Anomalous Weather, Prices and the ‘Missing Middle’

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Abstract

Climate change will increase the frequency of extreme weather events, affecting food systems. How food prices in domestic markets are affected by resulting supply shocks is key to understanding the impacts of climate change on food security. The expectation that supply shocks are fully translated into higher consumer prices may, however, not hold true even for commodities that see minimal processing from farm to plate and, in particular, where vertical chains deviate from perfect competition. Focussing on four major consuming countries, we show that anomalous weather patterns in exporting countries affects the spread between world and retail prices suggesting that shocks are mainly ameliorated (but in one case, exacerbated) by firms that comprise the supply chain - ‘the missing middle’. Our findings highlight placing equal emphasis on understanding how firms in this ‘missing middle’ will adapt to, and determine the impact of, climate shocks on participants in value chains.

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Abstract

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Introduction

Climate change and modified weather patterns have widely been shown to impact agricultural production, including that of many globally traded agricultural commodities (Lobell *et al.* 2012; Challinor *et al.* 2014; Rosenzweig *et al.* 2014, Iizumi *et al.* 2014). By extension, commodity prices are also expected to be affected, with direct consequences for food and nutritional security (IPCC, 2022). Empirical evidence on the effect of climatic phenomena on commodity prices has recently emerged with measures of anomalous weather patterns typically being measured by data on the El Niño-Southern Oscillation (ENSO). For example, studies have successfully identified ENSO anomalies as an important driver of world prices for a number of agricultural commodities, though effects often vary by commodity (Brunner 2002; Cashin *et al*. 2017; Ubiliva 2017)., The standard role for prices is that they have an important function in communicating information and signalling demand and supply shocks in markets. By extension, prices are anticipated to play a role in determining how consumers respond to climate change. However, there is a potential disconnect between prices for commodities on world markets and prices at the food retail level in national markets. Although linked, they may respond to shocks to differently and, to the extent they do, may impact on the consumer responses to anomalous weather patterns.

More specifically, the textbook role for prices may only apply to the fullest extent if domestic value chains are perfectly competitive at all stages of the value chain i.e. stages of food supply chains are not dominated by a small number of firms that can exercise market power.. But in recent years there have been increasing concerns from both academic and policy-making communities about competition in food chains across both developed and developing countries: McCorriston (2014) provides an overview of food chain competition issues in developed countries and Barrett *et al*. forthcoming for a summary of concerns relating to developing and emerging economies. However, the role of the characteristics of food supply chains may impact on climate-related issues has not been given adequate attention. For example, in the recent IPCC report, though concerns about climate change on food security were highlighted, the evidence-base was almost silent on the potential impact of the stages of food chains downstream from agriculture impacting on domestic food price impacts and food security more generally (IPCC, Chapter 5, 2022). We label this lack of focus on the impact of the downstream stages of the food chain on impacting on the potential impact of climate change and weather events on consumers as the 'missing middle'.

In the textbook treatment of perfectly competitive markets that is typically employed in the analysis of food markets, supply side shocks are transmitted to consumers one for one. To the extent that other costs are accounted for, spreads are assumed to be constant which also implies a constant relationship between producer and consumer prices reflecting the share of agricultural inputs in retail food prices. However, this standard framework does not fit with more detailed inspection. First, the share of agricultural output in the so-called 'food dollar' is relatively low and has been declining across most countries (Barrett et al, forthcoming). Second, anti-trust authorities across many developed and also emerging and developing countries have been increasingly concerned with competition issues in the food sector (see McCorriston, 2014). Third, the econometric evidence on price transmission indicates less than perfect price transmission (Lloyd, 2017). These issues tie together: the reason for low price transmission between agricultural and food prices has been directed at the role of market power in the downstream stages of the food chain though the wide body of quantitative research on price transmission does not uncover the main mechanism that links the lack of competition with price transmission. There are two issues that arise here. First, if competition concerns do impact on the changes in prices at one end of supply chains through to another, the key mechanism that accounts for low price transmission is the *change* in mark-ups (the prices that firms charge in excess of marginal costs); specifically how-controlling for other factors-spreads will change given exogenous shocks. This leads to a second issue: given that prices at both ends of the retail food-agricultural price will change, it is necessary to have an appropriate identification strategy to account for an exogenous shock that impacts on prices at both ends of food supply chains.

The focus on the 'missing middle' and how spreads change in response to exogenous shocks is the focus of this paper. In this paper, we account for anomalous weather patterns that jointly impact on producer and consumer prices i.e. the spread at either end of supply chain and, in so doing, identify the role of the missing middle in determining the outcome of weather anomalies on consumers. To the extent that the observed changes in the spreads deviate from the textbook characterisation where the missing middle plays no role in determining the impact of shocks, the results also casts new light on whether most of the burden of climate change is likely to fall on producers. To highlight the role of the missing middle, we focus on banana supply chains across several countries. Banana supply chains represent an excellent sector to focus on: first, it is a commodity with minimal processing between production and consumption which allows a clear link between producer and retail prices; second, as we report below, there have been long-standing concerns about competition and the functioning of banana supply chains.

In more detail, food supply chains involving multiple stages relating to procurement, distribution and retail are complex and the reality is far-removed from the textbook model. Our focus on the 'missing middle' covers all activities from production through to retail. The importance in focusing on how the spread between producer and consumer prices changes relates to how firms in the chain-the missing middle-accommodate changes in export prices while controlling for other costs in the supply chain; this is in line with the main mechanism that underpins incomplete price transmission. With retail prices for four major consuming countries (the UK, the US, France and Japan), we explore how retail-to-world price spreads change in response to anomalous weather events. To understand and quantify how climate change could influence changes in these spreads, we incorporate weather variation into our analyses. In the first instance, we utilise a global aggregate measure of weather variability, i.e. ENSO anomalies, that is commonly used in economic analyses of climate and agricultural commodity markets. However, to explore this issue in greater depth, we employ detailed weather data to derive temperature and precipitation anomalies for each of the countries that export to the four consuming countries we consider here. We show that spreads in banana supply chains across the above-mentioned countries respond significantly to supply side shocks. Moreover, the use of more granular weather data indicates that the use of the ENSO aggregate (used in other studies) is likely to underestimate the impact of supply side shocks on the change in spreads across supply chains, though anomalous temperature variation matters more than anomalous precipitation, While these results on the links between changes in spreads and anomalous weather patterns hold for our data coverage between 1998-2016, the response of the spread to anomalous temperature variation intensified and, in some cases, change direction in the post-2008 period. This latter period followed the commodity crises of 2008 and 2011 and also changes in many national food markets, most notably by the entry of discounters. Taken together, the results presented below therefore offer new perspectives on how the missing middle absorb or exacerbate shocks originating at one end of the supply chain through to the consumer stage and offers important insights for assessing the impact of climate change events.

