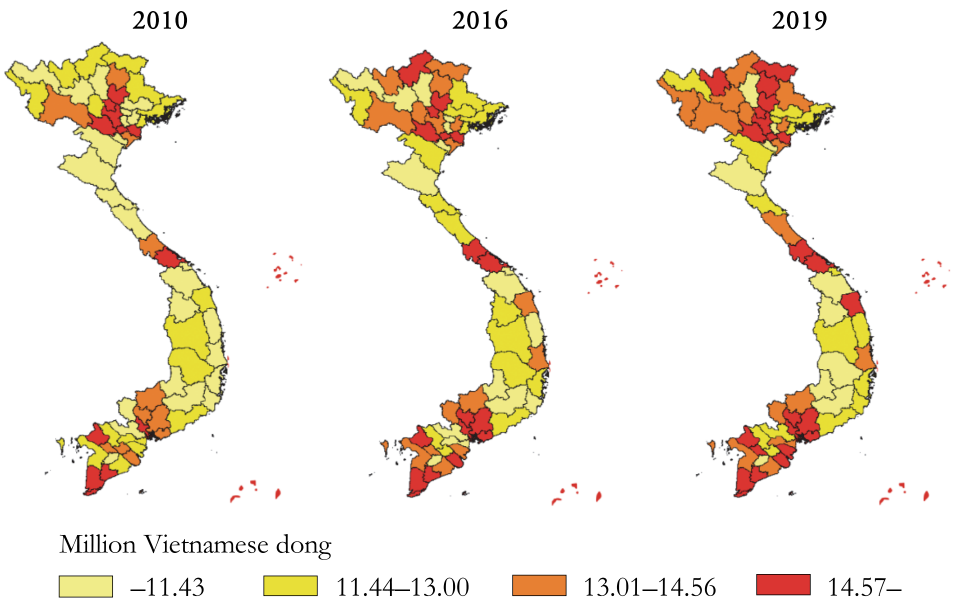


Table A1

Effect of averaged temperature on tax revenues from export and import activities

Dependent variable	Revenue from import and export activity on logarithm					
	(1)	(2)	(3)	(4)	(5)	(6)
$SD(Temperature_t)$	0.480*	0.358	0.058			
	(0.267)	(0.261)	(0.267)			
$SD(Temperature_{t-1})$		0.108	–0.057			
		(0.269)	(0.261)			
$SD(Temperature_{t-2})$			–0.178			
			(0.266)			
$Ln(Temperature_t)$				6.271**	4.708	1.020
				(3.134)	(3.058)	(3.180)
$Ln(Temperature_{t-1})$					1.653	–0.251
					(3.168)	(3.074)
$Ln(Temperature_{t-2})$						–1.697
						(3.136)
$SD(Rainfall_t)$	0.160	0.161	0.032	0.161	0.163	0.035
	(0.109)	(0.115)	(0.121)	(0.109)	(0.115)	(0.121)
Year Fes	Yes	Yes	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	630	567	504	630	567	504
R-squared	0.123	0.113	0.104	0.124	0.115	0.103
Number of provinces	63	63	63	63	63	63

Notes: standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A2

Hot and cold temperature shocks

Dependent variable	Revenue from import and export activities on logarithm		
	(1)	(2)	(3)
$\|Temperature\ Shock_t\|$	–0.435***		
	(0.168)		
$Heat\ Temperature\ Shock_t$		–1.417***	
		(0.363)	
$Cold\ Temperature\ Shock_t$			–0.768**
			(0.323)
Year Fes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes
Observations	630	300	330
R-squared	0.125	0.175	0.143
Number of provinces	63	63	63

Notes: standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A3

Lists of provinces with favourable temperature conditions and coastal zones

Optimal temperature conditions							
Bắc Giang	Bắc Kạn	Cao Bằng	Hà Giang	Hải Phòng	Lai Châu	Lào Cai	Lâm Đồng
Lạng Sơn	Nghệ An	Quảng Ninh	Sơn La	Thái Bình	Yên Bái	Điện Biên	Đắk Nông
Coastal zones							
Bình Thuận	Bình Định	Bạc Liêu	Bến Tre	Cà Mau	Gia Lai	HCM	Huế
Hà Tĩnh	Hải Phòng	Khánh Hòa	Kiên Giang	Nam Định	Nghệ An	Ninh Bình	Ninh Thuận
Phú Yên	Quảng Bình	Quảng Nam	Quảng Ninh	Quảng Trị	Sóc Trăng	Thanh Hóa	Thái Bình
Tiền Giang	Trà Vinh	Đà Nẵng					

