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Feeling the heat: extreme temperatures and price stability

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Abstract

We contribute to the debate surrounding central banks and climate change by investigating how extreme temperatures affect medium-term inflation, the primary objective of monetary policy. Using panel local projections for 48 advanced and emerging market economies (EMEs), we study the impact of country-specific temperature shocks on a range of prices: consumer prices, including the food and non-food components, producer prices and the GDP deflator. Hot summers increase food price inflation in the near term, especially in EMEs. But over the medium term, the impact across the various price indices tends to be either insignificant or negative. Such effect is largely non-linear, being more significant for larger shocks and at higher absolute temperatures. We also provide simulations from a two-country model to understand the rationale behind the results. Overall, our results suggest that temperature plays a non-negligible role in driving medium-term price developments. Climate change matters for price stability.

Keywords: inflation, climate change, extreme temperatures, panel local projections.

JEL Classification Code: E03, E31, Q51, Q54.

Non-Technical Summary

Climate change is the challenge of our generation, and there are increasing signs of its impact. According to the EU Copernicus Climate Change Service, 2020 was the hottest year on record in Europe, and the past six years comprise the hottest six on record worldwide. 2021 has witnessed record temperatures in North America, Southern Europe and Central Asia. There has been increasing research in recent years into the impact of these rising temperatures on economic activity. But to date little is known about the impact on inflation – and therefore on central banks' primary mandate. This paper aims to address that deficit, and focuses on the effects of temperature extremes on medium-term inflation.

For a panel of 48 advanced and emerging economies, we investigate how extreme temperatures affect various measures of prices: consumer prices (including the food and non-food components), producer prices and the GDP deflator. We use data on the seasonal divergence of temperatures from their country-level average in the middle of the 20th Century (1951-1980).

We also introduce a simple two-country New Keynesian model enriched with a role of temperature in influencing productivity for agricultural goods, in order to rationalise the effect of temperature shocks (both global and country-specific) on price developments.

We identify four key results:

1. Timing matters: extreme temperatures have differing impacts depending on when they occur within the year. By far the largest and longest-lasting impact derives from hot summers.

2. It is important to consider a wide range of prices and not just headline CPI. In particular, the short-run impact from hot summers mostly arises from the impact on food prices. This impact occurs in both advanced and emerging economies, but is stronger in the latter group.

3. The horizon also matters: we find evidence of negative inflation dynamics in the medium term, again particularly noticeable in emerging economies. This suggests that short-term supply disruption in agriculture can result in more longer-lasting downward pressure on demand.

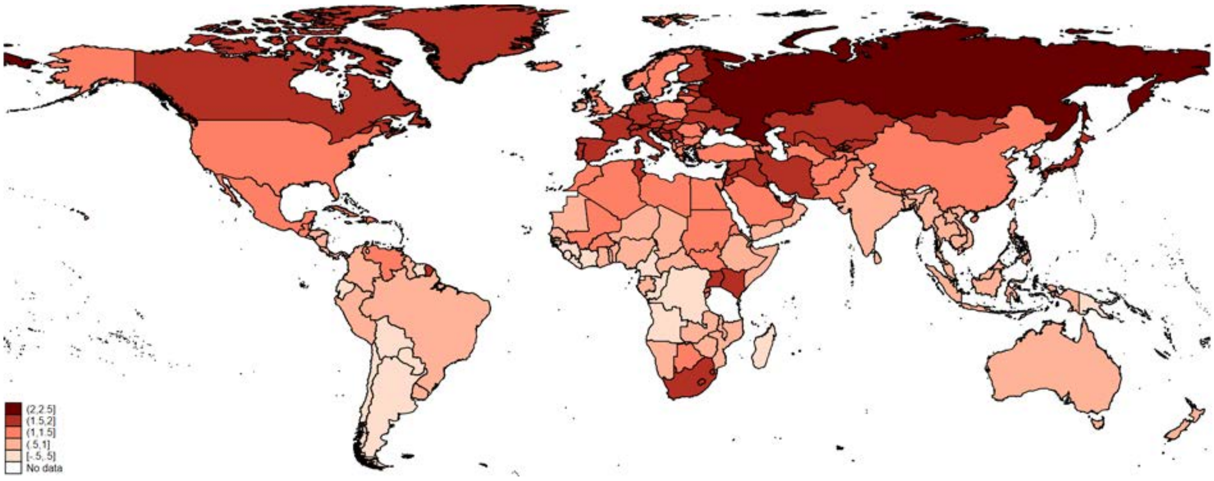
4. Finally, we show that the impact is non-linear, both in terms of divergence from average temperatures, and in terms of absolute temperature. This suggests that even for those countries where the impact has been limited to date, the future may be less benign.

Overall, we find that higher temperatures over recent decades have played an increasingly non-negligible role in driving price developments, including into the medium term. Climate change, in other words, is already starting to bear on the primary mandate of central banks. This provides some empirical justification for central banks to contribute to global efforts to combat climate change.

1 Introduction

Climate change represents one of the greatest societal and economic challenges of this century and action to combat it is becoming more urgent by the day. Human-induced climate change is already affecting observed weather and climate extremes across the globe (IPCC, 2021). According to the EU Copernicus Climate Change Service, 2020 was the warmest year on record in Europe, 0.4°C hotter than the previous record year, which was 2019. Temperature records have also tumbled worldwide in 2021, including in North America, Southern Europe, Arctic Russia and Central Asia. As figure 1 shows, across the globe temperatures have increased substantially over the past century, with the rise in temperatures being particularly pronounced in the Northern hemisphere and in mid-latitudes. That rise in average temperatures has been accompanied by greater variance, resulting in an increased occurrence of temperature extremes (see figure B.1 in the appendix). [1]

Figure 1: A century of temperature increases



Notes: This figure shows the difference in average temperatures between the first two decades of the 20th Century and the first two decades of the 21st Century, expressed in degrees Celsius. Source: World Bank Climate Knowledge Portal and authors' calculations.

Central banks are paying increasingly closer attention to the impacts of climate change: the Bank of England now has climate considerations explicitly incorporated into its mandate, the European Central Bank has a climate action plan following the recent conclusion of its review of monetary policy strategy, and the Network for Greening the Financial System has grown from

[1] Source: Copernicus Climate Change Centre

8 founding central banks and supervisors in December 2017 to more than a hundred members and observers today.

Yet despite the growing evidence of climatic impact and growing attention from policymakers, the implications of climate change for monetary policy – and on its primary objective of controlling inflation – have received little attention. Broadly speaking, there are three main channels through which climate change can affect inflation.[2] First, global warming is associated with a greater incidence of damaging climatic events, notably windstorms, extremes of precipitation and of temperature. Even if global warming is successfully restricted to 1.5°C, these events are still likely to become more commonplace (IPCC, 2021). Such events may impact specific prices, notably food prices.

Second, the transition to a net zero carbon emission world is likely to involve sharp increases in the price of carbon. That in turn is likely to affect consumer prices directly through higher electricity, gas and petrol prices, and indirectly through increased costs of production for firms across a broad range of sectors. Finally, higher temperatures themselves may dampen economic activity and reduce labour productivity through higher rates of mortality, morbidity and lower efficiency.

In this paper we focus on the first of these channels – specifically the impact of temperature extremes on inflation – in order to address the substantial gap in the literature surrounding these impacts. Concretely, we run panel local projections for 48 advanced and emerging economies, regressing various quarterly price indices (CPI, its food, and non-food components, PPI, and the GDP deflator) on measures of country-specific temperature anomalies. We also introduce a simple two-country New Keynesian model enriched with a role for temperature in influencing productivity for agricultural goods, in order to rationalise the effect of temperature shocks (both common and idiosyncratic) on price developments.

We make a number of important contributions that advance our collective understanding of the impact of extreme temperatures.

First, timing within the year matters. We do not find a significant impact of extreme temperatures in autumn. Cold winters similarly do not have an impact. While we do find some

[2] Lagarde (2021) discusses these channels in detail, noting that climate change and transition policies "have macroeconomic and financial implications and have consequences for our primary objective of price stability."

significant impact from mild winters and springs, by far the largest – and most durable – impact arises from hot summers.

Second, it is important to consider a wide range of prices and not just headline CPI. We demonstrate that the higher prices arising in the short term from hot summers is mostly due to the impact on food prices, something that has not been directly studied before. This impact occurs in both advanced countries and emerging market economies (EMEs), although is stronger in the latter group of countries, where it also has a much larger impact on headline CPI through the greater weight of food in the consumption basket.

Third, the medium-term impact can be the opposite of the short-term impact, a finding of particular importance to central banks with inflation targets centred on the medium term. We find evidence of negative inflation dynamics in the medium term, with the results mainly driven by developments in EMEs. In terms of economic mechanisms, the contemporaneous increase in food price inflation could be explained by hot summers reducing food production, resulting in supply shortages. In the medium term, demand effects may occur in less developed countries, leading to falling prices and depressed economic activity. This is not surprising, given that in these countries both the contribution of the agricultural sector to GDP and share of food in the overall consumption basket are higher than in advanced economies. They are also likely to be less integrated in the global food market – and thus more dependent on domestic agricultural production – and less equipped with instruments aimed at mitigating the effect of temperature shocks on food production, such as irrigation networks.

Fourth, we consider the role of adaptation and non-linearities. We find significant impacts for hot summers, even when allowing for some adaptation to the gradual shift in mean temperatures. Moreover, we find that the impact on prices is non-linear, increasing with higher absolute temperatures and with the size of the temperature shock. This too points towards some limits of adaptation, and as mean temperatures increase worldwide, countries that to date have had little visible impact from hot summers may witness greater effects in future.

The paper is organised as follows. Section 2 summarises the related literature. Section 3 sketches a conceptual model to understand the impact of climate change on inflation. Section 4 describes the data. Section 5 presents the empirical model. Section 6 discusses the results. Section 7 concludes.

2 Related literature

Over the past decade, there has been a growing literature on the impact of disasters triggered by natural hazards – floods, droughts, windstorms and so forth – on economic activity (see e.g. Noy, 2009; Strobl, 2011; Fomby et al., 2013; Felbermayr and Gröschl, 2014). The consensus is that such events generally reduce economic activity in the near term, particularly in developing economies and for more severe events. There is less consensus surrounding the longer-term impact of such events, although several authors have found evidence of impacts that can last decades (see e.g. Coffman and Noy, 2012; Hornbeck, 2012; Hsiang and Jina, 2014). The impact of these events is generally assumed to be a supply shock – pushing down activity and pushing up prices. But a number of studies have questioned that assumption (e.g. Batten, 2018; Ciccarelli and Marotta, 2021). Asymmetric economic disruption can impact on demand in other sectors, putting downward pressure on activity and prices, via a process recently described as a 'Keynesian supply shock' (Guerrieri et al., 2020).

The impact of such disasters on inflation, by contrast, has been much less studied. Heinen et al. (2019) investigate the inflation impact of hurricanes on 15 Caribbean islands, calculating the potential impact of wind and flood damage. Split by sub-component, they find a significant contemporaneous impact on food inflation and on inflation excluding food, housing and utilities. Severe hurricanes also affect housing and utilities inflation.

Parker (2018b) considers the impact of disasters caused by natural hazards on inflation. He uses consumer price inflation data for 212 economies, including sub-components for food, energy, housing and a core inflation measure that excludes these three components. The overall impact for advanced economies is reasonably limited, but for developing economies it can be substantial and persist for a number of years. While food price inflation typically increases, the impact can be negative on other components for certain types of disasters resulting in an at times ambiguous impact on overall headline inflation.

Moreover, the existing literature on the economic impact of natural hazards has focused principally on earthquakes, windstorms, floods and droughts. The impact of extreme temperatures on economic activity has received very little attention until recently.

Dell et al. (2012) study the impact of annual fluctuations in temperature and precipitation over the period 1950-2003. They find higher temperatures depress economic growth rates in developing economies, and impact agricultural output, industrial production and political stability.

Acevedo et al. (2020) use annual data for 180 economies over the period 1950-2015. They find a non-linear impact on output, with a marginally positive impact on growth for economies where the average temperature is low, but increasingly negative impact on economies that have relatively high average temperatures. As regards the channels of impact, their analysis suggests that higher temperatures significantly lower labor productivity in heat-exposed sectors. On the other hand, temperature increase have no significant effect on labour productivity in non-heat-exposed industries, including in hot climate countries. They extrapolate their results using climate models and estimate that output would be lower by 9 percent for the typical low-income country by 2100.

Colacito et al. (2019) study the impact of temperatures on output in the United States, using quarterly data over the period 1957-2012. They find a significant impact on both GDP and for a range of economic sectors. But the impact does vary by quarter. A 1°F increase in summer temperatures reduces output by between 0.15 and 0.25 percentage points, but warmer temperatures in autumn are mildly positive for GDP. The differential findings by quarter may explain why previous results found little impact for higher income economies. In terms of channels of impact, they find that hot summers reduce the growth rate of labour productivity, including in non-agricultural sectors. The estimated impact of gradual warming in the United States for a range of variables is also summarised in Hsiang et al. (2017).

Bandt et al. (2021) study the impact of climate change on 126 low and middle income countries over the period 1960-2017, finding that a sustained 1 °C increase in temperature lowers annual growth in real GDP per capita by 0.74 to 1.52 percentage points.

Several studies focus on the impact of temperature changes on a limited number of highly exposed sectors, such as agriculture. Roberts and Schlenker (2013) study the impact on crop yields, finding that aggregate yields are humped-shaped, with higher temperatures initially increasing yields, before having increasingly negative effects. De Winne and Peersman (2018) find that adverse weather impacts on agricultural production can propagate worldwide through their effect on food commodity prices, implying potentially larger future economic disruptions for advanced economies arising from climate change, even if the share of agriculture in GDP is typically low in those countries. De Winne and Peersman (2021) find that swings in global food prices brought about by extreme weather events appear to be important for economic activity for many countries, including advanced economies.

Studies disagree on the extent to which adaptation, such as through planting different crops or air conditioning, can mitigate the economic impact of climate change. Mendelsohn et al. (1994) suggest there may be beneficial revenue effects from moving from wheat to grapes and citrus. However, they also note that even with this adaptation, divergence from mean temperatures can affect crop yields, and that hot summers are more damaging than hot winters.

As with other natural hazards, the impact of extreme temperatures on prices has received scant attention to date. Kim et al. (2021) include consumer prices in a smooth transition VAR at monthly frequency that studies the impact of extreme weather on a range of macroeconomic variables for the United States. They use the Actuaries Climate Index as their measure of extreme weather, which includes sub-indices for changes in the frequency of temperature extremes. Extreme weather is found to have a statistically significant impact on inflation, albeit small in magnitude. Mukherjee and Ouattara (2021) similarly study the impact of extreme temperatures in a VAR of macroeconomic variables at annual frequency, finding an impact on headline inflation.

When considering the implications for the conduct of monetary policy, it is also important to take into account how widespread and how durable is the impact on inflation. Shocks to one sector may affect relative prices. As a matter of theory, relative price adjustment could be thought as being independent from economy-wide inflation and monetary policy can therefore 'look through' the impact.

However, because relative price adjustment can first show up as inflation and the process can be protracted, a medium-term effect on inflation is certainly possible. Indeed, Reis and Watson (2010), relying on US data for the period 1959-2006, compute that only 15-20 percent of the variation in inflation is 'pure inflation' – namely an equi-proportional rise in all prices. The remaining, and dominant part of inflation variability entails some relative price adjustment. This consideration underpins the choice of focusing on different price indices in our empirical model.

Clearly, the medium-term impact of relative price adjustments, the associated temporary rise in actual inflation, and their influence on inflation expectations, depend on a number of factors, first and foremost the credibility of the monetary policy regime. A spike in oil prices, for example, only has a temporary effect on overall inflation if inflation expectations are well anchored, as illustrated for example in Choi et al. (2018). This can be seen in the discrepancy between the large response of inflation in most industrial countries to the oil price increases in the 1970s and the muted response in later periods, during the Great Moderation. Gelos and Ustyugova (2017) similarly find transmission of commodity price shocks into inflation depends on the credibility of monetary policy.

Even under a low-inflation regime, however, relative prices can be important for overall inflation. Peersman (forthcoming), for example, finds that exogenous shifts in international food commodity prices explain almost a third of medium-term inflation variability in the euro area.

3 A conceptual model

To illustrate the possible channels at play and derive some baseline simulations, we introduce a simple two country model with nominal rigidities.

There are two goods, food and the rest, both of which are tradable. Prices are assumed to be flexible in food production, and sticky à la Calvo in the other goods. Monetary policy follows a Taylor rule in both economies. The nominal exchange rate floats, with export and import prices set in the currency of the producer (producer currency pricing, PCP).

The two countries are assumed to be one advanced and one emerging economy: they are distinguished by (i) a larger weight for food and (ii) a lower responsiveness to inflation in the Taylor rule in the emerging economy. Finally, there is imperfect risk sharing, with only one-period nominal bonds traded between countries. Temperature influences the production of food: high temperatures represent a negative productivity shock. Temperature is subject to both country-specific and general shocks.