Retail-World Price Spreads across Four Countries

Globally, bananas are the most traded fruit (FAO, 2016), with exports accounting for 15% of total production (FAO 2020). As a commodity, bananas are essentially unchanged from plantations in exporting countries to retail markets in importing countries. Sources of procurement vary across the four countries considered here. For the US, imports are sourced from Latin America and Caribbean countries, so-called 'dollar' countries. For the UK and France, imports are sourced from this region as well as some African countries reflecting previous colonial ties. However, Japan sources almost all of its banana imports from the Philippines owing to its geographical proximity. Ideally, in exploring the role of the missing middle, we would relate country-specific export prices to import country-specific retail prices. While we have data on the latter, detailed export prices are unavailable though it is reasonable to conjecture that export country prices will be tied to world prices. Moreover, using prices at intermediate stages of the value chain is also not a desirable option as this will not fully reflect the alternative procurement patterns that characterise supply chains; for example, when retail outlets procure directly from exporting countries (as in the case of Tesco in the UK) or where multinational firms-in some cases where vertical integration is a feature of these firms-deal directly with retailers. In characterising the missing middle incorporating all activities in the banana supply chain for the four importing countries we investigate here, we therefore relate world prices to country-specific retail prices.

Figure 1 reports retail prices for the UK, US, France and Japan in comparison to world prices for the period 1998-2016-all prices have been converted into US dollars. As is well-known, world commodity prices are generally characterised by volatility (Gilbert and Morgan, 2010), world banana prices exhibiting this characteristic and showing an upward trend since the latter part of the 2000s. However, for each of the four importing countries, retail prices exhibit much less volatility and, in some cases, for periods of time no change at all even when world prices are changing; this is most apparent in the UK in the latter period of the data coverage. The coefficients of variation highlight this disconnect between world and retail prices. For world prices, the coefficient of variation is 0.322. This compares with the coefficient of variation at the retail stage in each of the four countries; for the UK, 0.117; for the US, 0.093; for Japan, 0.177, and, for France, 0.182. In principle, differences in price behaviour could reflect other costs in the supply chain; we control for this in the analyses presented below but given that bananas undergo minimal transformation, these comparisons imply a prima facie case that the behaviour of spreads across these four countries imply a departure from the textbook model of commodity and food markets and where the missing middle impacts on the adjustment to exogenous shocks.

In more detail, economic theory points to issues surrounding competition and characteristics of value chains as the principal potential reason for consumer prices not reflecting changes in producer prices (see, for example, Weyl and Fabinger 2013, and McCorriston *et al*. 1998). Other factors may also influence the behaviour of mark-ups (e.g. labour, transportation and distribution costs) and may change over time but once accounted for, the characteristics of supply chains and, in particular, issues relating to competition in supply chains will be the main candidate in causing changes in mark-ups following exogenous shocks. Reflecting the importance of downstream stages in banana supply chains, producers and workers account for a low proportion of the final value of the retail price with retail chains capturing a substantial share: in relation to bananas supplied from Ecuador to the EU, the production stage accounts for around 14% of the final consumer price with retailers accounting for around 42% (BASIC, 2015). For the intermediate stages of the banana supply chains, we have combinations of multinationals and national firms involved in procurement from exporting countries. Some of these multinationals are vertically-integrated to some extent (e.g. Chiquita) while others are not (e.g. Fyffes). These multinationals have different market shares in each of the importing countries. These multinationals also compete with national firms involved in procurement and sales to retail chains, increasingly so as the role of multinationals in the world banana market has decreased over the last decade or so (FAO, 2015). At the retail stage, we have variation in the extent of market concentration across the four countries. The least concentrated food retailing sector is Japan, the four-firm concentration level being around 20%; at the other extreme, the four-firm concentration ratio in the UK is around 75%. Concentration in the retail sector in France is around 50% while for the US, it is less concentrated though the principal issue with concentration in the US relates more to regional markets rather than national figures which are less meaningful given the size of the country (see McCorriston 2014 for a discussion of these issues and the definition of the relevant market for measuring concentration). Moreover, to add an additional layer of complexity to procurement and distribution in banana supply chains, some retail chains circumvent the role of multinationals and national firms and procure directly from the exporting countries.

Assessing competition issues is a significant challenge for economists, particularly so in multi-stage supply chains. There are several aspects to this. First, there is the issue of 'horizontal' competition where firms in sufficiently concentrated markets may exercise seller power i.e. limited competition between a few firms at a given stage in the supply chain charge prices above competitive levels to consumers; in multi-stage supply chains, this issue is exacerbated by the oligopoly at each stage of the supply chain where the issue of 'double marginalisation' arises i.e. the potential for mark-ups over competitive levels at each stage. However, while much of the economics literature addresses the issue of seller power, buyer power is also an issue in food supply chains (McCorriston, 2014). In this case, firms at one stage can exercise market power in procurement either vis-à-vis firms in the preceding stage or against producers. Moreover, where we have direct procurement, vertical integration or specific contract arrangements, while offering some degree of efficiency between procurement and distribution, issues of vertical foreclosure can also arise. These issues apply in banana supply chains. Of note, when assessing the potential impact of the proposed merger between Chiquita and Fyffes in 2013, concerns about the functioning of the supply chain noted in the European Commission's investigation related most notably to buyer power (European Commission, 2014). The issue of buyer power and the alternative forms of unfair trading practices in banana supply chains across Europe has also been elsewhere (BASIC, 2015).

The significance of competition for understanding the spread between producers and consumers at either end of the supply chain is that the spread-contingent on controlling for other costs-will not be constant. This is because when markets are imperfectly competitive, the spread changes in response to exogenous shocks in ways are predictable yet dependent on a range factors that reflect the characterisation of the market at hand. In many cases encountered in practice the spread falls. In technical terms and subject to reasonable characterisations of the consumer demand function, the mark-up elasticity is negative suggesting that firms absorb some of the impact of exogenous shocks by reducing their mark-ups. However, in the presence of buyer power, spreads may increase i.e. due to the presence of buyer power, in response to a supply shock, firms with buyer power may increase the spread between costs and consumer prices (Weldegebriel, 2005). In the absence of all the information required, , how spreads change in response to shocks is potentially ambiguous; they can rise or fall (or, if imperfect competition is not sufficiently strong, not show any response significantly different from zero). But it is the change in the spread-contingent on controlling for other costs-that determines whether the missing middle ameliorates or exacerbates the impact of climate shocks on consumers.