Table A4

Further analysis with interaction terms

Dependent variable	Revenue from import and export activity on logarithm			
	(1)	(2)	(3)	(4)
$Temperature\ Shock\ (LRP - \theta)$	–3.658***	–3.017***	–2.859***	–2.824***
	(0.600)	(0.502)	(0.506)	(0.510)
$Temp\ Shock \times Optimal\ conditions$	0.814*			
	(0.429)			
$Temp\ Shock \times Coastal\ area$		–0.202		
		(0.431)		
$Temp\ Shock \times FDI\ zone$			–0.856**	
			(0.391)	
$Temp\ Shock \times FDI\ dependence$				–0.862**
				(0.429)
$X_{t-1} - Xt\ (\delta_1)$	5.540***	5.521***	5.698***	5.484***
	(0.933)	(0.945)	(0.938)	(0.933)
$X_{t-2} - Xt\ (\delta_2)$	–4.180***	–4.071***	–4.312***	–4.135***
	(0.787)	(0.795)	(0.794)	(0.786)
$X_{t-3} - Xt\ (\delta_3)$	1.156***	1.107***	1.195***	1.142***
	(0.247)	(0.248)	(0.249)	(0.246)
Market background control	Yes	Yes	Yes	Yes
Economic background control	Yes	Yes	Yes	Yes
Year Fes	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R-squared	0.211	0.204	0.214	0.212
Number of provinces	63	63	63	63

Notes: standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A5

List of provinces with strong power infrastructure and energy-intensive industries

Province	idmap	Explanation
Panel A: provinces with good power infrastructure		
Thanh Hóa	VN-21	Hosts 500 kV transformer stations; planned LNG plant (Nghi Sơn); strong grid development.
Bà Rịa – Vũng Tàu	VN-43	National energy hub, home to Phú Mỹ thermal power complex (40% of Vietnam's power output).
Ho Chi Minh City	VN-SG	Urban smart grid, underground cabling in central districts; highly reliable electricity.
Hà Nội	VN-HN	Dense 110–220 kV network; advanced demand-side management in urban areas.
Hải Phòng	VN-HP	Major seaport city; ongoing investments in LNG power; large load capacity infrastructure.
Ninh Thuận	VN-36	Vietnam's largest solar power base; solid renewable energy-grid integration.
Cần Thơ	VN-CT	Mekong Delta energy center; upgraded grid to support industrial and urban growth.
Đồng Tháp	VN-45	Rural electrification complete; improved 110 kV grid in agriculture-based economy.
Tây Ninh	VN-37	Border province with modern grid; cross-border power flow with Cambodia; solar growth.
Đà Nẵng	VN-DN	Central region's IT hub; stable urban electricity; smart metering deployment ongoing.
Quảng Ninh	VN-13	High-capacity grid with multiple coal-fired plants; transition plans toward LNG and renewables.
Bắc Ninh	VN-56	Industrial electronics hub; strong EVN support for grid reliability for Samsung, Foxconn.
Bình Dương	VN-57	Top-rated in PCI infrastructure index; modern grid serving dense industrial zones.
Đồng Nai	VN-39	Large industrial base; multiple 220 kV and 500 kV substations; high energy demand management.
Long An	VN-41	Strong logistics and industrial growth; receiving capacity from southern transmission system.
Khánh Hòa	VN-34	Power infrastructure supports Cam Ranh port and tourism; 110–220 kV grid well developed.
Thái Nguyên	VN-69	Northern industrial province; upgraded infrastructure to serve Samsung and metallurgy sector.
Bình Phước	VN-58	Improving rural access; 110 kV investments to support agro-industrial expansion.
Bạc Liêu	VN-55	Wind power leader in Mekong; connected to national grid via modern substations.
Kiên Giang	VN-47	Coastal province with improved grid; Phú Quốc power cable connection; LNG plans.
Kon Tum	VN-28	High-voltage grid expanded to support hydro and rural electrification.
Phú Yên	VN-32	Solar and wind development supported by 110 kV grid reinforcement.
Quảng Ngãi	VN-29	Refinery and industrial energy needs supported by solid 220 kV infrastructure.
Bắc Kạn	VN-53	Despite being mountainous, rural electrification rate is high; modernized substation systems.
Sơn La	VN-05	Home to Sơn La hydropower plant; strong grid capacity for regional energy redistribution.
Lạng Sơn	VN-09	Border grid strengthened; improved reliability in mountainous terrain.

(Table continues on the next page.)

(Continued.)