The main message from this model analysis is that the temperature shock in the home country leads to a rise of the price of domestically produced food, but the price of other items actually falls slightly. Overall inflation rises sharply on impact reflecting (flexible) food prices, but the effect dies down quickly or is even slightly reversed over the medium term.

We now describe the elements of the model – many of which are standard – in more detail.

3.1 Utility

The households in both countries derive utility from consumption and disutility from labour,

$$U = ln(c_t) - \frac{\chi}{2} {n_t}^2 \tag{1}$$

where c is a consumption basket and n is hours worked, and the parameter χ measures the disutility of labour.

3.2 Consumption baskets

Domestic households consume a composite consumption good defined through the CES aggregator of home and foreign goods,

$$c_{it} = ((1-\gamma)^{\frac{1}{\eta}} c_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} c_{Ft}^{\frac{\eta-1}{\eta}})^{\frac{\eta}{\eta-1}} \tag{2}$$

where η is the elasticity of substitution between domestically and foreign produced output, γ is the home bias parameter and P_H and P_F are respectively the prices of home and foreign output, so that $S = \frac{P_H}{P_F}$ is the terms of trade. A very similar definition holds for foreign households. Each of c_{Ht} and c_{Ft} are themselves aggregation of two types of goods, *food* and *non-food*.[3] For example, for domestically produced goods:

$$c_{Ht} = ((1-\alpha)^{\frac{1}{\omega}} c_{FoodHt}^{\frac{\omega-1}{\omega}} + \alpha^{\frac{1}{\omega}} c_{NonFoodHt}^{\frac{\omega}{\omega-1}})^{\frac{\omega}{\omega-1}} \tag{3}$$

where ω is the elasticity of substitution between food ($Food$) and non-food ($NonFood$) goods, and α is the consumption share of food. We calibrate the share of food to be higher in the foreign economy. Price aggregates are defined accordingly. Note that we assume that non-food goods are imperfectly substitutable, whereas food is close to perfectly substitutable internationally (see below on the calibration of the model).

[3]Note that we use the labels 'food' and 'non-food' as a catch-all term for weather-sensitive and weather-insensitive sectors. Also note that we do not consider weather-sensitive items as upstream intermediate inputs in the production of weather-insensitive goods (say, processed food), which would be an interesting extension of the model.

3.3 Budget constraint

The budget constraint for the home households reads:

$$P_t c_t + b_{t-1} R_{t-1} = W_t n_t + b_t + \Pi_t \tag{4}$$

where P_t is the price level obtained as a composite index in the standard way, W is the nominal wage, and b is a one-period bond, with R the gross interest rate; Π are the profits of the intermediate goods producers, which are rebated to households. We assume prices and bonds are invoiced in the currency of the producer; letting S_t be the nominal exchange rate defined in terms of foreign currency units per domestic currency (so that an increase denotes appreciation), then goods produced in the home economy cost $P_{Ht} S_t$ for the foreign household, and bonds equally cost $b_t S_t$.[4] As a matter of convention, we assume that only the home economy can issue bonds, so that they are always denominated in domestic currency. The PPP condition is assumed to hold for the food sector, reflecting the fact that food commodities are largely internationally traded.

3.4 The production side

Each intermediate good producing firm maximises profits subject to a simple linear production technology, $y_j = A_j n$, where j is the good type, A is productivity. Productivity for non-food is $A_{NF} = e^{\epsilon_{it}}$, where ϵ is a general productivity shock. Productivity for food, instead, is a function of the weather and in particular of temperature, which is subject to shocks (see below):

$$A_F = (e^{u_{it}})^{-1} \tag{5}$$

where u_{it} is a temperature shock. In other words, higher temperature leads to a fall in agricultural productivity, as found in several studies, (see e.g., recently in Colacito et al. (2019) and Acevedo et al. (2020)). The marginal cost is defined as, for example for domestic food production, as $MC_{FHt} = W_t e^{u_{it}}$.

Intermediate good producers are characterised by monopolistic competition and set prices at a mark-up over marginal costs, ideally with a constant mark-up $\mu > 0$. However, in non-food

[4]Exactly the opposite holds, of course, for the home economy as foreign-produced goods need to be divided by the nominal exchange rate.

production prices are sticky à la Calvo so that, in each period, only a share θ of prices can be adjusted. It is standard to show that this results in a price adjustment equation specified as follows,

$$\pi_t^j = \beta E_t \pi_{t+1}^j + \frac{(1-\theta)(1-\theta\beta)}{\theta}(\mu MC_t^j - P_t^j) \tag{6}$$

where π_t^j, MC_t^j and P_t^j are respectively inflation, marginal cost and price level defined on the good type j. In other words, inflation is higher, the smaller the current price level compared with a theoretical level given by the optimal mark-up over the marginal cost.

3.5 Climate

We assume that temperature is subject to both common and country-specific shocks; note that the latter are more important in our empirical section later on in the paper:

$$u_t = u_{Ht} + u_{Gt} \tag{7}$$

where u_{Ht} only hits the domestic economy, while u_{Gt} is a common shock leading to a rise in temperature in both countries. Note that both shocks are assumed to be persistent in the calibration.

3.6 Monetary policy

In both economies, monetary policy is assumed to be run according to a Taylor rule with partial adjustment. For example for the home economy,

$$R_t = \rho R_{t-1} + (1-\rho)(\frac{1}{\beta} + \phi \pi_t^{Nonfood}) \tag{8}$$

where $\phi > 1$ and $\pi_t^{Nonfood} = \frac{P_t^{Nonfood}}{P_{t-1}^{Nonfood}} - 1$ (note that we normalise the inflation target to zero in both economies). In line with the thinking in New Keynesian models, we assume that the central bank only reacts to the sticky price section of the price index, i.e. the non-food part. In the foreign economy, we assume that ρ is larger, so that the central bank is less responsive to inflation, in line with the idea that the emerging market economy has lower anti-inflationary credibility and inflation is more volatile ex post.[5]

[5] Rudebusch (2006), for example, discusses different types of monetary policy inertia that are consistent with partial adjustment. Here we interpret partial adjustment as pure (as opposed to optimal) inertia.

3.7 Calibration

In the baseline calibration, food and non-food goods are substitutes ($\omega = 3$) and the share of consumption on food is 0.1 in the advanced economy and 0.25 in the emerging economy. The international rate of substitution, η, is set at 3 for non-food and at 10 for food (proxying for full substitutability) and the consumption shares of domestically produced goods are 0.75 in both countries. In terms of price setting, the mark-up is assumed to be 1.125 in both countries and the Calvo parameter θ is set at 0.75, so that approximately one quarter of prices are set each quarter (or that prices are changed approximately once a year). The discount rate is 0.995 and the ϕ parameters in the Taylor rule are set at the conventional value of 1.5, with however the interest rate smoothing parameter at 0 for the advanced economy and at 0.75 for the emerging economy.

3.8 Model simulations

Figure 2 reports the impact of a home (blue dashed lines) and common (red solid line) temperature shock on prices in both economies. The rise in home temperature, which is the theoretical counterpart to our empirical exercise, results in a relatively sharp increase in home food price inflation, almost matched by the same rise in the foreign economy, while the price of non-food items actually falls slightly, both home and abroad. These results, and in particular the profile of the inflation response to the temperature shocks, is a consequence of the fact that food prices are flexible while non-food prices are sticky. The domestic currency depreciates, which also leads to a worsening of the terms of trade. Aggregate inflation goes up sharply on impact, given the rise in food prices which are assumed to be flexible, but the effect dies down quickly or is even slightly reversed in the following periods. Note the difference from a common temperature shock, for which the effect on food prices is qualitatively similar. In this case, non-food prices increase, albeit slightly, and there is (as expected) little movement in the exchange rate and terms of trade.

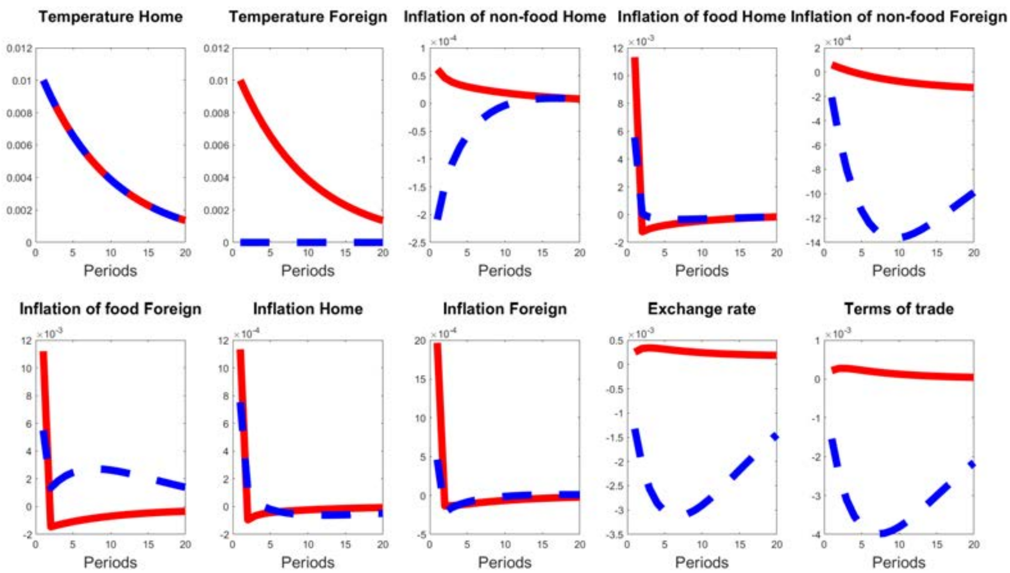
We also consider the idea of *complementarity* between food and non-food items, following the intuition championed by Guerrieri et al. (2020).[6] The model conclusions from this alternative

[6]The recent literature on 'Keynesian supply shocks' is also related to the idea that, when markets are incomplete, at low levels of substitution between good types, wealth effects can drive *up* the aggregate demand for good types even in the presence of negative endowment shocks; see Corsetti et al. (2008).

calibration with $\omega = 0.5$ (complementarity between food and non-food goods – not shown for brevity), however, are essentially the same. Our model, which features no collateral constraints, is therefore not able to create 'Keynesian supply shocks' whereby a negative productivity shock results in an overall lower price level, similar to a classical demand shock.

It is also interesting to look, in Figure 3, at a comparison between home and foreign local temperature shocks. As expected, the impulse responses are largely the mirror images of the other, notably on the exchange rate and the terms of trade. Due to the larger weight of food items in the consumption basket of the foreign (emerging) economy, however, the initial spike in overall inflation is much larger in the foreign economy, and also the impact on non-food prices is generally larger for the foreign shock, since the negative productivity shock in the food sector has a larger income effect.

Figure 2: The effects of common and home climate shocks

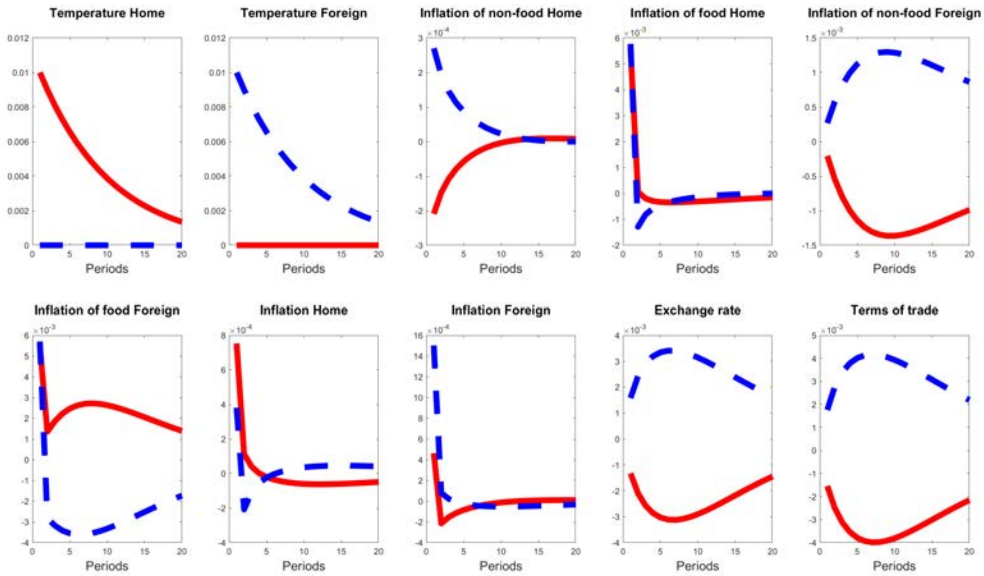


Notes: The red continuous lines show the effect of common climate shocks. The blue dashed lines refer to the effect of home climate shocks. See section 3.7 for the calibration of the model.

4 Data

To study the impact of climate change on price stability, we construct a dataset including information on producer and consumer prices and temperature anomalies for 48 countries. Our

Figure 3: The effects of home and foreign climate shocks



Notes: The red continuous lines show the effect of home climate shocks. The blue dashed lines refer to the effect of foreign climate shocks. See section 3.7 for the calibration of the model.

sample includes 33 countries that are classified by the IMF as advanced and 15 classified as emerging and developing economies. It covers the period 1990 to 2018. The detailed list of countries and country groupings is available in section A of the appendix. Our dataset has quarterly frequency, given the insights of Colacito et al. (2019) that it is difficult to assess the impact of temperature anomalies using annual data. For example, extreme summer and winter temperatures could average out throughout the year. Moreover, hot summers and mild winters may have opposite effects on economic activity. The latter could also hold for prices.

4.1 Price indicators

Our dataset contains information on a range of price indices. For consumer prices, we use the dataset developed in Parker (2018a). This dataset covers 223 economies on a quarterly basis over the period 1980-2012. It contains series for headline (or all items) CPI, consumer prices for food, and consumer prices for non-food. Coverage is not complete for all economies and years. We extend the data to 2018 for the 48 countries in our sample using a range of international and national sources, as set out in section A of the appendix. As data coverage is particularly poor for some price sub-indexes before 1990, we only report results for the period 1990 to 2018 in the rest of the paper. In addition, to ensure consistency between measures of headline CPI and of its components, we report results for headline CPI only when information on the sub-indices is available.

We also include two other national price measures beyond CPI: producer prices (PPI) and the GDP deflator. These price indices permit a broader view of the impact of extreme temperatures on economic activity by capturing transactions between businesses. Data for both are taken from the International Financial Statistics (IFS) database published by the IMF. We also include PPI data from national sources for five countries where it is not available for the whole period since 2000 in the IFS, as noted in section A in the appendix. Overall, compared to other databases on global inflation as such the one developed by Ha et al. (2021), our dataset has a broader coverage of inflation indicators at quarterly frequency for the group of countries in our sample. In addition, our dataset includes information on CPI excluding food, which is not available in the dataset developed by Ha et al. (2021).

4.2 Climate data

We retrieve climate data from three sources.

First, we obtain information on country-specific temperature anomalies at quarterly frequency from the FAOSTAT Agri-Environmental Indicators dataset. The latter compiles information from GISTEMP, the Global Surface Temperature Change data of the National Aeronautics and Space Administration Goddard Institute for Space Studies (NASA-GISS).[7] Temperature anomalies indicate by how much temperatures deviate in a particular period from the historical average climate, with the latter corresponding to the average of the 1951-1980 period. Weather anomalies are calculated at station level and are subsequently aggregated up to the country level, after correcting for a range of biases such as the station bias and heat-island effects in urban areas.

As shown by Hansen and Lebedeff (1987), temperature anomalies are more suited to measure climate change compared to absolute temperatures. The reason is that absolute temperatures are

[7] For more information on the GISTEMP dataset we refer to the data available on the GIS website (GIS, 2021) as well as to Hansen and Lebedeff (1987) and Lenssen et al. (2019).

very difficult to measure: they vary considerably in short distances depending on the location of the weather station and thus are subject to a considerable degree of uncertainty. By correcting for station effects before aggregating the data to the country level, temperature anomalies provide a more reliable measure of weather changes in larger regions.

FAOSTAT provides data on seasonal temperature anomalies following the meteorological year (which starts in December) rather than the calendar year. Therefore, in order to match data on temperature anomalies with macroeconomic variables, we assume that the meteorological winter (summer) in the Northern (Southern) Hemisphere – which includes the months from December to February – corresponds to the first quarter of the year and so forth.

As shown in table 1, there has been a notable increase in temperatures for the 48 countries in our sample compared with the period 1951–1980. For example, the median average summer temperature increased by about 0.7°C between the 1990s and the 2010s; a 1°C summer anomaly would have been just above the 75th percentile in the 1990s, but, by the 2010s, the *median* anomaly was about 1.3°C. Moreover, there has been a marked increase in the skew of the distribution of summer temperature anomalies, with the 90th percentile increasing by around 0.8°C over the same period.