In Figure 2, we report the pattern of spreads between world and retail prices for each of our four countries covering the period 1998-2016. All data has been converted into a common currency (US dollars) to ease comparison. There are three immediate observations from the data. First, the patterns of the spreads vary across countries. For the UK, the spread has shown a continual decline over the data period. For the US, the decline in the spread is apparent only from 2004 onwards though the decline is less obvious from 2010 onwards. For Japan, there is no obvious pattern to the spread as it increases and decreases over different sub-periods. This is also true of France. Second, the size of the spread varies across countries. The magnitude of the spread is lowest for the UK and US and relatively higher for Japan and France. This casual inspection of the data clearly suggests the role of the missing middle varies across our four countries and that the missing middle has a potential role to play in determining the impact of climate and weather shocks. Below, we set out how we deal with exogenous weather shocks that will impact on the banana supply chains in each of these countries. We also control for other costs in the supply chains in each of the four countries; however, manufacturing data exhibits relatively stable behaviour over time and is unlikely to account for the patterns of spread changes that are shown in Figure 2.

Estimating the Impact of Climate Shocks on Supply Chain Spreads

(a) ENSO effects

We formally explore the how the spreads for each country respond to climate shocks by employing local projection methods (Jordà 2015, 2019) which is an efficient way to measure the change in one variable (i.e. the measure of a weather or climate shock) on another variable (i.e. the retail-world price spread) while accounting for other factors as control variables (e.g. other costs that may influence retail prices). For the latter, we employ a measure of food sector manufacturing costs which accounts for energy and distribution costs that is specific to each of the four countries. Since most of the distribution of value-added in banana supply chains comes from the downstream stages (see above), this seems an appropriate measure to employ and which is also available at the same time frequency over the data period. Our dependent variable is the log of the retail-world price for each country; we have accounted tested for and-where appropriate-corrected for non-stationarity and accounting for an appropriate lag structure (see Methods section).

Fluctuations in the El Nino Southern Oscillation (ENSO) index is a commonly used proxy that captures weather variability in the econometric modelling of climate impacts on commodity markets (e.g. Cashin *et al*. 2017; Ubiliva 2017). ENSO is an aperiodic cycle of ocean and atmospheric currents across the equatorial Pacific ocean with wide ranging teleconnections to global weather systems and crop production (Iizumi *et al* 2014).Hence, we incorporated ENSO anomalies in our local projection methods to assess the role of the 'missing middle' in determining the effects of anomalous weather on consumers via changes in price spread.

The results are presented as impulse response effects together with confidence intervals are reported in Figure 3. The immediate observation is how the effects of the ENSO shock (taken as a one standard deviation of the underlying ENSO data) on the (log of the) retail-world spreads vary across the four countries. For the UK and US, the spread declines; for Japan, there is some weak evidence of a decline in the spread; for France, the effect of an ENSO shock is that the spread increases. The effects are statistically and economically significant. For the UK, after 6 months, a one standard deviation or 0.89 increase in the ENSO anomaly is associated with a 7.8% decrease (90 % C.I.=+/-4.23%) in the spread after 12 months. For the US, for the same 6 month period, the corresponding decline in the spread is 4.3% (90% C.I.=+/-2.49%) and where the effect is more long-lasting. In the case of Japan, aside from a temporary though statistically significant decrease (4.8 per cent after 4 months, 90% C.I.=2.27%), the decline in the spread is effectively zero over a longer time period. France stands out as an exceptional case however; the results from the ENSO shock result in an increase in the missing middle spread; at the 12-month interval, the spread increases by 6.6% (90% C.I.=+/-2.55%), the effect increasing to around 8% (90% C.I.=+/-2.79%) by 18 months.

(b) Local conditions

The attraction of using ENSO anomaly data is that it is easily accessible, and therefore, serves as a useful proxy for weather patterns that can be used to gauge effects on commodity markets. However, as an aggregate global metric, it translates to a variety of weather outcomes across the world (Dai and Wigley 2000; Holmgren *et al.* 2001; Larkin and Harrison 2005). Hence, it may not be precise enough when assessing weather effects on specific commodity markets and/or for a subset of countries within a global import-export network of a commodity. This is particularly relevant given the geographical spread of the four countries we cover and the location of the exporting countries where bananas are sourced from. Further, specifically for bananas, previous research has shown that changing climate can have a variety of country-specific effects on productivity (Varma and Bebber 2019). The ENSO anomaly data does not capture this phenomenon. Hence, there is a need to incorporate producer country specific weather data in models for a robust assessment.

To address this issue, we use temperature and precipitation data that applies directly to banana growing areas in countries that export to the UK. We constructed measures of anomalous variation in temperature and precipitation for each banana exporter which were then averaged across exporter countries. To ensure these weather anomaly data are more pertinent to each of the four countries, the averaging of anomalies was weighted by exporter country share to the each importing country. These weighted anomalies for temperature and precipitation substituted ENSO anomaly data in separate local projections. We also maintain the control for other costs and when dealing with the impact of each weather anomaly, we include the other anomaly measure as a control.

The detailed weather anomaly data provides more nuanced insights into the effects of weather shocks for each of the four supply chains. The results of the temperature anomaly shocks are presented in Figure 4. In the case of Japan, the effect of anomalous temperature variations is similar to the ENSO anomaly effect while, in the case of Japan, apart from short-lived declines in the spread, the impact of temperature anomalies is effectively zero. For France, the spread continues to exhibit an increase; for the corresponding 12 month period, a 1 standard deviation (0.37 degree C) increase in temperature increases the retail-world price spread by 3.71% (90%C.I=+/-2.55%) rising to. 8 per cent over the 17th month period However, for the UK and US notable differences arise. In the case of the UK, changes in the spread are much more pronounced: a 1 standard deviation increase in temperature leads to a decrease in the spread of around 10 per cent after 9 months. This is approximately 22% increase above the measured effect with the ENSO anomaly measure. The effect on the spread is also more persistent. For the US, the impact of a temperature increase (5.2%; 90%C.I=+/-2.76%) is marginally above the ENSO case though the adjustment in the spread takes longer to emerge and it is less persistent compared with the ENSO results.

Precipitation anomalies on the other hand show no statistically significant effects across any of the four countries. The results are presented in Figure 5; in all cases, the impact of precipitation anomalies is broadly similar and, in all cases, the effects are bounded by the confidence intervals around zero. This is not an unexpected finding as, compared to changes in temperature, changes in precipitation patterns can be mitigated against to a greater degree during production (e.g. greater use of irrigation during drier than average periods, farm drainage infrastructure to mitigate against minor local flooding, etc.). Indeed, a recent global analysis reported that changes in temperature, rather than precipitation, over the past few decades has been a stronger driver of change in banana yields (Varma and Bebber 2019).

