Short economic and financial analyses

The effect of extreme weather events on unprocessed food inflation in Slovenia

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June 2024

BANKA SLOVENIJE

EVROSISTEM

Collection: Short economic and financial analyses

Title: The effect of extreme weather events on unprocessed food inflation in Slovenia

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Issue: June 2024

Place of publication: Ljubljana

Issued by:
Banka Slovenije
Slovenska 35, 1505 Ljubljana, Slovenija
www.bsi.si

Electronic edition:
https://www.bsi.si/en/publications/research/short-economic-and-financial-analyses

Kataložni zapis o publikaciji (CIP) pripravili v Narodni in univerzitetni knjižnici v Ljubljani
COBISS.SI-ID **198007811**
ISBN 978-961-96526-8-8 (PDF

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1 Introduction

Extreme weather events are becoming more intense and frequent due to climate change and nature degradation, both consequences of human activity.

The relevance of this study is based on the fact that extreme weather shocks are becoming more intense and frequent as the consequences of climate change continue to unfold. The impact of extreme weather events on the economy is becoming more pronounced as human activity continues to contribute to nature degradation, resulting in nature's diminished ability to curb their adverse effects.[1]

Climate risks can have an impact on the economy through direct or indirect channels.

The 2021 strategy review of the ECB compelled policymakers to recognise the growing impact of climate change and climate policy on the economy, and to therefore consider these effects in their projection analyses. Climate risks are twofold, physical and transition. The latter concern indirect risks stemming from changes in climate policy, behavioural changes of economic agents and green technology innovations, while the former pertain to environmental events affecting the economy directly.

The increasing frequency and magnitude of extreme weather events are increasingly affecting agricultural production and food prices, which indicates the importance of their inclusion in inflation projections.

With the increasing frequency and magnitude of extreme weather events related to climate change, their relevance in impacting inflation especially via food prices, which are prone to increase due primarily to negatively affected agricultural output, is becoming pronounced. In Slovenia, we saw indications of higher food inflation on account of drought in the summer of 2022.[2] This revealed a gap in modelling apparatus that would allow a more informative quantitative evaluation of such events on projected inflation.

[1] See Boldrini et al. (2023).

[2] To account for the effects of drought in the summer of 2022 on food inflation projections in December 2022 BMPE exercise, explicit judgment was made to revise it upward by one percentage point (the revision came also on account of the intensity of the pass-through effect of higher wholesale food commodity prices and energy prices into production costs).

To investigate the relationship between extreme weather events and unprocessed food inflation in Slovenia, a non-linear STAR methodological framework was employed.

This study aims to quantify these effects by introducing a smooth-transition auto-regression (STAR) model which is employed due to its ability to discern a weather event extremity and afterwards map it to potential effects on the prices of unprocessed food in Slovenia, thus better comprehending the impact of climate-related events for the purpose of informing inflation projections.

Existing empirical evidence points to upward effects on inflation, with significance stemming from the rise in intensity and frequency of extreme weather events in recent periods and asymmetry based on underlying country temperature.

Within a smooth transition vector autoregression framework, Kim et al. (2022) show that in recent years of the available sample, where the intensity and frequency of extreme weather events increases, extreme weather shocks impact the US macroeconomy via reduced industrial production and consumption growth, while on the other hand, unemployment and inflation rates increase. For the case of Croatia, Škrinjarić (2023) demonstrates a similar finding using a vector autoregression framework, with drought emphasised as the main driver of inflation pressures stemming from climate events. Furthermore, the existing literature points to non-linear and asymmetric effects of extreme weather events on inflation dynamics. Exemplifying the case for non-linearity, Kotz et al. (2023) find that above-average temperatures lead to non-linear upward inflationary pressures with persistence over 12 months for the case of both higher and lower income countries, while Ciccarelli et al. (2023) show relatively stronger effects for warmer euro area countries, evidencing asymmetry.

The contribution of this study is the analysis on the effects of extreme weather events within the framework of the Slovenian macroeconomy, using a novel aggregate extreme weather events indicator the European Extreme Events Climate (E3CI) Index.

2 Extreme weather events in Slovenia

Extreme weather events in Slovenia are observed through the lens of the E3CI index.