Province	idmap	Explanation
		Panel B: provinces with energy-intensive industries
Ho Chi Minh City	VN-SG	Vietnam's largest economic hub; top in number of key energy users (~330+); dense industry.
Hà Nội	VN-HN	Capital city with major industrial zones, logistics, and heavy public infrastructure loads.
Bình Dương	VN-57	Leading manufacturing province; high energy consumption in textile, wood, and electronics.
Đồng Nai	VN-39	Home to Amata, Loteco, Biên Hòa IZs; high share of heavy manufacturing and metallurgy.
Bà Rịa – Vũng Tàu	VN-43	Energy base of Vietnam; hosts petroleum, chemical, and thermal power industries.
Long An	VN-41	Rapid industrial expansion with dozens of active industrial zones and logistics centers.
Bắc Ninh	VN-56	Electronics manufacturing hub (Samsung, Foxconn); dense high-tech factories.
Đà Nẵng	VN-DN	Central industrial and port city; concentration of rubber, textile, mechanical industries.
Vĩnh Phúc	VN-70	Strong automobile and electronics sector (Toyota, Honda); significant industrial loads.
Hải Dương	VN-61	Well-established in cement, ceramics, and automobile component manufacturing.
Cần Thơ	VN-CT	Mekong Delta's processing center; food, rice milling, and fertilizer plants are dominant.
Hưng Yên	VN-66	Located in Red River Delta industrial belt; strong light and heavy manufacturing base.
Hải Phòng	VN-HP	Deep-water port city; high energy demand from shipbuilding, cement, and heavy industries.
Quảng Nam	VN-27	Hosts Chu Lai EZ; focuses on automotive assembly and supporting industries.
Bắc Giang	VN-54	Emerging electronics and textile hub; significant FDI inflows; Samsung/BOE presence.
Nghệ An	VN-22	Nghi Sơn Cement and thermal plants; growing logistics & manufacturing zones.
Thái Nguyên	VN-69	Base of Samsung Electronics; also hosts steel, coal, and heavy chemical industries.
Quảng Ninh	VN-13	Vietnam's coal capital; numerous cement, thermal power, and mining-related factories.
Lâm Đồng	VN-35	Large-scale aluminum (bauxite) processing; energy use in agriculture and mining.
Hà Giang	VN-03	Emerging hydro-mining and construction material sectors in mountainous zones.
Thái Bình	VN-20	Energy demand from fertilizer, mechanical, and textile industries.
Lào Cai	VN-02	Major copper and apatite mining province; chemical processing and metallurgy present.
Yên Bái	VN-06	Cement, construction materials, and hydropower generation support energy-intensive label.
Hòa Bình	VN-14	Known for Hòa Bình Hydropower Plant and several industrial clusters in cement production.

Table A6

Robustness check of tax behavior: using placebos

Panel A:	Revenue from crude oil on logarithm			
	(1)	(2)	(3)	(4)
Dynamic control (Y_{t-1})				
$Temperature\ Shock$	0.029	0.021	0.010	0.013
	(0.049)	(0.051)	(0.051)	(0.051)
$X_{t-1} - Xt\ (\delta_1)$	–0.048	–0.039	–0.020	–0.027
	(0.091)	(0.091)	(0.091)	(0.090)
$X_{t-2} - Xt\ (\delta_2)$	0.025	0.018	0.003	0.009
	(0.076)	(0.077)	(0.077)	(0.076)
$X_{t-3} - Xt\ (\delta_3)$	–0.004	–0.002	0.001	0.000
	(0.024)	(0.024)	(0.024)	(0.024)
Climate background control	Yes	Yes	Yes	Yes
Market background control	Yes	Yes	Yes	Yes
Economic background control	Yes	Yes	Yes	Yes
Time Fes	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R-squared	0.058	0.061	0.086	0.117
Number of provinces	63	63	63	63
	(5)	(6)	(7)	(8)
Dynamic control (Y_{t-1})	0.600***	0.600***	0.597***	0.591***
	(0.032)	(0.032)	(0.033)	(0.034)
$Temperature\ Shock$	–0.008	–0.013	–0.015	–0.017
	(0.035)	(0.037)	(0.037)	(0.037)
$X_{t-1} - Xt\ (\delta_1)$	0.021	0.029	0.031	0.032
	(0.065)	(0.066)	(0.066)	(0.067)
$X_{t-2} - Xt\ (\delta_2)$	–0.027	–0.033	–0.034	–0.035
	(0.055)	(0.055)	(0.056)	(0.056)
$X_{t-3} - Xt\ (\delta_3)$	0.011	0.012	0.013	0.013
	(0.017)	(0.017)	(0.017)	(0.017)
Climate background control	Yes	Yes	Yes	Yes
Market background control	Yes	Yes	Yes	Yes
Economic background control	Yes	Yes	Yes	Yes
Time Fes	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R-squared	0.517	0.518	0.519	0.521
Number of provinces	63	63	63	63

(Table continues on the next page.)