Finally, note that the structure of supply chains and the trends in world prices can change over time; so too can the relationships between consumer and world prices. In the context of the banana sector, this may arise, for example, due to trade policy reforms and the entry of food discounters which are pertinent to supply chains in the EU (e.g. the market penetration of Lidl and Aldi) and the US (WaltMart). We therefore explored the impact of temperature changes on the spreads post-2008. For Japan and the US, there were no notable differences in the impact on spreads in this latter period. However, for the UK and France there were notable changes: for the UK, the decrease in the spread due to temperature anomalies was around 44% after 13 months; this represents a considerable increase compared with the full sample period but arguably not surprising given that retail banana prices exhibited hardly any change in the post-2010 period despite the changes in world market prices (see Figure 1). For France, the impact on the spread changes sign: rather than indicating an increase in the spread over the full sample period, the impact of temperature anomalies in the post-2008 period indicates a decrease of around 9% (90%C.I=+/-3.43%) after 6 months.

General Insights

A number of more general observations arise from the above and which underpin the significance of accounting for the role of the missing middle in assessments of climate and weather-related events on food prices. First, even for a common commodity sourced from-in large part the same exporting countries-the characteristics and role of the missing middle can vary across countries. The differences in the results across the four countries covered here shows that there is no one-size-fits-all though the effect of anomalous weather variations is economically and statistically significant in all 4 countries we covered. Second, the insights will extend to other commodity sectors particularly where there is low, or no processing between the output that is produced in the exporting country to what appears on retail shelves. This is particularly relevant to fresh fruit and vegetables, which are key to healthy diets but may be particularly vulnerable to climate change (Springmann *et al*. 2016). The minimal degree of processing that applies in this case, and the control for other factors that may impact on the transmission of climate and weather shocks, allows us to infer that the role of the structure of the value chain is influencing how the spreads between producers and consumers adjust. Since other supply chains will be characterised by multinationals, large domestic procuring firms supplying retail food sectors which may-to varying degrees-be highly concentrated-the role of the missing middle will be crucial to other food supply chains.

We should draw out an overall headline about who is most likely to be affected by climate change in the presence of the missing middle. To the extent that the missing middle ameliorates the impact of climate shocks, producers are more likely to carry the burden of adjustment to climate change. Given the increasing concerns with climate change and extreme events, our research has shown that measures of anomalous weather patterns in exporting countries will give a more fine-grained characterisation of weather shocks and how they will affect value chains and ultimately consumers. In sum, the 'missing middle' matters.

Finally, our overall headline is that the missing middle should be a key focus on how adjustments to climate change occur in domestic supply chains. To benchmark the results we report here, we can note that the impact of ENSO on changes in the spreads in each of the four countries we cover here are well in excess of the estimated impact of ENSO on world prices that have been reported in other studies (Ubilava, 2017). Ignoring the 'missing middle' risks ignoring a key aspect of how food markets will be impacted by climate change and anomalous weather patterns.

Conclusion

Our analyses point to the importance of firms in value chains that link producers and consumers, or the 'missing middle', in addressing how climate change will affect food markets. Prices of commodities on 'world' markets can behave quite differently from prices in national markets, particularly at the retail level, even when the product itself is more or less physically identical between the production and retail stages of the supply chain. But supply chains across importing countries differ; their organisation is complex and the nature of competition-across both horizontal and vertical dimensions-involving both seller and buyer power are difficult to assess. To circumvent these issues, we therefore focussed on the adjustment in retail-world price spreads across four countries. These issues will generalise to other commodities and national markets which share similar characteristics (i.e. where competition at stages of value chains is limited to a small number of competing firms; where seller and buyer power play a role and where the retail sector becomes increasingly dominant). The general lack of attention on the organisation of food supply chains and the firms that constitute them-which we label as the 'missing middle'-is an important omission in any assessment of the impact of climate change and anomalous weather patterns on food prices and food security more generally.

Taken together, intermediary and retail firms can play a role in ameliorating (or even exacerbating) the impacts of relative price effects between consumers and producers due to weather variability and climate phenomena. This implies caution in interpreting changes in world prices as being commensurate with changes in consumer prices even for products sold at retail with minimal levels of transformation. If producers in exporting countries are taking a relatively small share of value added in supply chains, the difference in the price changes at either end of the supply chain also implies they are likely to be more affected by climate events compared with consumers.

But this also points to another issue particularly in the case where spreads decline to absorb the impact of weather shocks: if consumers are being shielded from the price impacts, how resilient are supply chains given the expected extents of climate modification weather variability that will occur over time (Hoegh-Guldberg *et al.* 2018)? If intermediary firms are absorbing shocks, this will have implications for the structure and, by extension, competition in the value chain in the longer run. Resilience in value chains relates not only to producers and consumers at either end but also how firms can sustainably cope with these shocks if not being shared with consumers. Therefore, formulating effective policy for food security relies on gauging the full spectrum of climate impacts on food commodity value chains, and relies on understanding the role of the 'missing middle'.

References

Barrett, C.B., T. Reardon, J. Swinnen and D. Zilberman. Agri-food value chain revolutions in low and middle-income countries. *Journal of Economic Literature* (forthcoming)

BASIC. Banana value chains in Europe and the consequences of Unfair Trading Practices. Bureau for Appraisal of Social Impacts for Consumer Information (BASIC) October (2015)

Brunner, A.D. El Niño and world primary commodity prices: warm water or hot air? *Review of Economics and Statistics* **84**, 176-183 (2002)

Cashin, P., Mohaddes, K. and Raissi, M. Fair weather or foul? The macroeconomic effects of El Niño. *Journal of International Economics* **106**, 37-54, (2017)

Challinor, A. J. et al. A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change* **4**, 287–291 (2014).

Dai, A. & Wigley, T. M. L. Global patterns of ENSO-induced precipitation. *Geophysical Research Letters* **27**, 1283–1286 (2000).

European Commission. Case No. COMP/M.7220-Chiquita Brands International/Fyffes. Merger Procedure. European Commission, Brussels C92014) 7268 Final (2014).

FAO *Banana Market Review, 2019*. Food and Agriculture Organisation, Rome (2020)

FAO *Ecuador's Banana Sector under Climate Change*. Food and Agriculture Organisation, Rome (2016)

Gilbert, C.I. and Morgan. C.W. Food price volatility. *Philosophical Transactions of the Royal Society B*, 3023-3034

Harris, I., Jones, P. D., Osborn, T. J. & Lister, D. H. Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. *International Journal of Climatology.* **34**, 623–642 (2014).

Hoegh-Guldberg, O. *et al.* Impacts of 1.5 C global warming on natural and human systems. *Global warming of 1.5 C. An IPCC Special Report* (2018).