To gauge extreme weather events, the European Extreme Events Climate (E3CI) Index, developed by International Foundation Big Data and Artificial Intelligence for Human Development (IFAB), was employed. Following the comparable index developed for North America, the Actuaries Climate Index, the E3CI index includes monthly information about the frequency and magnitude of weather-induced hazards from 1981 across all European countries. It is a composite of seven climate events: extreme maximum and minimum temperature, drought, extreme precipitation, extreme wind, forest fire, and hail.

The E3CI index indicates increased frequency and magnitude of extreme weather events through time, especially after 2011.

Table 1 shows the descriptive statistics of the E3CI index, covering three samples: the full set from 1981 until 2023, the reduced sample from 2000 until 2023, and last, the set from 2011 until 2023. It indicates that through time, both the average value of the index and its volatility have increased. When adjusting for the number of data points, it is evident further that the frequency of extreme weather events has increased through time, altering the structure of the index. For instance, only 3.7% of all weather events from 1981 until 2023 were recorded as extreme, whereas in the period from 2011 to 2023, the figure stands at 7.1%.

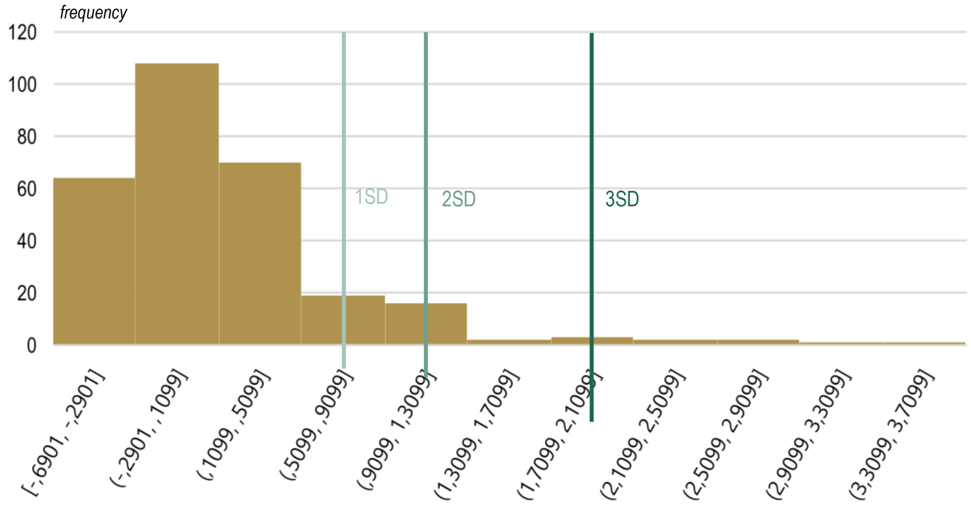
Table 1: **Descriptive statistics of the E3CI index**

	1981	**2000**	**2011**
mean	0.03	0.13	0.27
1SD	0.52	0.62	0.74
2SD	1.03	1.23	1.48
3SD	1.55	1.85	2.23
number of occurrences ≥ 2SD	19	13	11
number of occurrences ≥ 3SD	11	8	6
number of occurrences ≥ 2SD / n	3.7%	4.5%	7.1%
number of occurrences ≥ 3SD / n	2.1%	2.8%	3.9%

Source: IFAB, author's calculations. Latest data: December 2023.

Chart 1 presents the distribution of the E3CI index. Since 2000, 13 cases (4.5% of total events) have been detected where the value exceeded two standard deviations of the distribution, while 8 cases (2.8% of total events) exceeded three standard deviations of the distribution.