The second data source from which we obtain data on climate variables is the World Bank Climate Change Knowledge Portal. From this dataset, we retrieve information on absolute temperatures at country level. These data are used in the empirical analysis to assess whether temperature anomalies can have a different impact if temperatures exceed certain thresholds. They are also used to construct alternative measures of temperature anomalies for robustness checks.

Finally, we also retrieve climate data from the ifo Geological and Meteorological Events Database (GAME), which is the data underlying Felbermayr and Gröschl (2014). The GAME dataset identifies periods of precipitation extremes and hence helps clarify to what extent the impact on inflation is related to high temperatures as opposed to droughts.

4.3 Additional indicators

We complement our dataset with a number of additional indicators. First, we include information on seasonally adjusted real GDP in local currency at quarterly frequency from the OECD

Table 1: Distribution of country-specific temperature anomalies

Period	p10	p25	Median	p75	p90
Summer					
1990s	-0.11	0.22	0.57	1.04	1.65
2000s	0.24	0.54	0.92	1.42	1.96
2010s	0.43	0.83	1.26	1.80	2.44
Autumn					
1990s	-0.69	-0.15	0.31	0.76	1.17
1990s	-0.11	0.33	0.71	1.08	1.71
2010s	0.16	0.63	1.02	1.46	2.01
Winter					
1990s	-0.70	0.07	0.74	1.49	2.61
2000s	-0.55	0.13	0.80	1.65	2.69
2010s	-0.57	0.21	0.90	1.69	2.99
Spring					
1990s	-0.25	0.20	0.66	1.21	1.72
2000s	0.16	0.54	1.00	1.68	2.31
2010s	0.24	0.69	1.37	2.03	2.57

Notes: This table shows the distribution of temperature anomalies across seasons and decades. Temperature anomalies show how much temperatures deviate from the historical average climate of a particular place, with the latter corresponding to the average of the 1951-1980 period. In the Northern Hemisphere, the period December-January-February corresponds to winter; March-April-May to spring; June-July-August to summer; and September-October-November to autumn. In the Southern Hemisphere, the period December-January-February corresponds to summer; March-April-May to autumn; June-July-August to winter; and September-October-November to spring.

Quarterly National Accounts, Eurostat, and the IFS. Second, we augment our dataset with information at annual frequency from the World Bank World Development Indicators (WDI) dataset on real GDP per capita in USD and contribution of the agricultural sector to the GDP.

5 Empirical model

We use panel local projections à la Jordà (2005) to assess both the contemporaneous and medium-term effect of temperature shocks on inflation. Compared to other estimation methods such as vector autoregressive (VAR) models, panel local projections represent a flexible alternative, particularly suited to assessing how the impact of temperature shocks varies according to other parameters by the inclusion of interaction terms.

Building on the large stream of literature studying the impact of weather shocks on economic activity (see e.g., Fomby et al. (2013), Felbermayr and Gröschl (2014), and Colacito et al. (2019), among others), we treat within-country temperature fluctuations as exogenous after controlling for country and time fixed effects; subsequently, we regress them on a range of price indicators. We obtain the impulse responses of inflation to weather shocks by estimating the following set of panel regressions:

$$ln(P_{c,t+h}) - ln(P_{c,t-1}) = \beta_1^h Temp_{c,t} + \sum_{n=1}^{8} \gamma_n^h \Delta ln(P_{c,t-n}) + \alpha_c^h + \theta_t^h + \epsilon_{c,t}^h \quad (9)$$

where c is the country index and t stands for the time index with quarterly frequency. Regressions are estimated separately for each horizon h, with the latter taking values between 0 and 8 (included) to capture the contemporaneous effect as well as the impact over the subsequent two years.

The dependent variable is the cumulative growth of the outcome of interest (i.e. prices) between horizons $t + h$ and $t - 1$, defined as the difference in the natural logarithms of $P_{c,t}$. Specifically, $P_{c,t}$ is a vector including three consumer price indicators (headline, food, non-food), the producer price index, and the GDP deflator. Indeed, studying the impact of climate events across a range of countries requires a closer study of the individual sub-components of consumer prices. As found by Parker (2018b), the impact differs greatly between sub-components, which can result in an insignificant impact on headline CPI.

Furthermore, the relative weights of the sub-indices differ substantially between countries. For example, the average weight of food in the overall consumption basket is 15.4 percent for the advanced economies in our sample, but 25.5 percent for the emerging and developing economies. Across time and across countries, higher income per capita is in general associated with a lower share of food in total expenditure. This means that the impact on food price inflation has much less influence on headline inflation in advanced economies. For this reason, both in our model and in the empirical analysis we look separately at developments in food and non-food consumer prices.

All price indices are I(1), with the exception of the GDP deflator. However this should not be problematic given that we use lag-augmented local projections. Indeed, Montiel Olea and Plagborg-Møller (2021) have found that lag-augmented local projections are asymptotically valid uniformly over both stationary and non-stationary data, as well as over different response horizons.

The main variable of interest, for which we report the impulse response functions (IRFs) in the next section, is $Temp_{c,t}$, a dummy variable indicating *significant* temperature anomalies at country level. In the empirical analysis, we use different definitions of significant temperature anomalies, depending on the model specification. Full details are available in table 2. For example, when looking at the effect of hot summers in the baseline specification, the variable $Temp_{c,t}$ is set to be equal to 1 when the temperature recorded in the quarter exceeds the country's long-run mean temperature calculated over the period 1951–1980 by at least 1.5°C; it is set to 0 otherwise, as there are no particularly cold summers in our dataset. In other words, unlike e.g. Felbermayr and Gröschl (2014) and Colacito et al. (2019), we assume that small temperature fluctuations compared to historical regularities are not macro-critical.

Based on the definitions of temperature anomalies in table 2, we find that about 25% of all quarters have a significant temperature anomaly. The share of quarters with significant temperature anomalies varies between the two country groups. There are significant temperature anomalies in 29.3% of the quarters in advanced economies, while the percentage drops to 14.9% in EMEs. The same split broadly holds for significant summer temperature anomalies (28% vs. 15%). This is not surprising, as temperatures are rising faster in the latitudes where most of advanced economies are located. Chile is the only country in the sample with no significant temperature anomaly.

For the rest, the model is parsimonious. It includes lagged values of the dependent variable up to the 8th lag (corresponding to the length of the forecasting horizon, following Plagborg-Møller and Wolf (forthcoming) and Montiel Olea and Plagborg-Møller (2021)), and country (α_c^h) and time fixed effects (θ_t^h). The aim of the fixed effects is to control for important country-invariant factors, such as latitude, and time-specific phenomena, such as sharp swings in commodity prices unrelated to climate. To address the serial correlation in the error term due to the inclusion of lagged values of the dependent variable, we use Driscoll and Kraay (1998) standard errors. The latter are robust to heteroskedasticity, autocorrelation and cross-sectional dependence.

6 Empirical evidence

We split the presentation of the results between the short and medium-term impact. Such distinction is useful when considering the optimal response by central banks. Given the lag

Table 2: Significant temperature anomalies: definitions

Name	Definition
	Temperature shocks across all seasons
Extreme temperatures	The variable $Temp$ takes a value of 1 when the temperature exceeds the country's historical average climate by at least 1.5°C or is more than -1.5°C below the historical average climate, corresponding to the period 1951–1980; zero otherwise.
	Seasonal temperature shocks
Hot summers, autumns, springs and winters	For each season, the variable $Temp$ takes a value of 1 when the temperature exceeds the country's historical average climate by at least 1.5°C over the season. $Temp$ is set to missing when the temperature is more than -1.5°C below the country's historical average climate over the season; zero otherwise.
Cold winters	For winter quarters, the variable $Temp$ assumes value 1 when the temperature is more than -1.5°C below the country's historical average climate over the season. $Temp$ is set to missing when the temperature exceeds the country's historical average climate by at least 1.5°C; zero otherwise.

Notes: There are insufficient events to meaningfully analyse cold summers, cold autumns and cold springs. Specifically, there are no cold springs and cold autumns. As there are only two cold summer events and in these instances temperature anomalies are not below -1.6°C, we set the variable hot summer to zero for all summer quarters with a temperature anomaly below 1.5°C, including those below -1.5°C.

involved in policy transmission, policymakers generally react only to changes in medium-term inflationary pressure, since reacting to short-lived changes in prices risks exacerbating volatility.

6.1 Short-term effects

6.1.1 Effects of large temperature anomalies on prices across different seasons

We begin by considering whether the impact of large temperature anomalies on prices differs across seasons and between episodes of large positive and negative anomalies. Results for horizon 0 (contemporaneous) and horizon 1 (i.e. the subsequent quarter) are presented in table 3.

Panel A of table 3 reports the effect on prices of both particularly hot and cold events thought the whole year, with the variable 'Temperature Anomaly' assuming value 1 both for anomalies below -1.5°C and above 1.5°C compared to a country long-run mean. None of the

Table 3: Short-term effect of weather shocks on inflation across different seasons

	Horizon 0					Horizon 1				
	(1) CPI	(2) Food	(3) Non-Food	(4) PPI	(5) GDP defl.	(6) CPI	(7) Food	(8) Non-Food	(9) PPI	(10) GDP defl.
Panel A: Whole year, all types of temperature anomalies										
All seasons	-0.02	-0.02	-0.00	-0.02	0.08	0.01	0.09	-0.01	-0.12	0.06
	(0.05)	(0.08)	(0.05)	(0.14)	(0.08)	(0.08)	(0.16)	(0.08)	(0.28)	(0.14)
Observations	4311	4733	4311	4698	4420	4265	4687	4265	4652	4374
R^2	0.57	0.37	0.60	0.34	0.49	0.56	0.39	0.58	0.37	0.51
Panel B: Effect by season and type of episode										
Cold winters	0.20	0.58	0.14	0.70	-0.65	0.18	0.14	0.08	0.55	-0.43
	(0.15)	(0.42)	(0.15)	(0.53)	(0.60)	(0.22)	(0.65)	(0.19)	(0.73)	(0.63)
Observations	774	857	774	838	780	774	857	774	838	780
R^2	0.75	0.53	0.77	0.70	0.65	0.68	0.45	0.71	0.68	0.65
Hot winters	-0.06	-0.29***	0.01	-0.03	0.11	0.07	-0.07	0.09	-0.13	-0.06
	(0.09)	(0.11)	(0.09)	(0.23)	(0.17)	(0.21)	(0.19)	(0.20)	(0.31)	(0.20)
Observations	1032	1142	1032	1131	1055	1032	1142	1032	1131	1055
R^2	0.74	0.51	0.73	0.64	0.62	0.61	0.42	0.62	0.63	0.61
Hot springs	-0.10**	0.03	-0.11***	-0.02	0.08	-0.10	0.21	-0.16**	-0.19	0.02
	(0.04)	(0.09)	(0.04)	(0.14)	(0.12)	(0.07)	(0.18)	(0.07)	(0.22)	(0.17)
Observations	1086	1188	1086	1180	1114	1080	1182	1080	1174	1109
R^2	0.58	0.37	0.66	0.49	0.63	0.57	0.42	0.63	0.44	0.72
Hot summers	0.04	0.38***	-0.05	-0.08	-0.00	0.13	0.47***	0.03	-0.35	-0.05
	(0.05)	(0.13)	(0.06)	(0.18)	(0.16)	(0.08)	(0.16)	(0.08)	(0.26)	(0.18)
Observations	1083	1186	1083	1176	1111	1083	1186	1083	1176	1110
R^2	0.63	0.51	0.65	0.47	0.72	0.66	0.49	0.68	0.44	0.72
Hot autumns	-0.02	-0.11	-0.00	-0.10	0.06	-0.10	-0.02	-0.15	-0.04	0.26
	(0.09)	(0.15)	(0.09)	(0.24)	(0.13)	(0.13)	(0.21)	(0.12)	(0.39)	(0.30)
Observations	1077	1172	1077	1163	1102	1037	1132	1037	1123	1062
R^2	0.69	0.51	0.70	0.56	0.68	0.73	0.57	0.74	0.64	0.59

Driscoll and Kraay (1998) standard errors in parenthesis – *** p <0.01, ** p <0.05, * p <0.1

Notes: This table shows the short-term effect of temperature shocks on a set of inflation components. For 'all seasons', the dependent variable takes a value of 1 when the temperature exceeds the country's historical average climate by at least 1.5°C or is more than -1.5°C below the historical average climate, corresponding to the period 1951–1980; zero otherwise. In the seasonal regressions for large positive (hot) temperature anomalies, the dependent variable takes a value of 1 when the temperature exceeds the country's historical average climate by at least 1.5°C and value 0 when the temperature anomaly is between -1.5°C and 1.5°C; missing otherwise. In the seasonal regressions for large negative (cold) temperature anomalies, the dependent variable takes a value of 1 when the temperature is more than -1.5°C below the country's historical average climate and a value of 0 when the temperature is between -1.5°C and 1.5°C; missing otherwise. Only cold winter anomalies are shown due to the limited number of cold events in the other seasons.

estimated coefficients is statistically significant. However, results change when we break down annual temperature anomalies into seasons and we distinguish between hot and cold temperature shocks (displayed in Panel B of table 3).

Starting with negative temperature anomalies, there are insufficient events to consider the impact in spring, summer, or autumn under the baseline definition. The degree of warming already present in our country sample over recent decades means that these events are too rare for meaningful analysis. We do not find any significant impact on any price index at any horizon for cold winters.

Moving to positive temperature anomalies, we do find significant impacts. Mild winters result in a significant contemporaneous fall in food prices of -0.29 percentage points but the effect disappears by the subsequent quarter. Mild springs result in a small fall in non-food prices in the contemporaneous and in the subsequent quarter, which is also reflected in headline CPI. Mild autumns do not appear to have any significant impact on any price index considered here.

By contrast, we find a statistically significant – and economically meaningful – impact on prices arising from hot summer events. Food prices increase by 0.38 percentage points contemporaneously, which is greater than a one standard deviation quarterly change in the series. The positive impact on food prices increases further in the subsequent quarter. In terms of economic mechanisms, the contemporaneous increase in food price inflation could be explained by a negative effect of hot summers on food production, resulting in supply shortage effects.

In short, extreme temperatures – hot or cold – in most seasons have to date had little or no impact on prices. The notable exception is hot summer events, where there is a significant, meaningful and longer-lasting impact. For this reason, we focus on the effect of hot summer temperature anomalies on prices in the remainder of this paper.

We begin by demonstrating that the short-term results are robust to a range of alternative specifications, which are shown in table 4. For example, using four lags of the lagged inflation rate, quarterly rather than annual fixed effects or including the lagged price level in the estimation all deliver an estimated impact on food prices that are qualitatively and quantitatively alike (columns (1) – (3)).

Results for the models presented in columns (1) – (3) of table 4 are estimated with country fixed effects. Hence, an implicit assumption is that both the impact of temperature and lagged inflation dynamics is homogeneous across countries. In column (4), we relax this assumption and we show the results using the mean group estimator of Pesaran and Smith (1995). This estimator allows the coefficients on the anomalies to vary across countries – for example permitting the response of prices to an extreme temperature event in Canada to differ from the response in Chile – by estimating separately for each country. The estimated coefficients are then averaged across countries. Here again the impact is similar, albeit somewhat more pronounced at horizon 1.

Finally, we control for the potential simultaneous occurrence of droughts alongside summer extreme temperatures, drawing from the GAME dataset. Droughts are defined as a quarter in which the average rainfall is at least 50% below average for at least two months within the quarter. The data show that hot summers tend to be drier on average than less warm summers (see figure B.2 in the appendix). However, droughts are very rare events, with only 7% of hot summers coinciding with droughts, compared with 1% for other summers. Incorporating a dummy for drought leads to qualitatively similar results for the coefficient on extreme summer temperatures, and the drought dummy itself is insignificant (column (5)). Note that the GAME database ends in 2010, so does not have a complete coverage for our sample.

6.1.2 Effects of hot summer temperature anomalies on prices by level of development

Parker (2018b) finds differing inflation impact of disasters by level of development. Results displayed in Panel A of table 5 show that this also occurs following significant summer temperature anomalies. While we do not find any significant effect in advanced economies, food price inflation significantly increases in EMEs following a particularly hot summer. The increase in food price inflation in emerging economies translates into an increase in the overall CPI inflation, likely reflecting the higher share of food in the consumption basket of this country group. These empirical results accord with the predictions from the theoretical model presented above.