Holmgren, M., Scheffer, M., Ezcurra, E., Gutiérrez, J. R. & Mohren, G. M. J. El Niño effects on the dynamics of terrestrial ecosystems. *Trends in Ecology & Evolution* **16**, 89–94 (2001).

Iizumi, T., Luo, J-J., Challinor, A.J., Sukurai, H., Brown, M.E., and Yamagata, T. Impacts of El Niño Southern Oscillation on the global yields of major crops. *Nature Communications*, **5**, 3712

IPCC *Sixth Assessment Report: Impact, Adaptation and Vulnerability*. (2022)

Jordà, O. Estimation and inference of impulse responses by local projections" *American Economic Review* **95**, 161-182. (2005)

Jordà, Ò. Simultaneous confidence regions for impulse responses". *The Review of Economics and Statistics* **91**, 629-647. (2009)

Larkin, N. K. & Harrison, D. E. Global seasonal temperature and precipitation anomalies during El Niño autumn and winter. *Geophysical Research Letters* **32**, (2005).

Lloyd, T.A. Forty years of price transmission research in the food industry: insights, challenges and prospects. *Journal of Agricultural Economics* **68**, 3-21. (2017)

Lobell, D. B. & Gourdji, S. M. The Influence of Climate Change on Global Crop Productivity. *Plant Physiology* **160**, 1686–1697 (2012).

McCorriston, S. *Competition Issues in the Food Chain Industry*. OECD. Organisation for Economic Cooperation and Development, Paris. (2014)

McCorriston, S., Morgan, C.W. and Rayner, A.J. Processing technology, market power and price transmission. *Journal of Agricultural Economics* **49**, 185-201 (1998)

Rosenzweig, C. et al. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model inter-comparison. *PNAS* **111**, 3268–3273 (2014).

Springmann, M., Mason-D'Croz, D., Robinson, S., Garnett, T., Godfray, H.C.J., Gollin, D., Rayner, M., Ballon, P. & Scarborough, P. Global and regional health effects of future food production under climate change: a modelling study. *The Lancet*, **387**, 1937–1946 (2016)

Turner, D. W., Fortescue, J. A. & Thomas, D. S. Environmental physiology of the bananas (Musa spp.). *Brazilian Journal of Plant Physiology* **19**, 463–484 (2007).

Ubiliva, D. The role of El Niño Southern Oscillation in commodity price movement and predictability *American Journal of Agricultural Economics* **100**, 239-263 (2017)

Varma, V. & Bebber, D. P. Climate change impacts on banana yields around the world. *Nature Climate Change* **9**, 752–757 (2019).

Weldegebriel, H.T. Imperfect price transmission: is market power really to blame? *Journal of Agricultural Economics*, **55**: 101-124 (2005)

Weyl, G.E. and Fabinger, M. Pass-through as an economic tool: principles of incidence under imperfect competition. *Journal of Political Economy* **121**, 528-583. (2013)

Figure 1: Retail and World Prices across the UK, US, Japan and France

Figure 2: Price Spreads across the UK, US, Japan and France

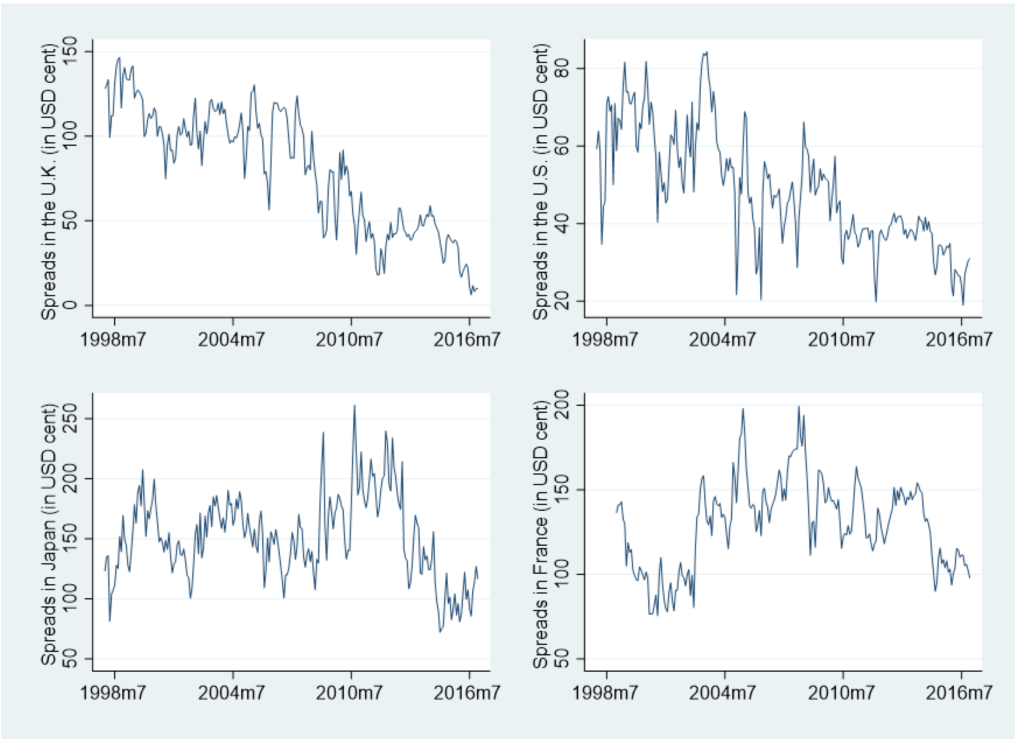


Figure 3: Effect of 1 SD Change in ENSO Anomaly Index on Price Spreads across the UK, US, Japan and France