Chart 1: **Distribution of the E3CI index**

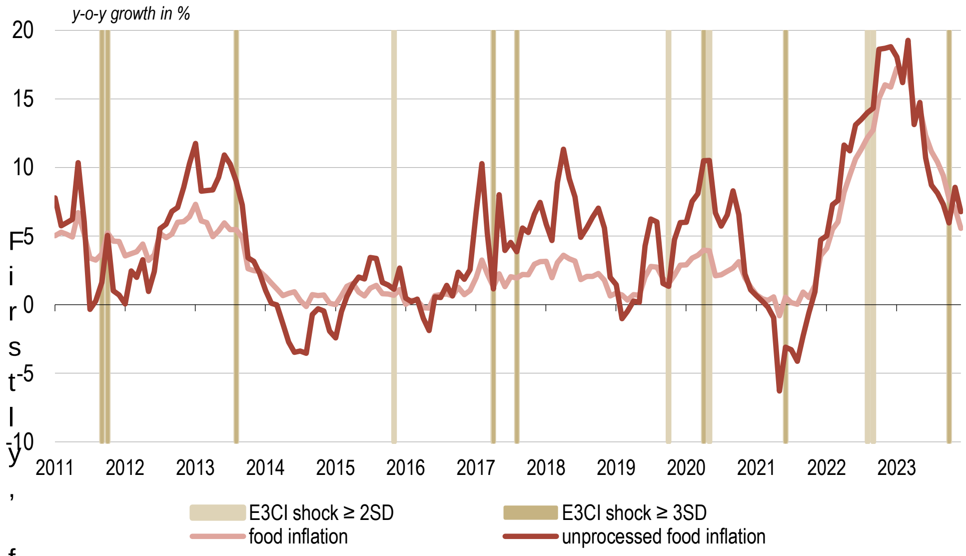


Source: IFAB, author's calculations. Data: January 2000 to December 2023.

Following an extreme weather event, the growth of unprocessed food prices often increases with a lag of one to three months. Extreme weather event realisations in Slovenia and their aftermath largely confirm this dynamic.

Chart 2 shows that extreme weather events are often followed by an increase in unprocessed food inflation with a lag of one to three months. To gain more insight behind large E3CI values, considered as E3CI shocks, this section explores their root cause(s) and inspects their aftermath. It begins after 2011, where the magnitude and frequency of extreme weather events intensified.

Chart 2: **Food inflation and E3CI shocks**



Sources: SORS, IFAB, author's calculations. Data: January 2000 to December 2023.

Firstly, following a shock in the E3CI index in **September 2011**, a 3.4 percentage point increase of unprocessed food inflation[3] followed a month after. For the case of the shock in **August 2013**, no such relationship exited, arguably due to other domi-

[3] As measured by the HICP in year-over-year terms.

nant downward inflationary pressures.[4] Looking further, following an observation of the E3CI index for **April 2017** with the value of 2.0 index points, unprocessed food inflation increased from 1.1% in April to 8.0% the following month and to 4.0% the month after, resulting therefore in an upward change to unprocessed food inflation of 6.9 and 2.9 percentage points respectively. As per the structure of the E3CI shock, four components constituted its extremity: forest fire, extreme wind, extreme maximum temperature and extreme precipitation.[5]

Next, the E3CI observation for **August 2017** measured 2.3 index points. Then, unprocessed food inflation stood at 3.9% and increased by 1.4 percentage points in October, 2.7 percentage points by November and 3.6 percentage points by December. The extreme weather event came mainly on account of hail and extreme maximum temperature.[6] Further, the E3CI value for **October 2019** measured 1.6 index points on account of extreme maximum temperature.[7] From October to December, unprocessed food inflation increased by 4.7 percentage points, from 1.3% to 6.0%.

Extreme weather event shocks also occurred in **April and May 2020**; however, no subsequent rise in unprocessed food inflation ensued, presumably on account of the ongoing deflationary pressures stemming from the COVID-19 pandemic, which was unfolding during this time. Similarly, an E3CI shock that occurred in **June 2021**, which concurred with the COVID-19 pandemic, resulted only in a mild increase of unprocessed food inflation after three months.

On the other hand, extreme weather events in 2022 coincided with a widespread rise in inflation in Slovenia and Europe; while this materialised for several reasons,[8] one of which is presumed to be an increase in the frequency and magnitude of extreme weather-related physical risks,[9] and therefore it is discussed in this section. The E3CI value for **August 2022** measured 1.6 index values on the back of forest fire, drought and extreme maximum temperature. Unprocessed food inflation in August gauged 14.0% and increased to 18.6% by October. Several sources, e.g. the European Commission and the Slovenian Chamber of Commerce, reported the decreased amount of crops that followed the widespread drought across Europe. In addition, the forest fire on the Karst plateau, which lasted from July 15 to July 31 and affected areas in both Slovenia and Italy, contributed to the weather extremity in both July and August 2022. Finally, an E3CI shock in **October 2023** originated from extreme maximum temperature, which marked 2023 as the hottest year in the last 125,000 years, as reported by Copernicus, and resulted in a 2.6 percentage point increase in unprocessed food inflation a month after.

[4] From 2013 to 2019, the euro area was undergoing low inflation environment due to a number of cyclical and structural forces (see Koester et al., 2021).

[5] The Slovenian meteorological agency ARSO issued a report of extreme precipitation in Slovenia from 25 to 28 April, with the highest recording across Slovenia in the Julian Alps of precipitation between 300 and 500 millimetres.