While results in Panel A allow for a diverging impact of temperature anomalies on prices in advanced and emerging market economies, they implicitly assume an homogeneous impact of

Table 4: Short-term effect of summer weather shocks on food prices – Robustness checks

	(1) 4 lags	(2) Qrt FE	(3) Level	(4) MGE	(5) Droughts
At horizon 0:					
Temperature anomaly	0.39***	0.37***	0.36***	0.36**	0.49***
	(0.13)	(0.13)	(0.14)	(0.16)	(0.19)
Droughts					0.32
					(0.61)
Observations	1232	1186	1186	1186	813
R^2	0.49	0.54	0.51	NA	0.54
At horizon 1:					
Temperature anomaly	0.47***	0.43**	0.43**	0.58**	0.66***
	(0.16)	(0.17)	(0.16)	(0.26)	(0.22)
Droughts					0.97
					(0.70)
Observations	1186	1186	1186	1186	813
R^2	0.49	0.53	0.52	NA	0.52
Country FE	Yes	Yes	Yes	NA	Yes
Year FE	Yes	No	Yes	NA	Yes
Quarter FE	No	Yes	No	NA	No
Lags 1st diff	4	8	8	8	8
Lag level	No	No	Yes	No	No
Model	Std LP	Std LP	Std LP	MGE	Std LP

Standard errors in parenthesis – *** p <0.01, ** p <0.05, * p <0.1

Notes: This figure shows the short term effect of hot summer temperature anomalies on food prices across different model specifications. Results reported in columns (1) – (3) and (5) are based on a standard local projection model (Std LP) à la Jordà (2005), with Driscoll and Kraay (1998) standard errors that are robust to heteroskedasticity and to serial and spatial correlation. Compared to the baseline model in equation 9, column (1) includes four lags of the lagged inflation rate (instead of 8), column (2) considers quarterly rather than annual fixed effects, column (3) controls also for the lagged price level and column (5) adds droughts as an additional control. Results reported in column (4) are based on the mean group estimator (MGE) of Pesaran and Smith (1995), estimated for both horizon 0 and horizon 1.

lagged inflation dynamics across the whole sample. To check whether this affects the results, in Panel B and Panel C we split the sample between the 34 advanced and 14 emerging economies following the IMF classification. Here, we find that both country groups exhibit a positive impact on food price growth at horizon zero. For advanced economies, the impact on CPI food price inflation is no longer significant by horizon 1. The impact on food price inflation in EMEs is markedly larger – 1.51 percentage points at horizon 0, and increasing to 2.55 percentage points at horizon 1. There is also a positive impact on headline consumer prices in EMEs in line with results displayed in Panel A. For both country groups, there is no significant impact on non-food CPI, PPI nor the GDP deflator in the near term.

A potential explanation for the stronger and longer lasting effect of hot domestic weather

Table 5: Short-term effect of summer weather shocks on inflation and its components by country group

	(1) CPI	(2) Food	(3) Non-Food	(4) PPI	(5) GDP deflator
Panel A: Full sample					
At horizon 0:					
Temperature anomaly	-0.03	0.20	-0.05	0.08	-0.01
	(0.06)	(0.13)	(0.06)	(0.16)	(0.13)
Temperature anomaly × EME	0.45**	1.28***	0.03	-0.96	0.04
	(0.18)	(0.34)	(0.19)	(0.86)	(0.31)
Observations	1083	1186	1083	1176	1111
R^2	0.63	0.51	0.65	0.47	0.72
At horizon 1:					
Temperature anomaly	0.04	0.18	0.03	0.09	-0.06
	(0.09)	(0.15)	(0.08)	(0.22)	(0.17)
Temperature anomaly × EME	0.58*	2.03***	-0.02	-2.70	0.09
	(0.30)	(0.54)	(0.33)	(1.77)	(0.80)
Observations	1083	1186	1083	1176	1110
R^2	0.66	0.50	0.68	0.45	0.72
Panel B: Advanced economies					
At horizon 0:					
Temperature anomaly	-0.03	0.18*	-0.04	-0.02	-0.11
	(0.06)	(0.10)	(0.06)	(0.14)	(0.12)
Observations	751	832	751	816	769
R^2	0.55	0.45	0.56	0.45	0.80
At horizon 1:					
Temperature anomaly	0.05	0.15	0.05	-0.19	-0.16
	(0.10)	(0.16)	(0.09)	(0.23)	(0.14)
Observations	751	832	751	816	769
R^2	0.55	0.44	0.57	0.33	0.59
Panel C: Emerging market economies					
At horizon 0:					
Temperature anomaly	0.41**	1.51***	-0.04	-0.78	0.41
	(0.20)	(0.42)	(0.18)	(0.78)	(0.41)
Observations	332	354	332	360	342
R^2	0.63	0.58	0.65	0.54	0.67
At horizon 1:					
Temperature anomaly	0.64**	2.55***	0.05	-2.27	0.60
	(0.28)	(0.61)	(0.30)	(1.50)	(0.74)
Observations	332	354	332	360	341
R^2	0.66	0.52	0.70	0.56	0.76
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Driscoll and Kraay (1998) standard errors in parenthesis – *** p <0.01, ** p <0.05, * p <0.1

Notes: This table shows the short-term effect of temperature shocks on inflation components. In Panel A, we augment the estimation of equation 9 by including a dummy indicating whether a country is an emerging market economy and its interaction with the 'Temperature anomaly' dummy. Panel B and Panel C are based on the regression model in equation 9, run separately for advanced and emerging economies.

shocks on price dynamics in EMEs is that these countries are likely to be less integrated in the global food market and thus more dependent on domestic agricultural production. In addition, in this country group the agricultural sector may be less equipped with instruments aimed at mitigating the effect of temperature shocks on food production, such as irrigation networks.[8]

In this respect, columns (1) and (2) of table 6 allow for a diverging impact of summer weather shocks on food price inflation by the importance of the agricultural sector for the domestic economy. The thresholds for determining the importance of the agricultural sector for the domestic economy are calculated separately for each country group given that the agriculture GDP share varies considerably between the two. For any given year, a country is classified as having a low agriculture GDP share if the latter is below the 33th percentile of the distribution within its country group; it is considered as having a middle agriculture GDP share if the latter is between the 33th percentile and the 66th percentile of the distribution within its country group; it is considered as having a high agriculture GDP share if the latter is above the 66th percentile of the distribution within its country group. Results reported in table 6 refer to the impact at horizon zero ('contemporaneous impact').

The main findings are as follows. While the share of the agricultural sector for the domestic economy does not play a role in advanced economies, temperature shocks have a stronger contemporaneous impact in emerging countries with a more rural economy. This suggests that food prices in EMEs that are more dependent on domestic agricultural production are more affected by domestic weather shocks. This holds if we assume that the importance of the agricultural sector for the domestic economy is a good proxy for the importance of domestic agricultural production in the food consumption basket.

We also investigate whether the impact of summer temperature anomalies on food price inflation varies according to the absolute temperature level recorded in the summer in which they happen. Indeed, it could be that a particularly hot summer compared to the country historical average climate in, for example, the United Kingdom might be a favorable shock for agricultural production, but could have the opposite impact in a country with a hotter

[8] In this respect, De Winne and Peersman (2018) find the opposite for global agricultural price and weather shocks; that is, the decline in economic activity is less in low-income countries and countries with large agricultural sectors, which is probably the consequences of the fact that these countries are more isolated from shocks in global markets. Parker (2018a) also finds a much greater impact of global developments on food prices for advanced economies. Dependent on the measure used, global food price inflation explains 38-54% of food price inflation variance in advanced economies, falling to 18-24% in middle income and 10-13% in low income countries.

Table 6: Short-term effect of summer weather shocks on food inflation – Potential drivers

	(1) Advanced	(2) EME	(3) Advanced	(4) EME
Temperature anomaly	0.17	1.19*	0.19	0.65
	(0.17)	(0.67)	(0.15)	(0.53)
Middle agriculture GDP share	-0.02	-0.97*		
	(0.17)	(0.54)		
High agriculture GDP share	0.53**	-2.01***		
	(0.24)	(0.60)		
Middle agriculture GDP share × Temperature anomaly	0.24	-0.68		
	(0.22)	(0.86)		
High agriculture GDP share × Temperature anomaly	-0.42	6.06***		
	(0.28)	(1.65)		
Mild climate			0.14	-0.45
			(0.18)	(0.50)
Hot climate			-0.16	0.19
			(0.43)	(0.64)
Temperature anomaly × Mild climate			-0.15	1.23*
			(0.25)	(0.68)
Temperature anomaly × Hot climate			0.11	2.46***
			(0.20)	(0.71)
Observations	797	353	832	354
R^2	0.48	0.61	0.46	0.58
Country FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Driscoll and Kraay (1998) standard errors in parenthesis – *** p <0.01, ** p <0.05, * p <0.1

Notes: This table shows the short term effect of temperature shocks on food inflation. In columns (1) and (2) we augment the estimation of equation 9 by including dummies on the importance of the agricultural sector for the domestic economy and as well as their interaction with the 'Temperature anomaly' dummy. In columns (3) and (4) we replicate the same exercise for different absolute temperature levels.

climate. Schlenker and Roberts (2009) find that crop yields increase with temperature up to approximately 30°C, while temperatures above this thresholds are harmful.

In this respect, columns (2) and (3) of table 6 allow for a diverging impact of summer weather shocks at different temperature levels. We classify a country as having a cold, mild or hot climate in any given year using the same method employed for the importance of the agricultural sector. We find that temperature shocks at higher absolute temperature levels lead to a significant increase in food price inflation in emerging market economies. While we do not see any significant impact for advanced economies, the impact becomes larger as absolute temperatures increase.[9]

Overall, our findings contain a cautionary message for the future. They suggest that as temperatures increase worldwide, the impact of hot summers on food prices could well be larger in the future than it has been in the past.

[9] We also run an alternative regression model whereby the classification as 'cold climate', 'mild climate' or 'hot climate' is time-invariant and the results obtained are in line with those displayed in table 6.

6.2 Medium-term effects

6.2.1 Effects of hot summer temperature anomalies by level of development

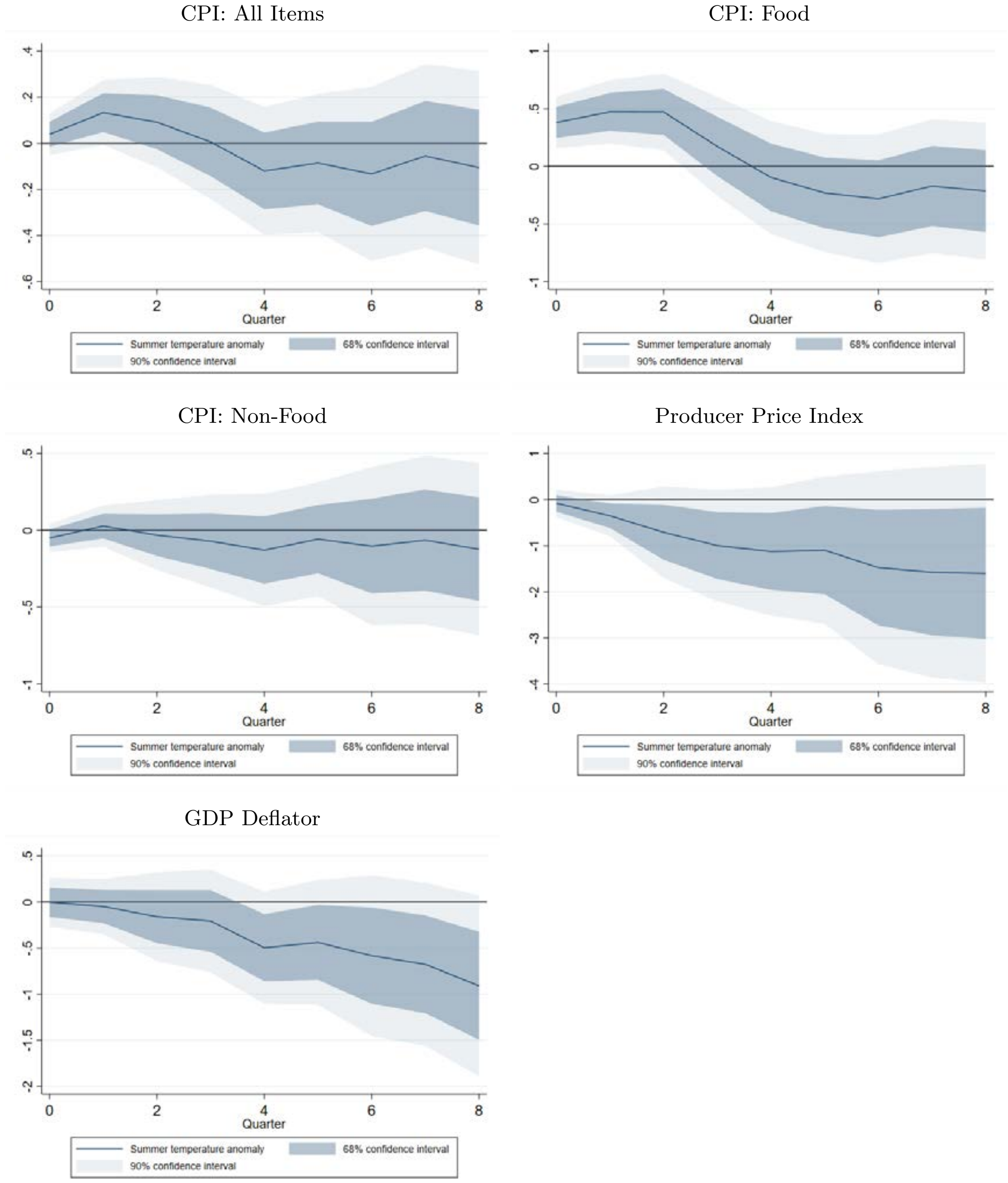
Figure 4 reports the response of inflation to hot summer temperature anomalies up to 8 quarters following the initial shock. The results obtained show some signs of a long-lasting effect of hot summer temperatures on prices. While food price inflation returns to the pre-shock levels within three quarters following the shock, producer prices and the GDP deflator continue to fall the following year.

Again, the results obtained are largely robust to a set of alternative specifications – such as using four lags of the lagged inflation rate, including quarterly rather than annual fixed effects, adding the lagged price level, controlling for the occurrence of droughts in the estimation, or employing the mean group estimator. This is shown by figures B.3 – B.7 in the appendix. We also considered the impact of hot summers temperature anomalies on inflation components depending on past inflation levels (see figure B.8 in the appendix). We calculated the average inflation by country over the previous five years, then split the sample by the median. In general, the response of high inflation countries has much larger variation, in common with the positive correlation between average inflation and inflation volatility. While the initial impact on food prices is similar between the two groups, it grows over time for the higher inflation group and remains more persistent. This is in keeping with the findings of Choi et al. (2018) that the impact of relative price shocks is larger and more persistent when inflation expectations are less well anchored.

The negative medium-term effect of summers temperature anomalies on prices is mainly driven by developments in EMEs. Figure 5 shows that, in this country group, producer prices start to fall following the temperature shock, with the effect becoming stronger each quarter, both economically and statistically. On the other hand, the effect of temperature anomalies on the GDP deflator reported in figure 4 seems to be mainly driven by developments in advanced economies – which account for bulk of the economies in our sample – although the effect is broadly insignificant.