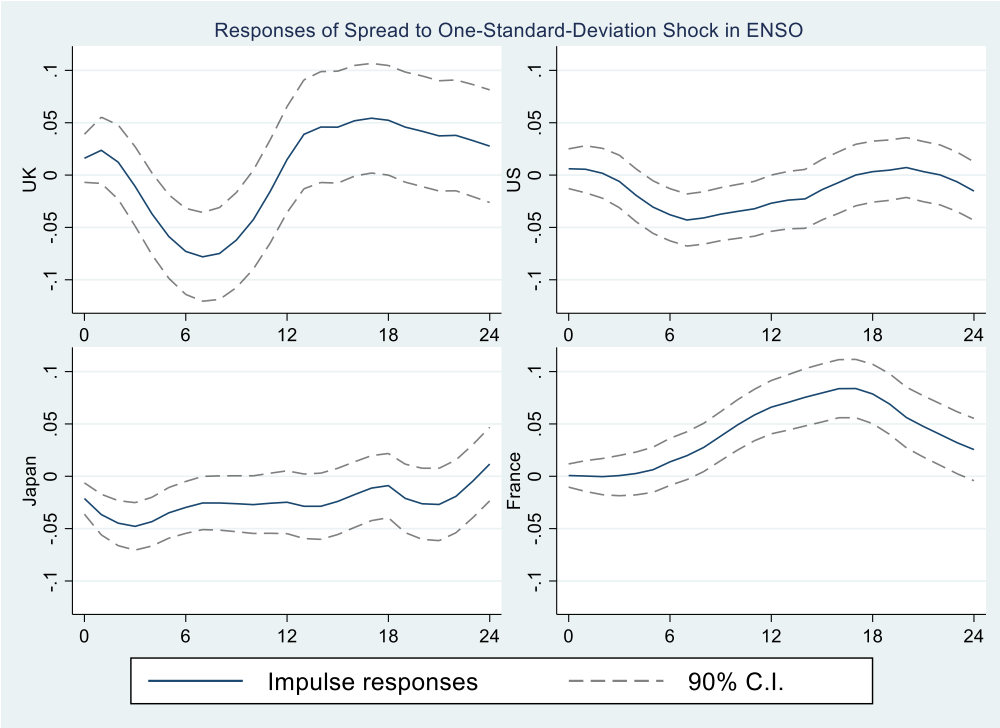


Figure 4: Effect of 1 SD Change in Temperature Anomaly on Price Spreads across the UK, US, Japan and France

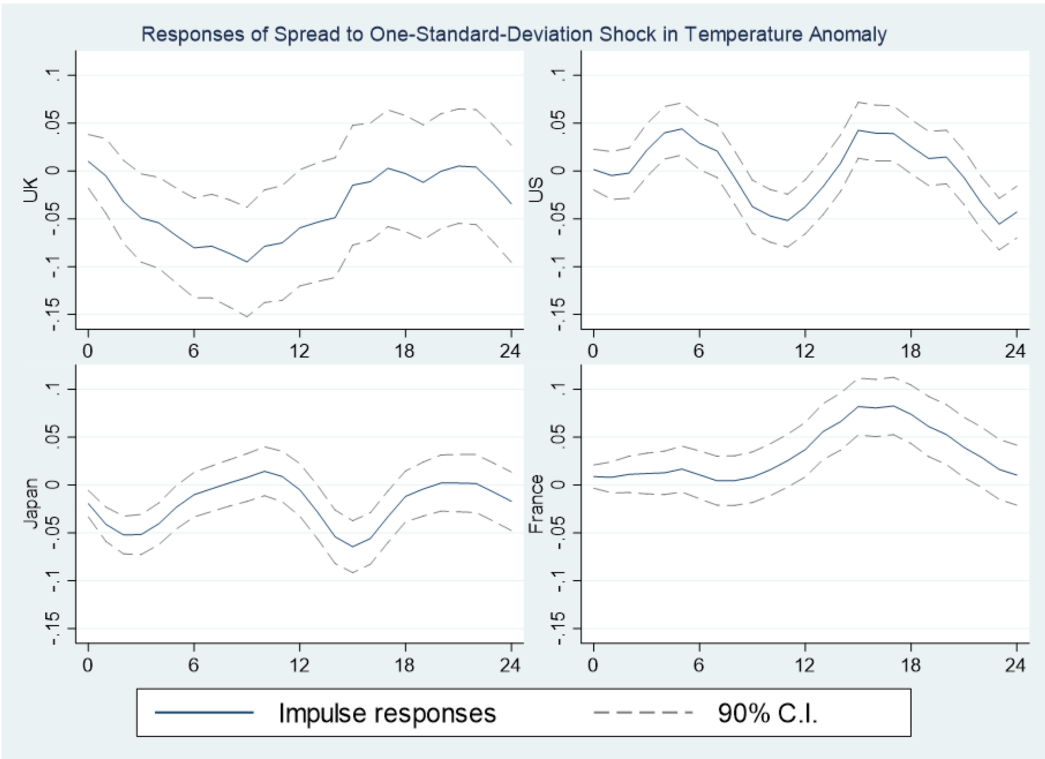
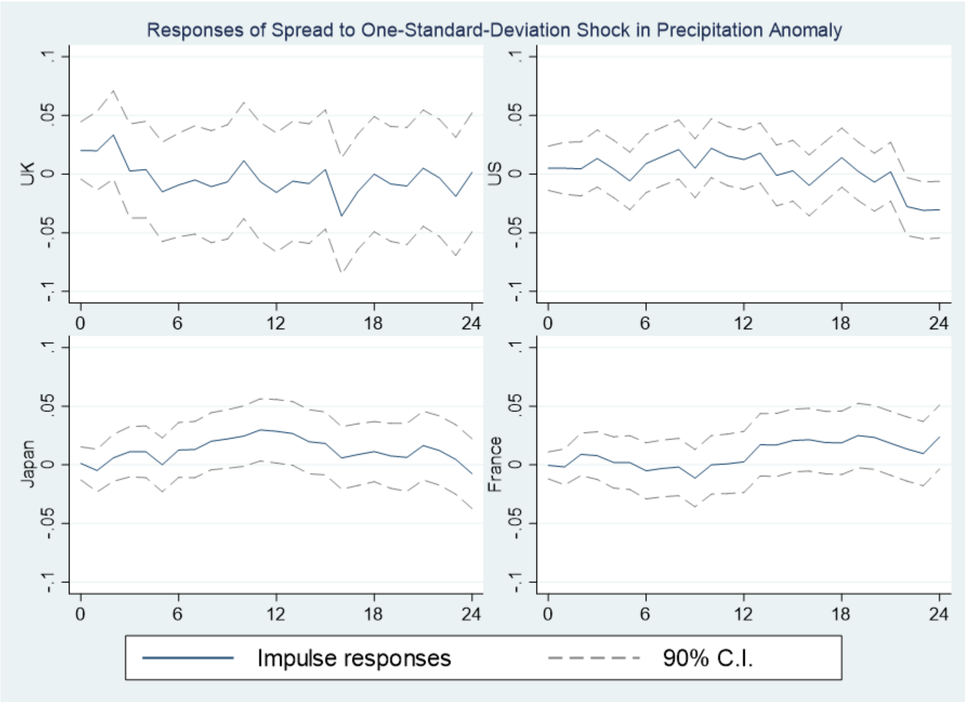


Figure 5: Effect of 1 SD Change in Precipitation Anomalies on Price Spreads across the UK, US, Japan and France



Methods

Banana price data. This study uses monthly series of the world price, retail prices for the banana market from 1998 to 2016 covering four countries: the UK, the US, Japan and France. World banana prices (represented by the price of Ecuadorian bananas in New York) were sourced from the UN Food and Agriculture Organisation (FAO) (http://www.fao.org/economic/est/est-commodities/bananas/banana-prices/en/). UK retail prices represent the average price of bananas per kg and are available from the UK's Office for National Statistics (ONS) (https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/czmv/mm23). Retail prices for the UK, Japan and France are sourced from the Food and Agriculture Organisation's *Banana Statistics Compendium*. The spreads reported in Figure 2 are defined as retail prices minus world prices.