[6] The Slovenian meteorological agency ARSO reported extreme heat stress and storms between 31 July and 6 August, with temperatures of above 40°C and above 30°C in some higher-altitude regions. The newspaper *Dnevnik* reported on 3 August on hail the size of hazelnuts.

[7] The broadcasting agency RTV SLO reported that October 2019 was the hottest October in the last 38 years. This record was superseded by October 2023, with 2023 being the hottest year in the last 125,000 years, as reported by Copernicus.

[8] The reasons for increased inflation rates across Europe in 2022 on the supply side include energy, food and other commodity cost price shocks and related supply bottlenecks stemming amid others from the war in Ukraine and on the demand side, heightened rates of economic recovery following the COVID-19 pandemic, both passing through as second-round effects to core inflation components, additional factors of which in 2022 and 2023 were labour market tightness and wage growth.

[9] As found for example in the study by Kotz et al. (2023) and warned against in ECB (2021).

3 Empirical estimation and results

The empirical estimation of the impact of extreme weather events on unprocessed food inflation is based on monthly data from January 2000 to December 2023.

The data runs on a monthly basis from January 2000 to December 2023. Unprocessed food inflation is measured by the HICP in year-over-year terms and is obtained from the Statistical Office of the Republic of Slovenia. The E3CI index is provided by International Foundation Big Data and Artificial Intelligence for Human Development.[10] Additionally, the model controls for the external factors via international wholesale food commodity prices, obtained from the ECB.[11]

The analysis is conducted within a non-linear methodological framework which is able to distinguish the impact on unprocessed food inflation between extreme and non-extreme weather event states.

To empirically evaluate the impact of extreme weather events on unprocessed food inflation, a non-linear methodological framework of smooth transition autoregression (STAR) was used. The use of a non-linear framework is motivated by the evidence on state-dependency pass-through, highlighted in the literature review above and by the non-normal distribution of the E3CI index, as shown by the histogram in Chart 1. Subject to the movement of the E3CI index, the STAR model therefore transitions to the state of extreme weather event in accordance with a logistic function, which considers the E3CI index as a transition variable. In that way, the model is able to distinguish between extreme and non-extreme weather event states.

The effect of an increase in the E3CI index on unprocessed food inflation is positive and asymmetrically larger in the state when the weather event is considered extreme.

Table 2 presents the estimated coefficients in the estimated STAR model; the state-dependent coefficients relate to the constant and the two-period lag of the E3CI index, while the autoregressive coefficient and the impact of farm gate prices are assumed state-independent. The results show that in the state of non-extreme weather conditions, an increase in the E3CI index by 1 index point leads to a reduction in unprocessed food by 0.53 percentage points two periods after. In this particular state, the impact therefore remains puzzling and could be related to asymmetric effects of weather shocks. In contrast, an increase in the E3CI index consistent with the extreme weather conditions leads to a positive and quantitatively much larger effect of 6.12 percentage points on unprocessed food inflation. Considering the state-independent coefficients, the unprocessed inflation dynamics exhibit fairly strong per-

[10] Source for the E3CI index.
[11] Source for international wholesale food commodity prices.

sistence and a statistically significant, albeit small, positive relation to one-period lagged growth of international wholesale food prices.

Table 2: **Estimated coefficients in a STAR model**

Dependent variable	State-dependent variables				State-independent variables		Threshold
	Linear part		*Nonlinear part*				
Unprocessed food inflation_t	constant	E3CI_{t-2}	constant	E3CI_{t-2}	Unp. food inflation_{t-1}	Farm gate_{t-1}	E3CI_t
	0.32*	-0.53*	-2.10	6.12*	0.89***	0.04***	1.81***