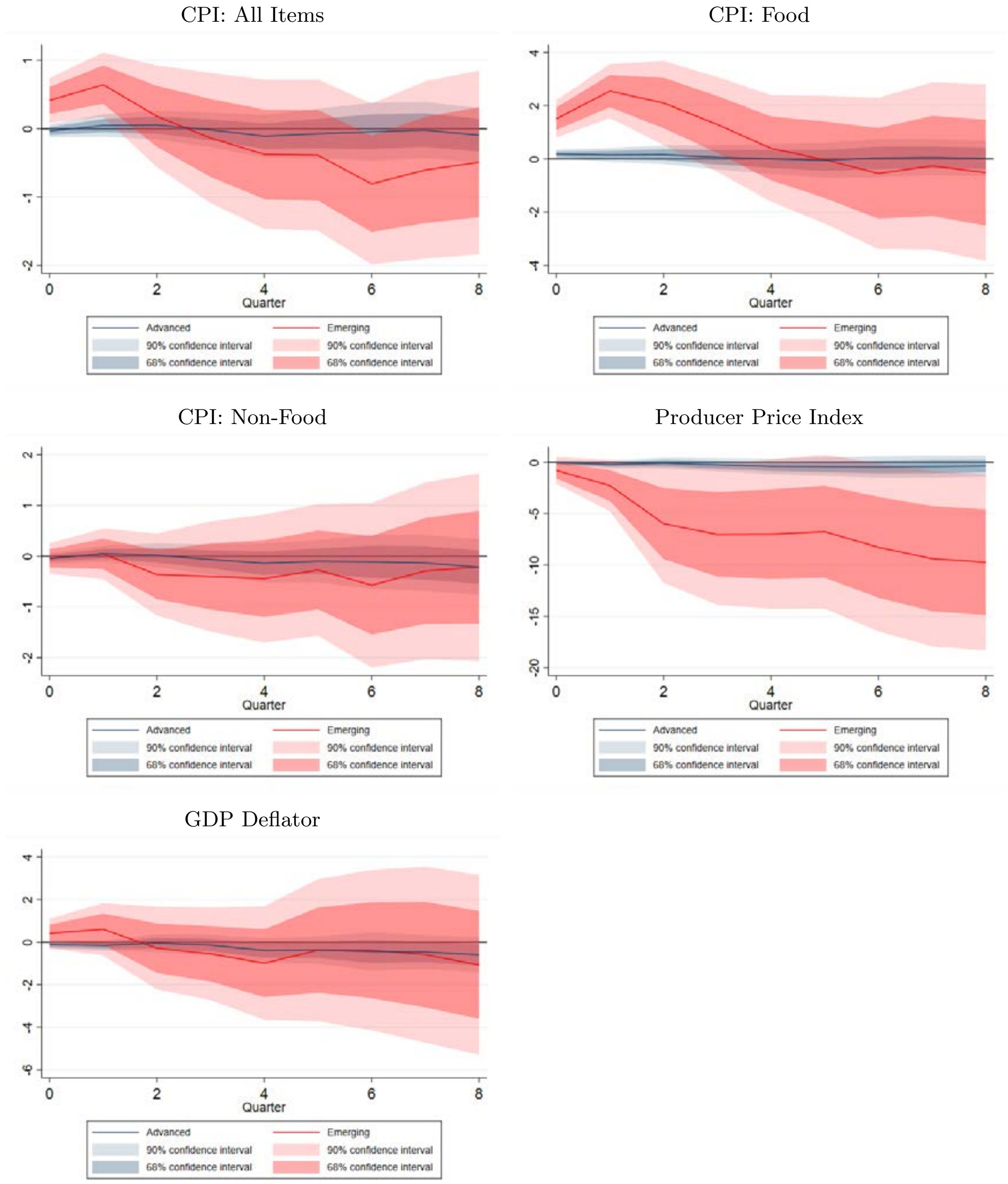
In order to interpret our results, the left hand side column of figure 6 reports the impulse responses of GDP growth to significant summer temperature anomalies. The IRFs are estimated

Figure 4: Effect of summer weather shocks on inflation and its components over the medium term



Notes: Impulse responses to hot summer temperature anomalies at horizon 0 using the baseline specification. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

Figure 5: Effect of summer weather shocks on inflation and its components over the medium term, by country group



Notes: Impulse responses to hot summer temperature anomalies at horizon 0 using the baseline specification and estimated for advanced economies (displayed in blue) and emerging market economies (displayed in red). Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

using the same model as in equation 9, with the inclusion of the level of the GDP per capita in USD as a control to take into account catch-up effects. Our results are as follows. First, GDP growth turns negative in emerging market economies following a hot summer temperature anomaly. While also Dell et al. (2012), Acevedo et al. (2020) and Felbermayr and Gröschl (2014) find that hot temperatures affect economic growth negatively, these studies look at yearly temperature fluctuations, without distinguishing across seasons. In this respect, we also run our model for yearly temperature anomalies and we did not find a significant effect on GDP growth. Second, we do not find evidence of dampened economic activity in advanced economies following a hot summer temperature shock. This result is in line with the main findings of Dell et al. (2012), Felbermayr and Gröschl (2014) and Acevedo et al. (2020) (although they focus on yearly average temperatures), while it is in contrast with those of Colacito et al. (2019) which however focus only on the U.S. economy.[10]

The negative effect of temperature anomalies on prices and economic activity in the medium term suggests that demand effects may occur in less developed countries following a particularly hot summer. As mentioned in the previous section, this may reflect the fact that in this country group both the contribution of the agricultural sector to GDP and share of food in the overall consumption are higher compared to advanced economies.

6.2.2 Alternative measures of temperature anomalies

In this section, we test whether our results hold for alternative measures of temperature anomalies.

We begin by considering whether our findings are robust to an alternative measure of significant temperature anomalies based on World Bank data for the calendar year, which corresponds to the frequency of the macroeconomic variables included in our dataset. As discussed in section 4, FAOSTAT provides information on seasonal temperature anomalies following the meteorological year (which starts in December) rather than the calendar one.

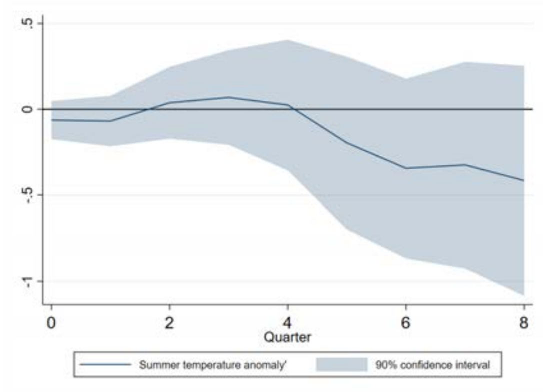
As a first step, we check consistency between the two data sources. Therefore, we construct temperature anomalies relative to the 1951-1980 average based on World Bank data for the

[10]Also Acevedo et al. (2020) find a temporary increase in GDP growth in advanced economies in the year following a temperature increase. Similarly to our findings, such increase is temporary and weakly significant.

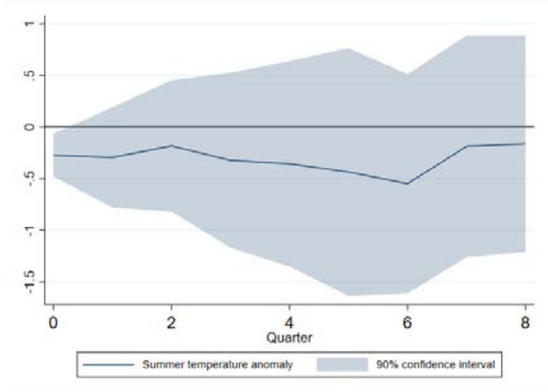
Figure 6: Effect of summer weather shocks on GDP growth over the medium term

Full sample

Baseline

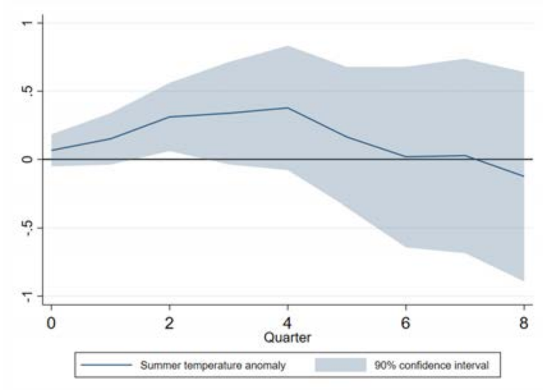


Adaptation

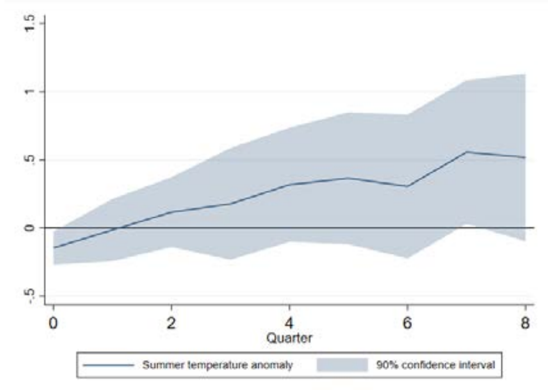


Advanced economies

Baseline climatology

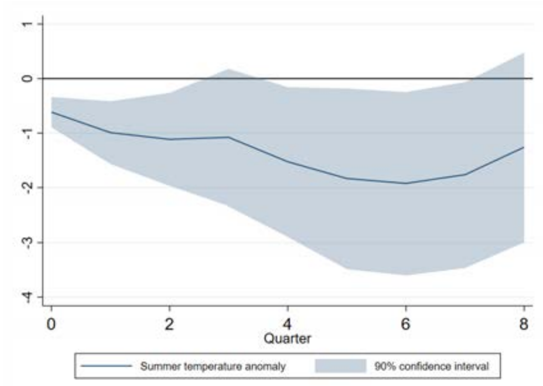


Adaptation

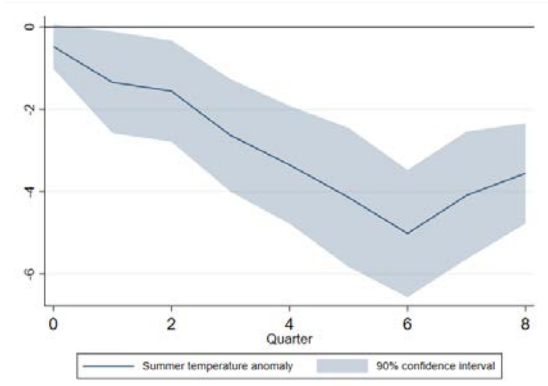


Emerging market economies

Baseline climatology



Adaptation



Notes: Impulse responses to hot summer temperature anomalies at horizon 0 using the baseline specification. Shaded areas 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

meteorological year to align with the FAOSTAT definition. As the data obtained from the World Bank are provided in the form of monthly average temperatures, we construct anomalies by subtracting the 1951-1980 average for the relevant month/country. Quarterly anomalies are then derived by averaging the monthly anomalies.

As shown by figure B.9 in the appendix, temperature anomalies based on the meteorological year are similar across the two data sources, but not perfectly matched. This is not surprising as there are differences in the way data are compiled. Most importantly, country temperature anomalies from FAOSTAT are more refined as they are computed by subtracting the current absolute temperature from the 1951-80 average at station level, rather than at country level.

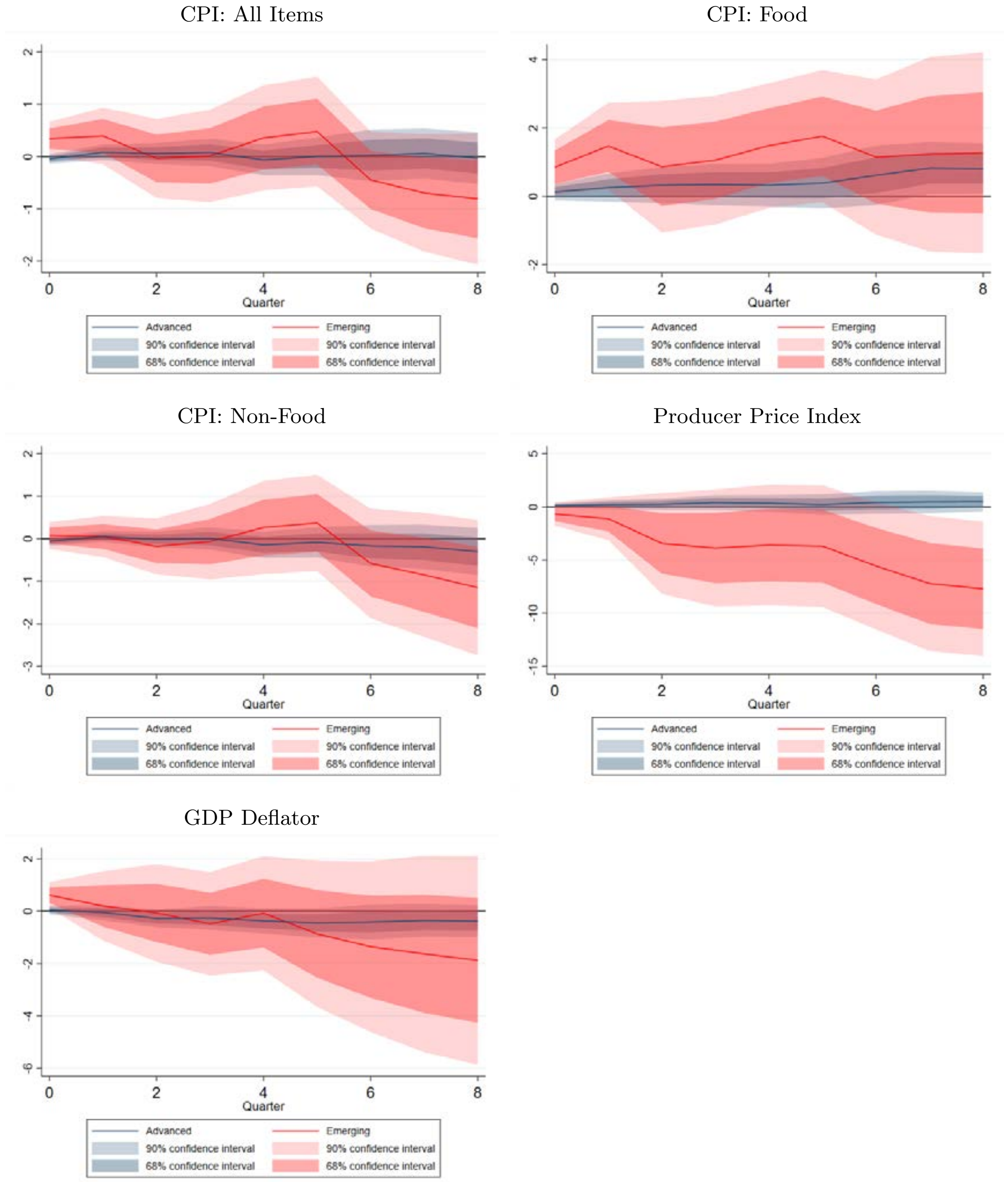
Having verified the consistency between FAOSTAT and World Bank temperature data, figure 7 reports the IRFs of inflation and its components to significant temperature anomalies based on the calendar year using World Bank data. In line with results reported in figure 5, we see some signs of prices falling in the medium term in emerging market economies following a particularly hot summer. We do not find any meaningful impact of heatwaves on prices in advanced economies. A notable exception is a positive effect on food inflation at the end of the estimation horizon, but this increase is weakly significant and could also potentially be driven by the way the data are computed.[11]

Next we consider an alternative way of calculating the anomalies, in order to allow for a gradual process of adaptation to higher temperatures. As Mendelsohn et al. (1994) point out, it is possible to adapt to changes in climate by planting different crops to account for the change in average temperatures. For this purpose, we construct a new proxy of country-specific temperature anomalies, measured as temperature deviations from the mean anomaly in the preceding decade, instead of the 1951-1980 average. This allows for possible adaptation to increasingly warmer temperatures in recent years, by shifting the distributions of temperature anomalies to the left (figure B.10 in the appendix).

Figure 8 reports the IRFs of prices to significant temperature anomalies taking into account the role of adaptation. Overall, the results obtained for inflation are in line with those under the baseline climatology scenario. The responses of GDP growth are shown in the right hand

[11] We refer to section 4 for a discussion on the challenges associated with using absolute temperatures calculated at country level for measuring climate change. For further information, we refer to GIS (2021) as well as to Hansen and Lebedeff (1987) and Lenssen et al. (2019).

Figure 7: Effect of summer weather shocks on inflation and its components over the medium term by country group – alternative measure of temperature anomalies



Notes: Impulse responses to hot summer temperature anomalies at horizon 0 using the baseline specification and estimated for advanced economies (displayed in blue) and emerging market economies (displayed in red). Temperature anomalies are computed in order to take into account the role of adaptation. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

side column of figure 6, and demonstrate that temperature anomalies can impact output, even when accounting for the trend increase in overall temperatures, although this is mostly a factor in emerging economies. This highlights the need to consider not just the increase in average temperatures arising from climate change, but also the increase in variability relative to the mean.