(Continued.)

Panel B:	Domestic revenue on logarithm			
	(1)	(2)	(3)	(4)
Dynamic control (Y_{t-1})				
$Temperature\ Shock$	0.049	0.050	0.042	0.064
	(0.061)	(0.065)	(0.064)	(0.060)
$X_{t-1} - Xt\ (\delta_1)$	–0.109	–0.121	–0.113	–0.163
	(0.115)	(0.115)	(0.114)	(0.107)
$X_{t-2} - Xt\ (\delta_2)$	0.104	0.110	0.107	0.139
	(0.096)	(0.097)	(0.096)	(0.090)
$X_{t-3} - Xt\ (\delta_3)$	–0.039	–0.040	–0.040	–0.046
	(0.030)	(0.030)	(0.030)	(0.028)
Climate background control	Yes	Yes	Yes	Yes
Market background control	Yes	Yes	Yes	Yes
Economic background control	Yes	Yes	Yes	Yes
Time Fes	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R-squared	0.825	0.826	0.832	0.854
Number of provinces	63	63	63	63
	(5)	(6)	(7)	(8)
Dynamic control (Y_{t-1})	0.307***	0.305***	0.296***	0.187***
	(0.050)	(0.050)	(0.050)	(0.052)
$Temperature\ Shock$	0.061	0.058	0.052	0.066
	(0.059)	(0.062)	(0.061)	(0.059)
$X_{t-1} - Xt\ (\delta_1)$	–0.136	–0.144	–0.137	–0.169
	(0.109)	(0.110)	(0.110)	(0.106)
$X_{t-2} - Xt\ (\delta_2)$	0.133	0.136	0.133	0.149*
	(0.092)	(0.093)	(0.092)	(0.089)
$X_{t-3} - Xt\ (\delta_3)$	–0.048*	–0.049*	–0.048*	–0.050*
	(0.029)	(0.029)	(0.029)	(0.028)
Climate background control	Yes	Yes	Yes	Yes
Market background control	Yes	Yes	Yes	Yes
Economic background control	Yes	Yes	Yes	Yes
Time Fes	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes
Observations	441	441	441	441
R-squared	0.842	0.842	0.846	0.859
Number of provinces	63	63	63	63

Notes: standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A7

Robustness check – trimming by average FDI

Dependent variable	Revenue from import and export activity on logarithm					
	sample trimmed at 95th percentile of averaged FDI		sample trimmed at 5th percentile of averaged FDI		sample trimmed at 5th and 95th percentiles of averaged FDI	
	(1)	(2)	(3)	(4)	(5)	(6)
$Temperature\ Shock\ (LRP - \theta)$	–3.407***	–3.455***	–3.588***	–3.704***	–3.609***	–3.714***
	(0.538)	(0.542)	(0.518)	(0.528)	(0.534)	(0.545)
$X_{t-1} - Xt\ (\delta_1)$	5.581***	5.560***	5.811***	5.889***	5.848***	5.914***
	(0.959)	(0.964)	(0.894)	(0.902)	(0.923)	(0.932)
$X_{t-2} - Xt\ (\delta_2)$	–4.210***	–4.186***	–4.443***	–4.498***	–4.477***	–4.522***
	(0.807)	(0.810)	(0.755)	(0.760)	(0.780)	(0.786)
$X_{t-3} - Xt\ (\delta_3)$	1.160***	1.153***	1.243***	1.257***	1.254***	1.266***
	(0.253)	(0.253)	(0.237)	(0.238)	(0.245)	(0.246)
Climate background control	Yes	Yes	Yes	Yes	Yes	Yes
Market background control	Yes	Yes	Yes	Yes	Yes	Yes
Economic background control	Yes	Yes	Yes	Yes	Yes	Yes
Time Fes	Yes	Yes	Yes	Yes	Yes	Yes
Province Fes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	420	420	413	413	392	392
R-squared	0.198	0.220	0.218	0.241	0.219	0.243
Number of provinces	60	60	59	59	56	56

Notes: this robustness check addresses potential selection bias arising from the concentration of FDI and industrial zones in hotter provinces. The sample is trimmed by excluding provinces in the top 5%, bottom 5%, or both tails of the FDI distribution (measured at the 5th and 95th percentiles). Across all trimmed samples, the estimated long-run propensity ($LRP = \theta$) of temperature shocks remains negative, economically sizable, and statistically significant, indicating that the main results are not driven by provinces with extreme levels of FDI concentration. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

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