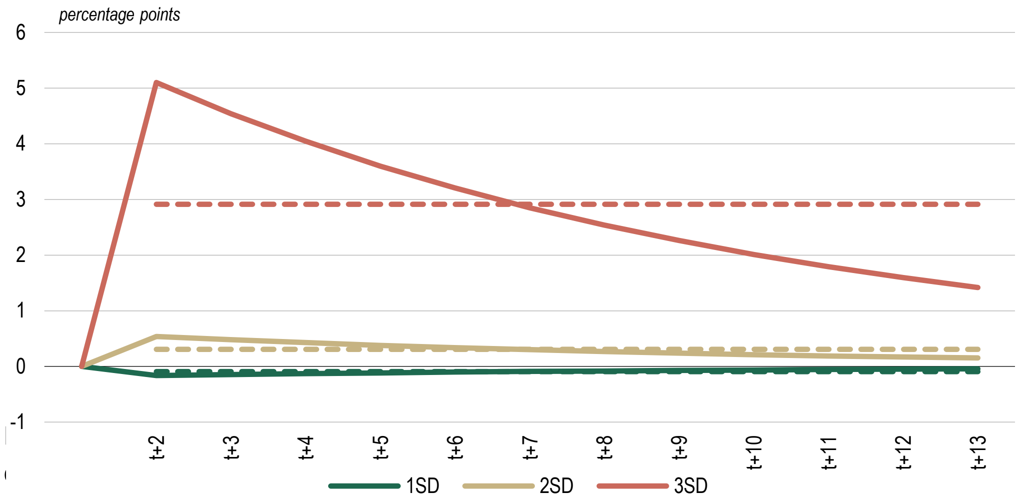
Sources: IFAB, SORS, ECB, author's calculations.
Notes: Coefficients are depicted in percentage points. * p < 0.10; ** p < 0.05; *** p < 0.01.

Importantly, the model-estimated threshold stands at 1.81 and is statistically significant at 1%, indicating that values of the E3CI index from just below its three standard deviations and beyond are considered extreme weather events. In the sample from 2000, 2.8% of observations fall under this characterisation.

The dynamic response shows that following a three standard deviation E3CI shock, unprocessed food inflation increases by an average of 2.9 percentage points over one year, corresponding to 0.6 and 0.1 percentage points in food and headline inflation respectively.

Taking into account the non-linear nature of a weather-related impact on unprocessed food inflation, a dynamic response is analysed via three different impulse response functions subject to an E3CI shock of one standard deviation, two standard deviations and three standard deviations. Chart 3 illustrates that a positive and quantitatively larger effect of an E3CI shock on unprocessed food inflation (in year-over-year terms) is expected only in cases where the shock is considered extreme, which applies only to the shock to the E3CI index of three standard deviations, while otherwise, the effect is close to zero or negative.

Chart 3: **Impulse responses of unprocessed food inflation to E3CI shocks of three different magnitudes**



Sources: IFAB, SORS, ECB, author's calculations.
Notes: Full lines show the impulse response function, while dashed lines indicate the average response over 12 months.

For the case of extreme weather shock in the size of three standard deviations, the peak response of unprocessed food inflation amounts to just over 5 percentage points,[12] while over the course of a 12-month period, the impact averages at 2.9 percentage points. This in turn corresponds to on average impact on food and headline inflation in the amount of 0.6 and 0.1 percentage points, respectively, over the course of one year after the shock.[13]

4 Conclusion and policy discussion

Extreme weather events have in the past two decades become importantly intensified, in terms both of the frequency of their occurrence and their magnitude. This note attempts to address the analytical gap of evaluating the impact of extreme weather events from an economic perspective by empirically examining the dynamic response of unprocessed food prices, which are deemed most susceptible to physical climate risks. The analysis for Slovenia confirms past research, showing that the effect of weather effects tends to be non-linear and dependent on the magnitude of the shock.

The difference between the impacts from the shock to the E3CI index of three standard deviations to two standard deviations is just under ten-fold, highlighting the importance of the definition of weather event extremity. Only when weather shocks are so extreme that the ability of producers to absorb heightened costs due to negatively affected supply, for instance, because they materialise in debilitating combinations (such as extreme maximum temperature, drought and forest fire in August 2022), does upward pressure on consumer prices become tangible.

Further work would encompass disentangling extreme weather events arising from different climate areas and juxtaposing them against regional characteristics, such as the underlying average temperature. Furthermore, the analysis assumed the transmission channel worked through reduced agricultural production, but effects can also be found on the demand side, for instance through the increased consumption of fruit against the background of increasingly higher temperatures.

Finally, this research demonstrates the concrete effects of upward pressure on inflation stemming from climate risk, which is imperative for economic projections and policymakers with a mandate to provide price, economic and financial stability.

[12] This effect is comparable to one standard deviation of unprocessed food inflation, which stands at 5.3 percentage points.

[13] This effect is roughly in line with the findings from Kotz et al. (2023), who find that the 2022 summer heat increased food inflation in Europe by 0.67 (0.43–0.93) percentage points.

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