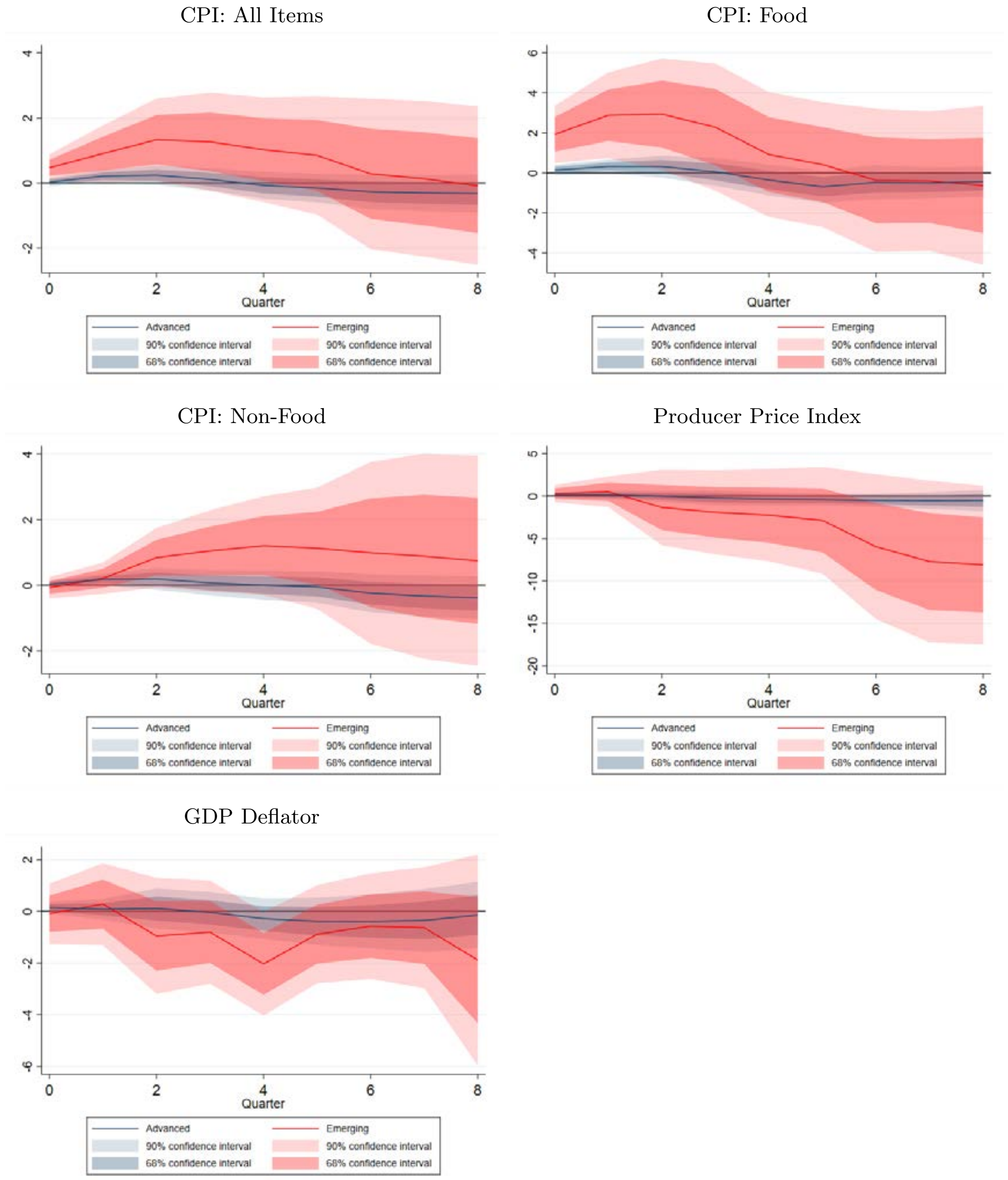
Finally, we consider the impact of larger temperature anomalies. The literature on extreme climatic events points to non-linear impacts, with larger events having proportionately greater impacts on GDP and inflation, sometimes including changes in the direction of effect (see Fomby et al., 2013; Felbermayr and Gröschl, 2014; Parker, 2018b).

We investigate potential non-linearities by moving the threshold of the temperature anomaly dummy variable from 1.5 °C to 2 °C, which we call hereafter 'very hot' summers. The higher threshold naturally means fewer extreme events in our sample, falling to around 5% of summers in EMEs and around 10% for advanced economies. As with the baseline case, the events have become markedly more frequent in recent years compared with the start of our sample. These factors combined mean that the results should be treated with a little more caution than the main results.

Those caveats in mind, the results obtained demonstrate the existence of non-linearities. We consider the impact of hot events, now defined as having an anomaly between 1.5 °C and 2 °C, and very hot episodes (those with an anomaly above 2 °C) against a control group where neither hot nor very hot summers occur. That means the results shown below for hot summers differ somewhat from the baseline case shown in previous charts.

We focus on advanced economies, given the larger number of very hot events. Here, in contrast to the lower threshold in the baseline case, we find clear evidence of negative inflationary pressure over the medium term (figure 9). Very hot summer temperature anomalies have a negative medium-term impact on headline CPI, with the effect being visible in both food and non-food sub-components. They also affect the GDP deflator. By contrast, the short-term positive impact on food prices is now clearer in the re-defined hot summers, but it is not significant for very hot summers. These diverging results highlight the discussion earlier on the twin supply and demand impacts. For hot summers, the initial negative supply impact on food prices is clear. But for very hot summers, the impact on all sectors may point to a more widespread downward pressure on demand.

Figure 8: Effect of summer weather shocks on inflation and its components over the medium term by country group – the case of adaptation



Notes: Impulse responses to hot summer temperature anomalies at horizon 0 using the baseline specification and estimated for advanced economies (displayed in blue) and emerging market economies (displayed in red). Hot summer temperature anomalies are calculated based on world bank data. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

For completeness, the impact of very hot summers in EMEs is shown in figure B.11 in the appendix. The results for very hot summers are broadly similar to the baseline case. Given the limited number of events and the wider confidence intervals it is, however, hard to draw strong conclusions.

7 Conclusions

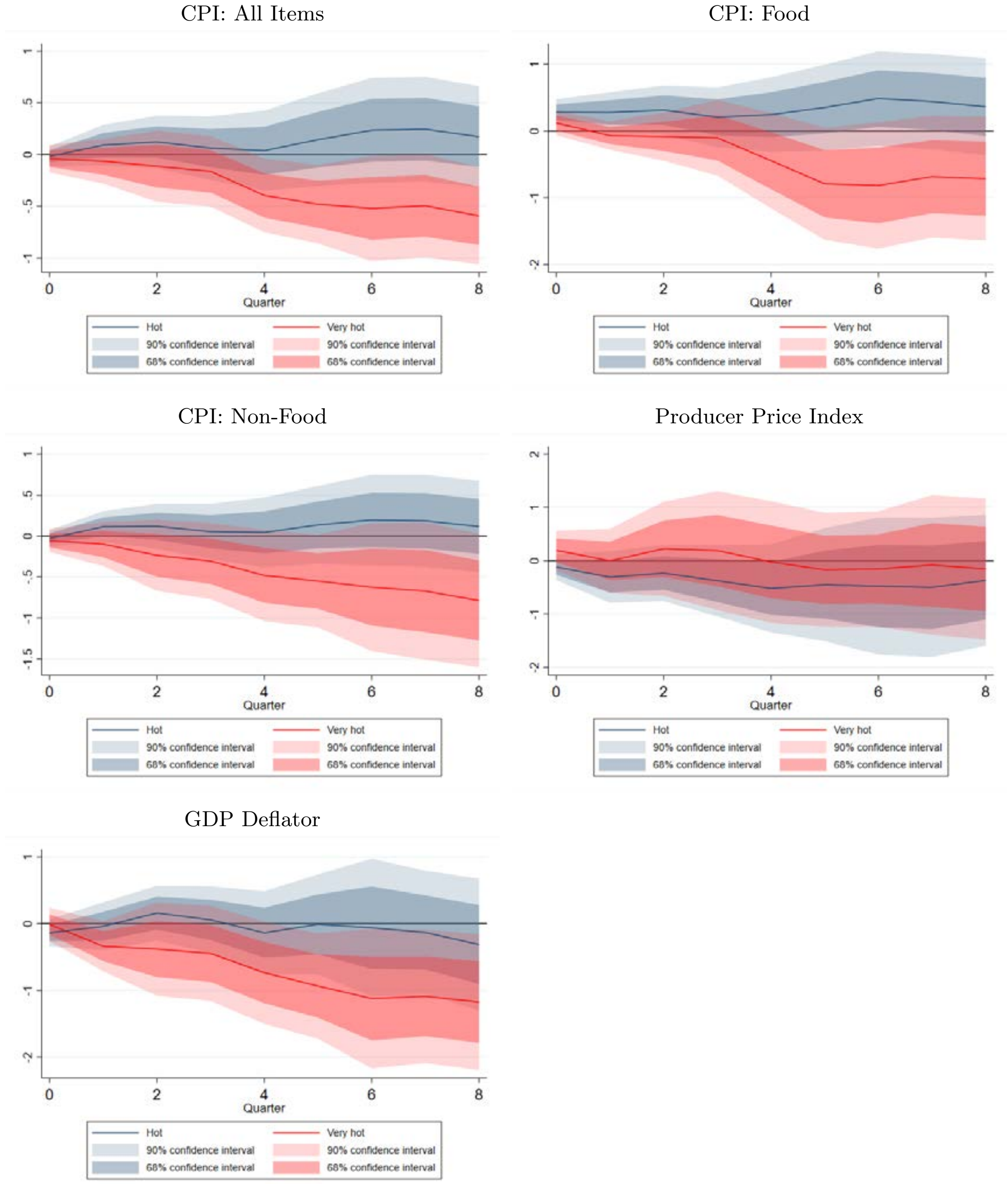
This paper is one of the first empirical contributions on the nexus between climate change and medium-term inflation. We find a significant and meaningful impact of extreme temperatures on a range of price indices, including consumer and producer prices and the GDP deflator. The interpretation of these empirical results is aided by a stylised two-country New Keynesian model enriched with a role for temperature to influence agricultural productivity.

Our analysis reaches four main conclusions. First, that the season matters. While there are some impacts from mild winters and springs, by far the largest and most durable impact is from hot summers. Second, the impact differs by sub-component, with the short-term impact most notable on food prices, particularly in EMEs. Third, in terms of economic mechanisms, the contemporaneous increase in food price inflation could be explained by a negative effect of hot summers on food production, resulting in supply shortages. In the medium term, negative demand effects may kick in, leading to falling prices and depressed economic activity. Fourth and finally, our findings point to the presence of a non-linear impact of global warming on prices, with the impact more significant for larger shocks and for higher absolute temperatures. In the context of rising temperatures, that means countries that have to date been spared economic impacts in the past may not be so fortunate in the future.

The results presented here consider national temperature anomalies and prices, which is the level at which monetary policy operates. That aggregation is likely to mask greater impacts at regional level from more intense, but more localised, events. The generalised lack of data at sub-national level – notably of consumer price indices – makes this regional analysis more difficult to conduct, but it would be a worthwhile continuation of the analysis presented here should suitable data be available.

In closing, the results here provide empirical support for the attention recently paid by central banks on climate change. While that attention has been predominantly on the financial

Figure 9: Effect of hot and very hot summers on inflation in advanced economies over the medium term



Notes: Impulse responses to hot summer temperature anomalies (displayed in blue) and very hot summers (displayed in red) at horizon 0 for advanced economies. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

stability implications, we find evidence that climate change is also important for the primary objective of price stability. Hot summers can have a meaningful impact on inflation, even into the medium term. Such events have become increasingly frequent over recent decades, and are projected to become more frequent still. Climate change, in short, is already starting to bear on the primary mandate of central banks.

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A Sample and data sources

A.1 Sample of countries and groupings

Advanced economies: Austria, Australia, Belgium, Cyprus, Czechia, Denmark, Estonia, Iceland, Finland, France, Germany, Greece, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States.

Emerging and developing economies: Bulgaria, Brazil, Chile, China, Costa Rica, Croatia, Hungary, Malaysia, Mexico, Paraguay, Peru, Philippines, Poland, Thailand, Turkey.

A.2 Data sources for price indices

Consumer prices

Parker (2018a) until 2012 Q4, then:

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom: EUROSTAT.

Chile, Costa Rica, Israel, Mexico: OECD.

Australia: Australian Bureau of Statistics.

China: National Bureau of Statistics via Haver Analytics.

Japan: Statistics Japan.

Korea: Korean National Statisitcs Office via Haver Analytics.

Malaysia Department of Statistics via Haver Analytics.

New Zealand: Statistics New Zealand.

Peru: Instituto Nacional de Estadistica e Informatica.

Philippines: Philippine Statistics Authority.

Singapore: Singapore Department of Statistics.

Thailand: Department of Internal Trade, Ministry of Commerce, via Haver Analytics.

Producer price indices

International Monetary Fund's International Financial Statistics, except:

Chile Banco Central do Chile: IPM Índice general (2007=100) to 2008 then IPP general industrias (2009=100) to 2013 then IPP general industrias (2014=100).

China National Bureau of Statistics: PPI for industrial products.

Iceland Statistics Iceland: Price index of marine products to 2003 Q3, thereafter PPI (2005=100).

Peru National Institute of Statistics and Informatics (INEI): Indice General al por Mayor.

Singapore Singapore Department of Statistics: Domestic Supply Price Index - Overall Items.

Real GDP

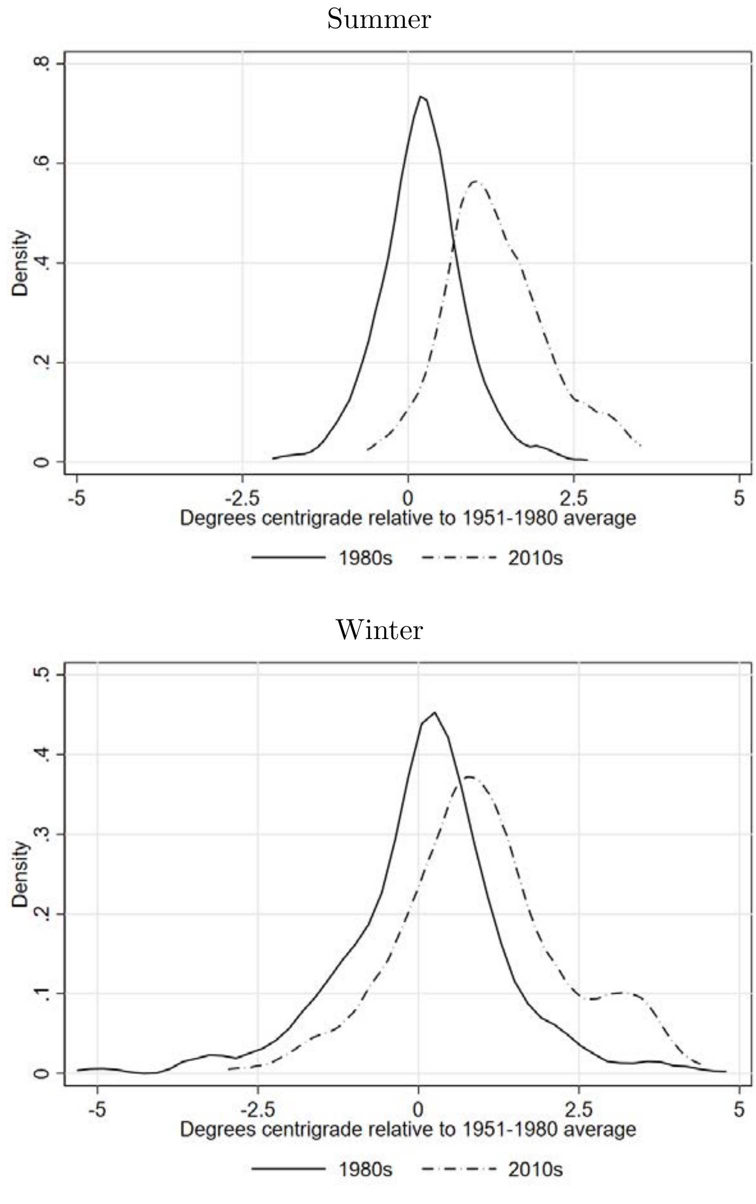
International Monetary Fund's International Financial Statistics