ENSO anomalies data. The El Nino Southern Oscillation (ENSO) index is one of the most popular metrics used to describe large scale fluctuations in weather patterns. The ENSO anomaly is derived from the deviation between the sea surface temperature in the central and eastern tropical Pacific Ocean. ENSO anomaly data was sourced from the National Oceanic and Atmospheric Administration (NOAA) (ENSO Index Dashboard: NOAA Physical Sciences Laboratory),

Producer/Exporter country temperature and precipitation anomaly data. Data on monthly temperature and precipitation from 1996 to 2016 for each country that exports bananas to the UK (i.e.

Colombia, the Dominican Republic, Costa Rica, Ecuador, Belize, Cote d'Ivoire and Cameroon) were extracted from the CRU TS v.4.01 product (Harris et al. 2014; https://crudata.uea.ac.uk/cru/data/hrg/). Data extraction and an elevation-based correction of temperature specific to banana production areas were performed according to Varma and Bebber (2019). These data were used to calculate the month-wise average temperatures and precipitation for each month and for each exporting country. Observed deviations from the corresponding monthly averages represented country-specific monthly anomalies. The monthly temperature and precipitation anomalies were then separately aggregated across the exporting countries weighted by each country's share of the UK market to derive a single series for temperature and precipitation anomalies. Country-specific exports to the UK were sourced from the World Integrated Trade Solution database accessed from the World Bank. (World Integrated Trade Solution UN COMTRADE (WITS-UN COMTRADE) | Data Catalog (worldbank.org)). These weights were derived from the exports for each country relative to total exports for this group of countries, with the weights relating to 2011; the results are invariant to the year of weighting. Further analyses used the 1998 to 2016 subset of the processed climate data. Weights for other countries were derived from data from the Food and Agriculture Organisation's *Banana Statistical Compendium*.

Manufacturing input costs data. UK manufacturing input costs including fuel and raw materials (excluding wages and salaries of labour), controlled for other costs determining retail prices, and was sourced from the UK's Office for National Statistics (ONS; https://www.ons.gov.uk/economy/inflationandpriceindices/bulletins/producerpriceinflation/july2018) For the US, Japan and France, manufacturing cost data was sourced from the Organisation for Economic Cooperation and Development.

Estimating the impact on spreads: impulse response functions by local projection. To estimate the dynamic effects of shocks to the weather variables on the (retail–world) price spread (reported in Figures 3-5), impulse response functions were calculated using the local projection technique pioneered by Jordà (2005, 2009). Retail-world price spreads are in logs. The spreads data was tested for non-stationarity and, where appropriate, a time trend was included as a control to account for this. This involves estimating (or projecting), sequentially, a set of regressions comprising the information set available at time t, H periods into the future. Assuming that $y_t \equiv (y_{1t},\ \ y_{2t,}\dots, y_{Kt})'$ and the information set contains p lags of y_t we have:

$$y_{t+h} = \alpha^s + B_1^h y_t + B_2^h y_{t-1} + \cdots B_p^h y_{t-p} + \mu_{t+h}, h = 1,2,\cdots,H \quad (1)$$

Here, the same set of lagged variables are used to predict the value of y_t $h = 1,2,\cdots,H$ periods ahead, meaning there are H separate models, each containing K equations (so the superscripts in equation (1) denote the horizon being considered rather than powers). Attention focuses on the $(K \times K)$ matrix of autoregressive coefficients $B_1^h, h = 1,2,\dots,H$. As is evident from equation (1), B_1^h, contain coefficients that measure the effect of changes in y_t on y_{t+h}, conditional on the information set available. As Jordà (2005) formally shows, this matrix contains coefficients that comprise the impulse response functions.

Direct estimation of these coefficients via equation (1) has several attractive properties, giving rise to the increasing popularity of local projection in the recent macro-econometrics literature (see, *inter alia*, Ronayne 2011; Brugnolini 2018). Most notably, the need to estimate and invert a Vector Autoregression (VAR) using the Wold decomposition in the usual two-step process is circumvented, since the coefficients of interest are estimated directly in equation (1). In cases where the VAR does not exist or offers a poor approximation to the data generating process, misspecification errors are compounded when obtaining the vector moving average (VMA) representation, giving rise to bias in the impulse response function as the horizon grows. Local projection is also simple to employ, since the impulse response for the j^{th} variable in y_t can be estimated by univariate regression of y_{jt+h} on lags of itself and other variables in the information set. A few other considerations are noteworthy. First, as Jordà (2005) shows, the regression errors μ_{t+h} from the projection in equation (1) are VMA of order h, implying that the use of a robust estimator of the variance covariance, such as the heteroscedasticity and autocorrelation consistent (HAC) estimator of Newey and West (1987) and Andrews (1991) is preferable to least squares. This practice is adopted here to calculate the confidence intervals displayed in the figures.

Second, as with all dynamic models, lag length selection is not an innocuous choice, although here too local projection tends to fair better in small samples than the alternative based on a VAR (see Brugnolini, 2018) owing to the direct estimation of an impulses response function. In the empirical analysis here, we select lag length based on AIC.

Effect of anomalous weather shocks on the retail-wholesale price spread (Fig 3):
The impulse response methods are used to estimate the effect of anomalous weather shocks on the retail-world price spread. Figures 3-5 relates to alternative features of the anomalous weather shocks as detailed below:

Impact of ENSO anomaly on retail-world price spread:

$$p_{t+h}^{sp} = \alpha_{1,h} + \vartheta_{1,h} shock_t^{ENSO} + \sum_{j=1}^{J} \beta_{1,j,h}\left(w_{t+1-j} - w_{t-j}\right) + \sum_{j=1}^{J} \gamma_{1,j,h}\left(p_{t+1-j}^{\wp} - p_{t-j}^{\wp}\right) + \epsilon_{t+h}^{1}$$

Impact of temperature anomaly on retail-world price spread:

$$p_{t+h}^{sp} = \alpha_{1,h} + \vartheta_{2,h} shock_t^{TEMP} + \vartheta_{3,h} PREC_t + \sum_{j=1}^{J} \beta_{2,j,h}\left(w_{t+1-j} - w_{t-j}\right) + \sum_{j=1}^{J} \gamma_{2,j,h}\left(p_{t+1-j}^{\wp} - p_{t-j}^{\wp}\right) + \epsilon_{t+h}^{2}$$