GDP deflator

International Monetary Fund's International Financial Statistics

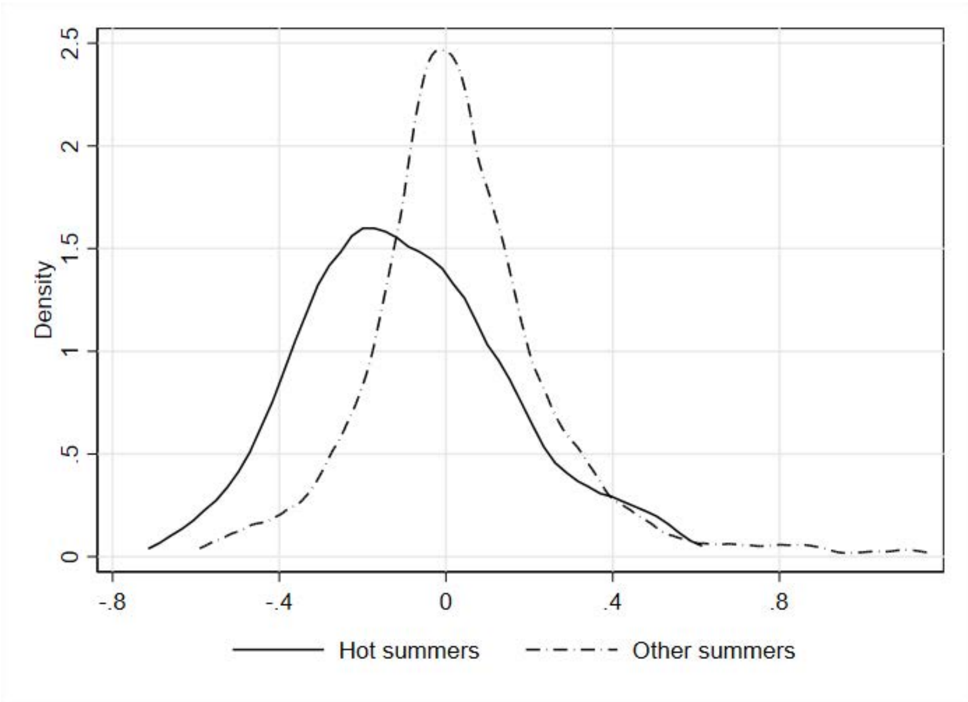
B Supplementary figures

Figure B.1: Distribution of temperature anomalies across seasons



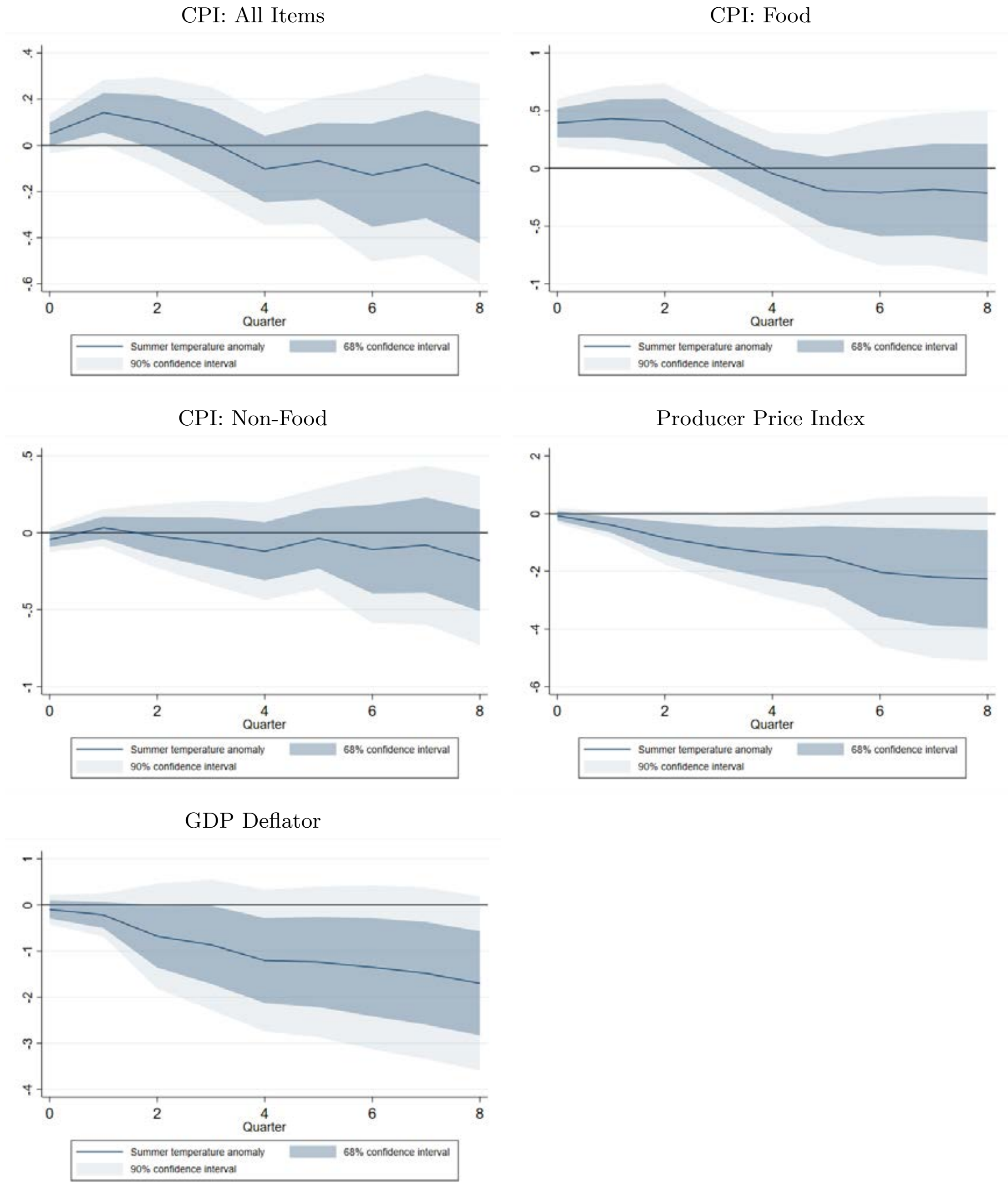
Notes: The figure shows the distribution (kernel density) of country-level temperature anomalies relative to the 1951-1980 average for the 48 countries in the sample used in this paper, distinguishing between summers and winters. Source: FAOSTAT and authors' calculations.

Figure B.2: Distribution of rainfall in summers



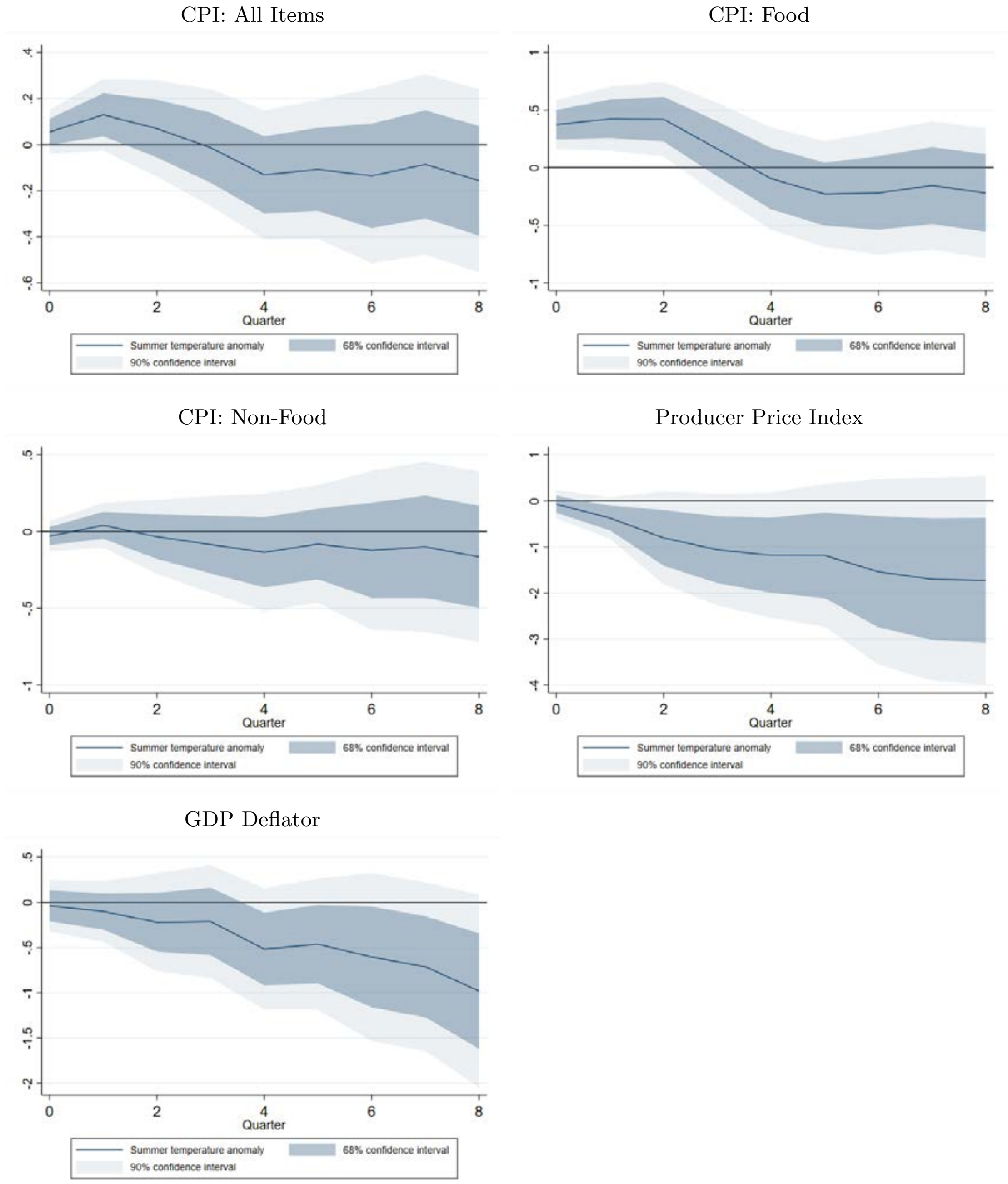
Notes: This figure shows distribution of the proportional deviations of rainfall from each country's average calculated over the period 1980-2010, distinguishing between hot summers and other summers. Source: GAME and authors' calculations.

Figure B.3: Effect of summer weather shocks on inflation and its components over the medium term – Robustness check with 4 lags instead of 8 lags



Notes: Impulse responses to hot summer temperature anomalies at horizon 0 based on a model with 4 lags of the first difference of the dependent variable (instead of 8 lags, as in the baseline specification) and estimated on the whole country sample. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

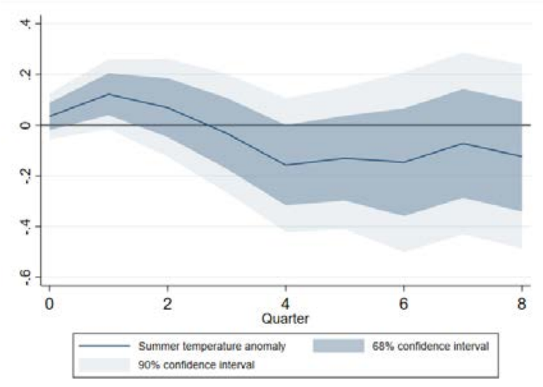
Figure B.4: Effect of summer weather shocks on inflation and its components over the medium term – Robustness check with quarter FE instead of year FE



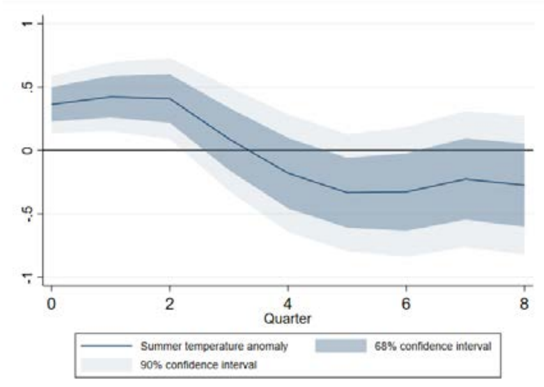
Notes: Impulse responses to hot summer temperature anomalies at horizon 0 based on a model with quarter FE (instead of year FE, as in the baseline specification) and estimated on the whole country sample. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

Figure B.5: Effect of summer weather shocks on inflation and its components over the medium term – Robustness check including the lagged level of the price index

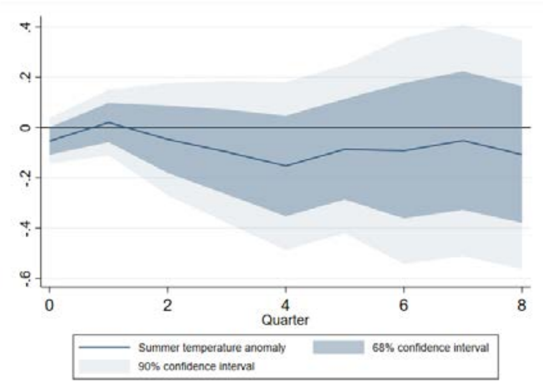
CPI: All Items



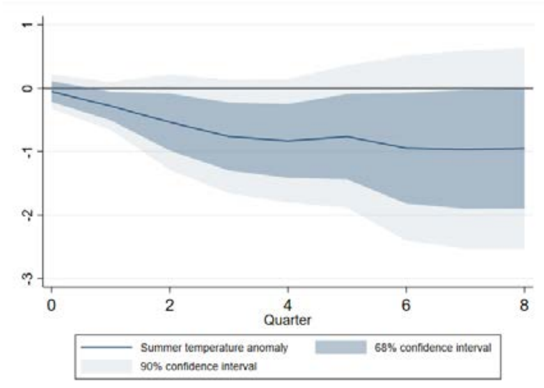
CPI: Food



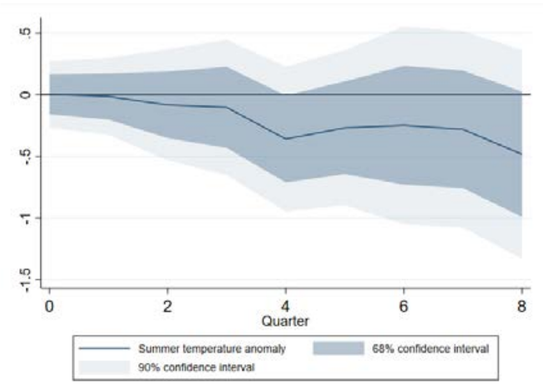
CPI: Non-Food



Producer Price Index

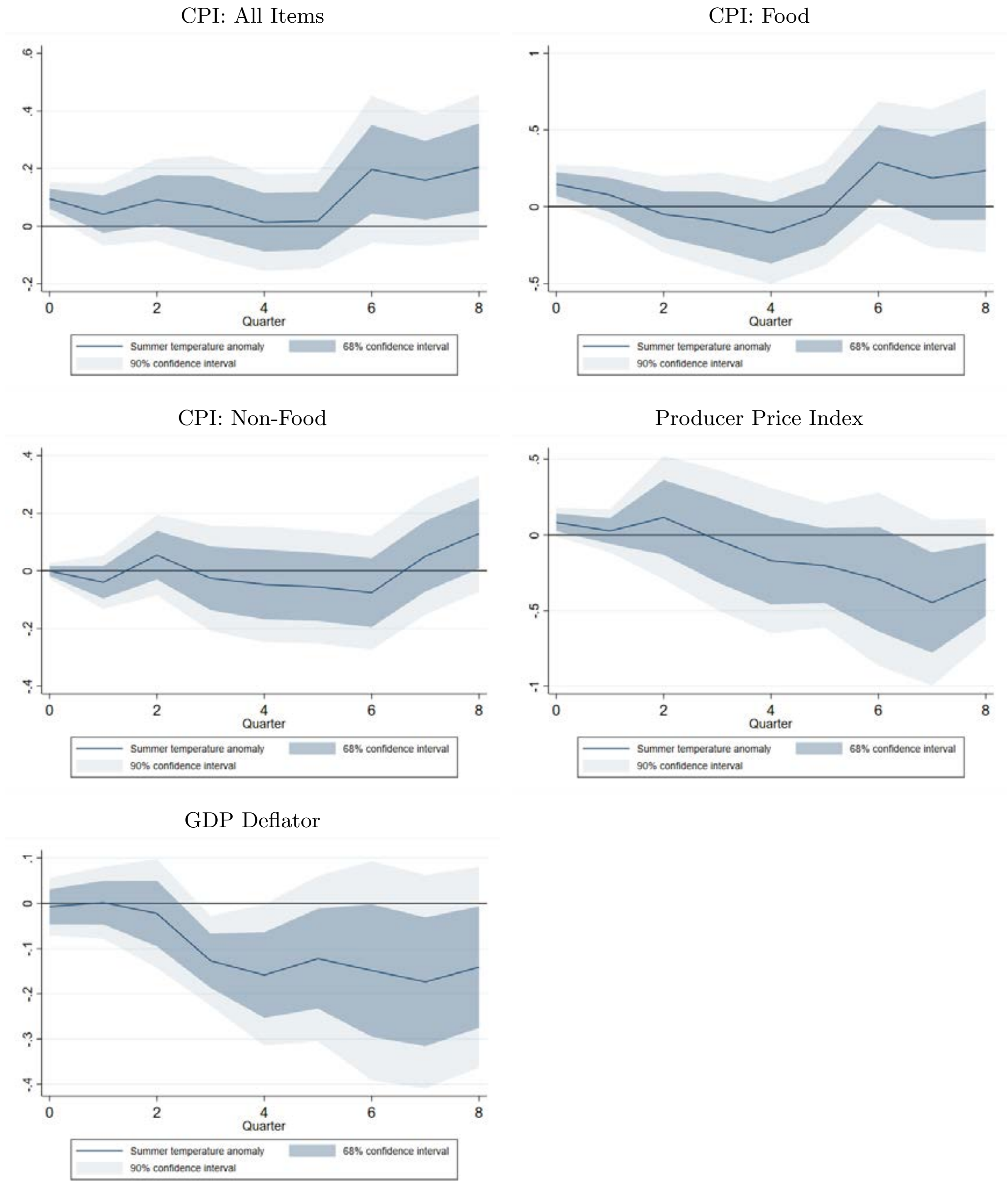


GDP Deflator



Notes: Impulse responses to hot summer temperature anomalies at horizon 0 based on a model including the lagged level of the price index and estimated on the whole country sample. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

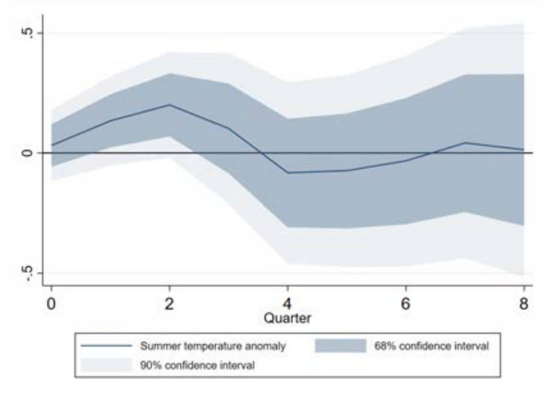
Figure B.6: Effect of summer weather shocks on inflation and its components over the medium term – Robustness check, mean group estimator



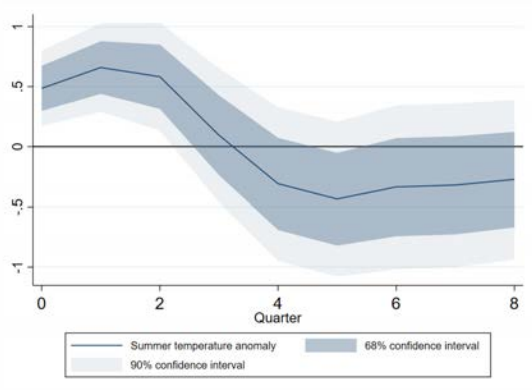
Notes: Impulse responses to hot summer temperature anomalies at horizon 0 using the Mean Group Panel Local Projection Estimator based on Pesaran and Smith (1995). The latter attributes less emphasis on outliers while computing the average coefficient and estimated on the whole country sample up to horizon 8. Shaded areas represent 68% and 90% confidence intervals.

Figure B.7: Effect of summer weather shocks on inflation and its components over the medium term – Robustness check controlling for the occurrence of droughts

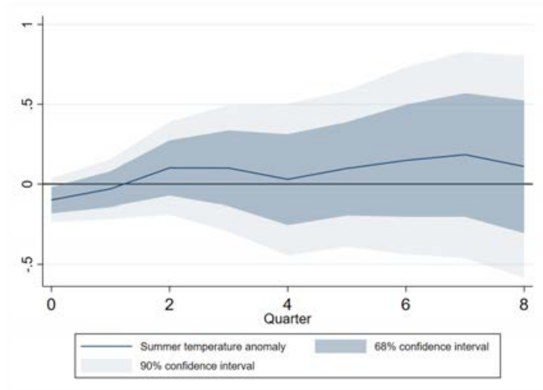
CPI: All Items



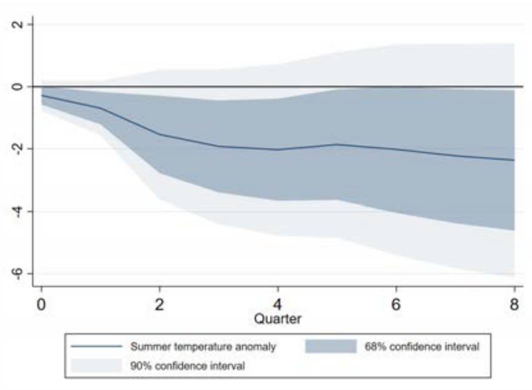
CPI: Food



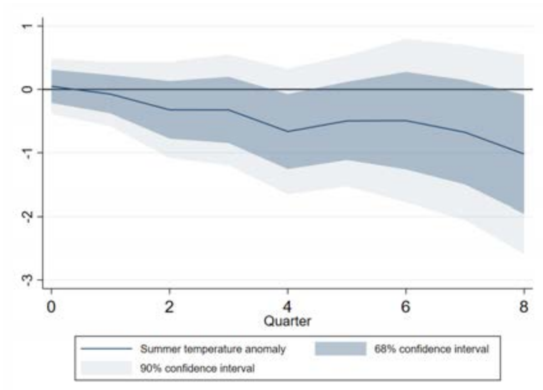
CPI: Non-Food



Producer Price Index

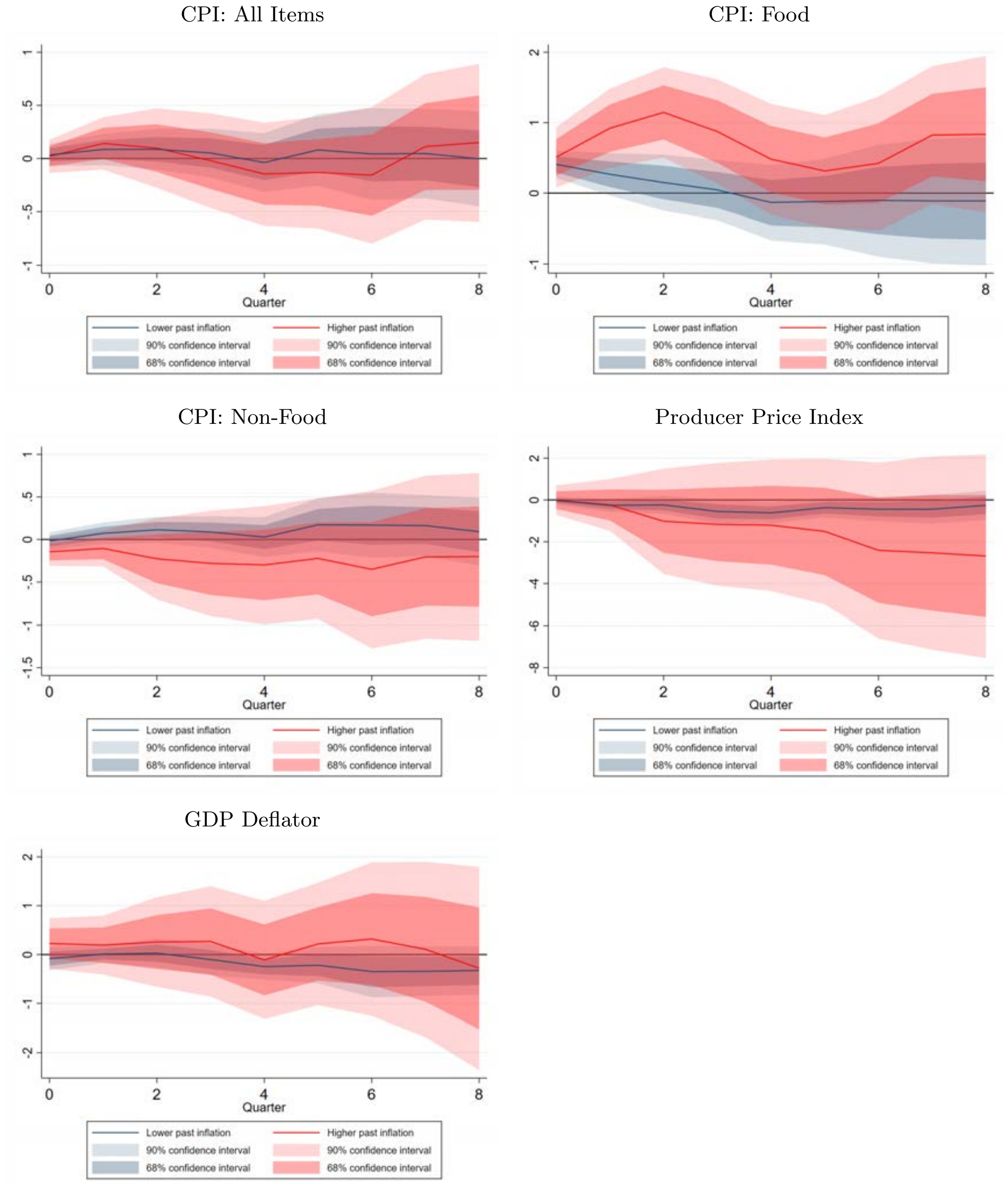


GDP Deflator



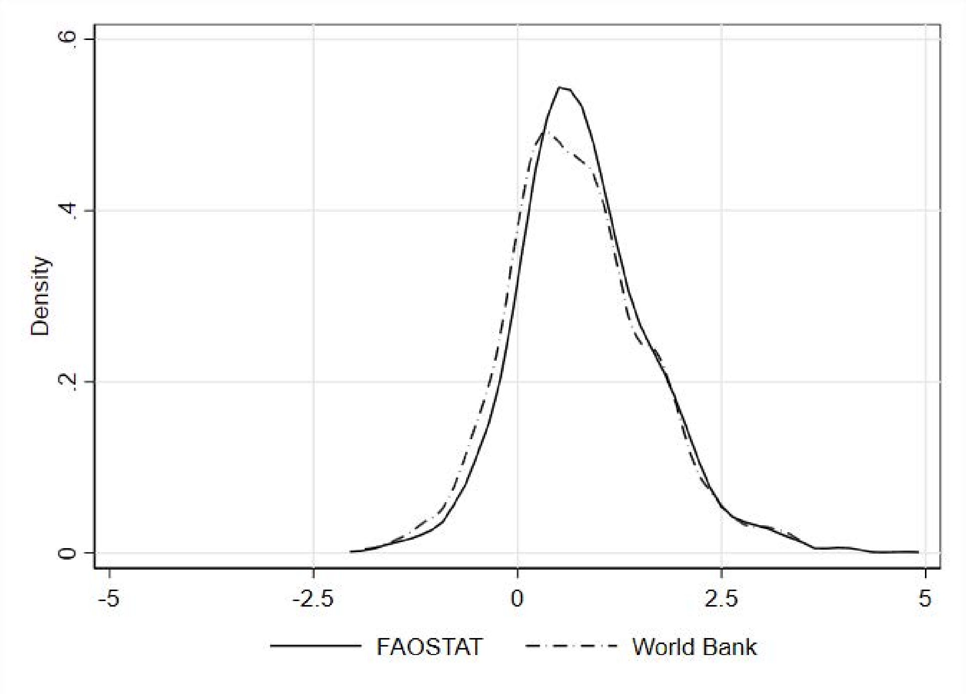
Notes: Impulse responses to hot summer temperature anomalies at horizon 0 based on a model controlling for the occurrence of droughts and estimated on the whole country sample. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

Figure B.8: Effect of summer weather shocks on inflation and its components over the medium term – Robustness check with a spilt of the sample according to the past level of inflation



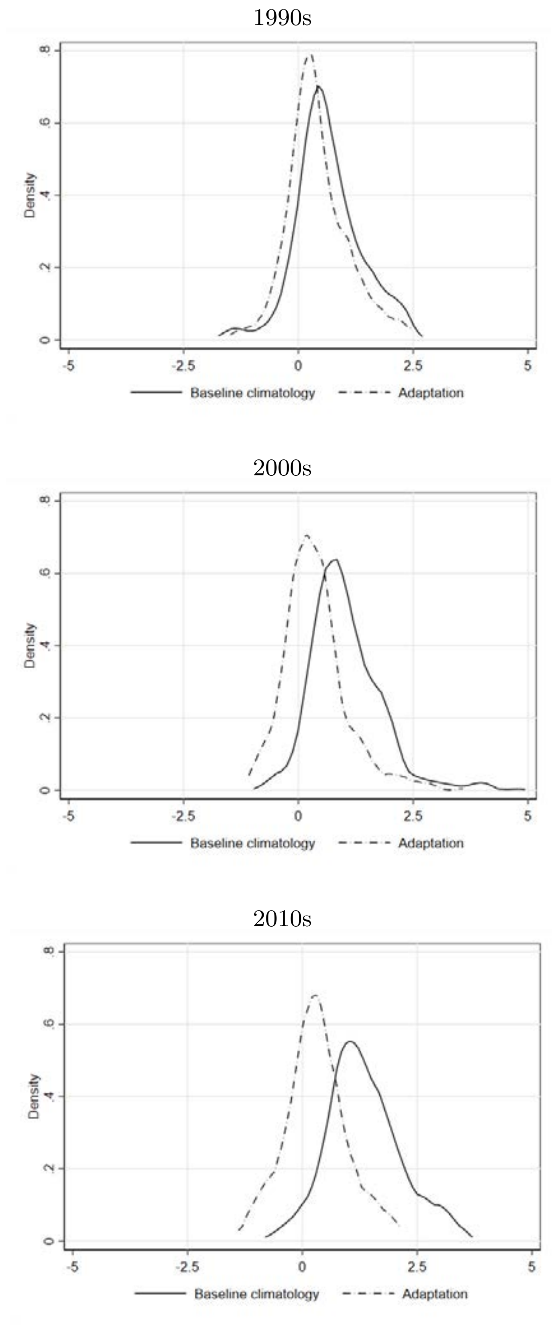
Notes: Impulse responses to hot summer temperature anomalies at horizon 0, splitting the sample in countries with relatively lower levels of past inflation (displayed in blue) and countries with relatively lower levels of past inflation (displayed in red). Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

Figure B.9: Distribution of summer temperature anomalies – FAOSTAT and World Bank data



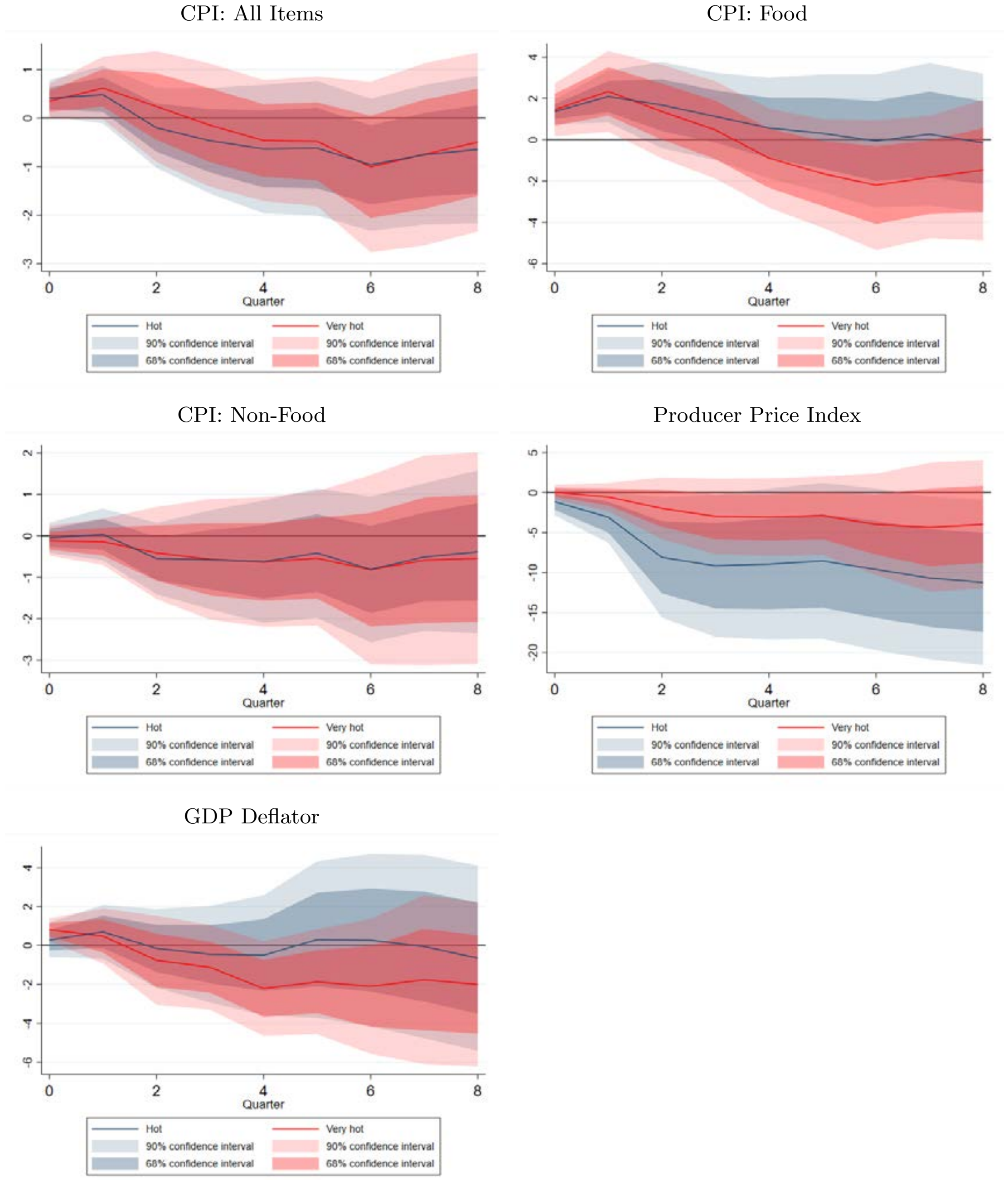
Notes: This figure shows distribution of summer temperature anomalies based on FAOSTAT and World Bank data. Source: FAOSTAT, World Bank Climate Knowledge Portal and authors' calculations.

Figure B.10: Distribution of summer temperature anomalies – baseline climatology and adaptation



Notes: This figure shows the distribution of summer temperature anomalies based on FAOSTAT data, calculated with respect to the country's 1951-1980 average (baseline climatology) and the average of the previous decade (adaptation). Source: FAOSTAT and authors' calculations.

Figure B.11: Effect of hot and very hot summers on inflation in emerging market economies over the medium term



Notes: Impulse responses to hot summer temperature anomalies (displayed in blue) and very hot summers (displayed in red) at horizon 0 for emerging market economies. Shaded areas represent 68% and 90% confidence intervals computed using Driscoll and Kraay (1998) standard errors.

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