Impact of precipitation anomaly of retail-world price spread:

$$p_{t+h}^{sp} = \alpha_{2,h} + \vartheta_{3,h} shock_t^{PREC} + \vartheta_{2,h} TEMP_t + \sum_{j=1}^{J} \beta_{3,j,h}\left(w_{t+1-j} - w_{t-j}\right) + \sum_{j=1}^{J} \gamma_{3,j,h}\left(p_{t+1-j}^{\wp} - p_{t-j}^{\wp}\right) + \epsilon_{t+h}^{3}$$

where p_{t+h}^{sp} is the retail-world price spreads at time t+h. The $shock_t^{ENSO}$, $shock_t^{TEMP}$ and $shock_t$ represent the ENSO anomalies shocks, temperature anomalies shocks, and precipitation anomalies shocks, respectively. In each weather-shock model, we also control for the other measure of anomalous weather: $PREC_t$ and $TEMP_t$ $\theta_{1,h}$, $\theta_{2,h}$ and $\theta_{3,h}$ indicate the response of price spreads to ENSO anomalies shocks, temperature anomalies shocks, and precipitation anomalies shocks at h-step ahead, respectively. w_t are other manufacturing input costs in the value chain that may also impact on the price spread. For our analyses, we imposed a shock representing one standard deviation change in the ENSO, temperature and precipitation anomalies, and the effect relates to the corresponding percentage change in the price spread following these shocks. $p_t^{\wp}$, are world banana prices that control for global shocks to the UK banana value chain.

Data availability

All data used are publicly available and open access. All banana data, climatic and topographic data sources are listed in the Methods.

References (Methods)

Andrews, D.W.K. Heteroskedasticity and autocorrelation consistent covariance matrix estimation", *Econometrica* **59**, 817-858. (1991)

Brugnolini, L. About local projection impulse response function reliability. Centre for Economic and International Studies, Working Paper No. 440, Rome. (2018)

Harris, I.P.D.J., Jones, P.D., Osborn, T.J. and Lister, D.H. Updated high-resolution grids of monthly climatic observations–the CRU TS3. 10 Dataset. *International Journal of Climatology* **34**, 623-642 (2014)

Jordà, Ò. Estimation and inference of impulse responses by local projections. *American Economic Review*, **95**, 161-182. (2005)

Jordà, Ò. Simultaneous confidence regions for impulse responses. *The Review of Economics and Statistics* **91**, 629-647. (2009)

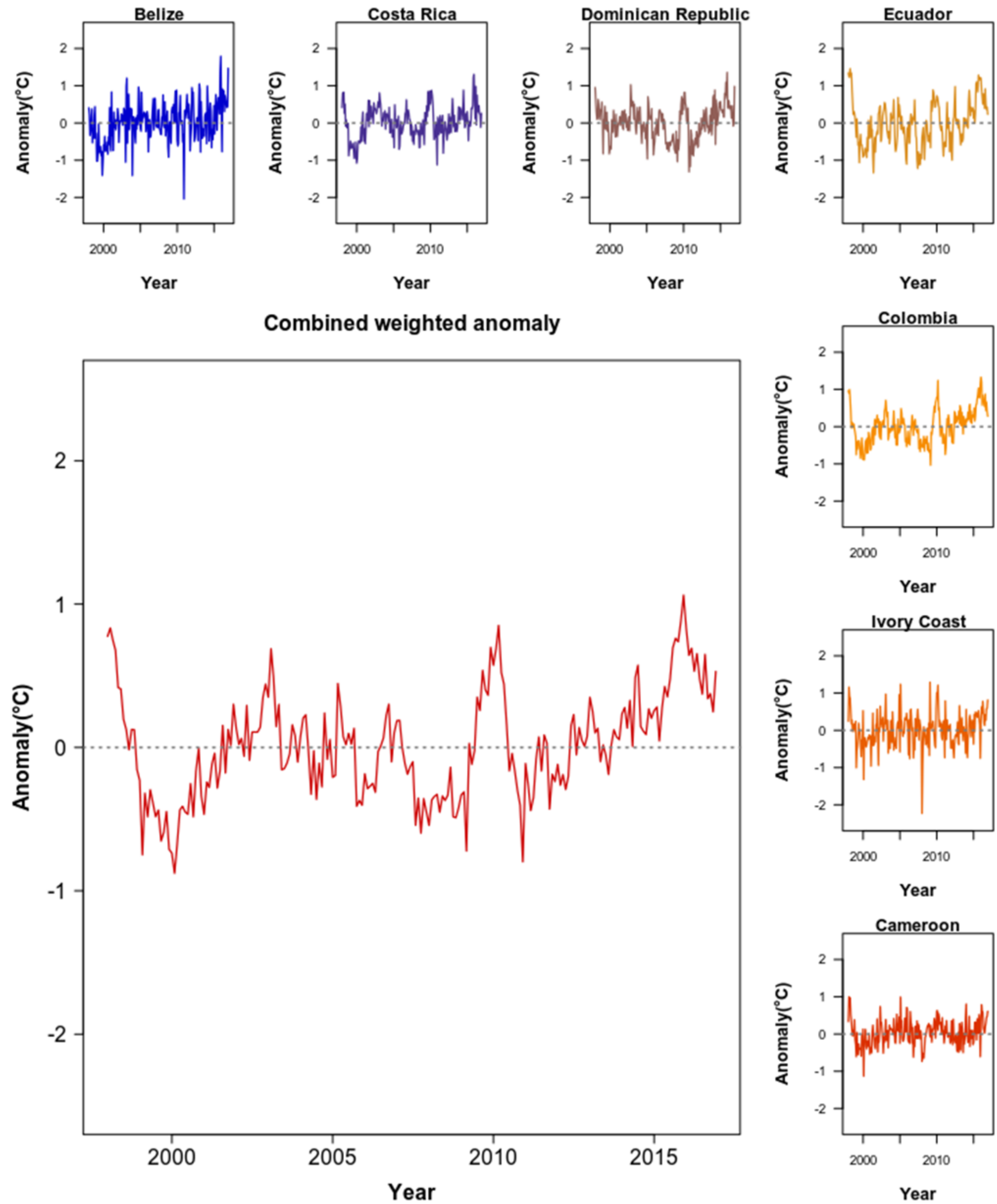
Newey, W.K. and West, K.D. A simple, positive semidefinite, heteroscedasticity and autocorrelation consistent covariance matrix", *Econometrica* **55**, 703-708. (1987)

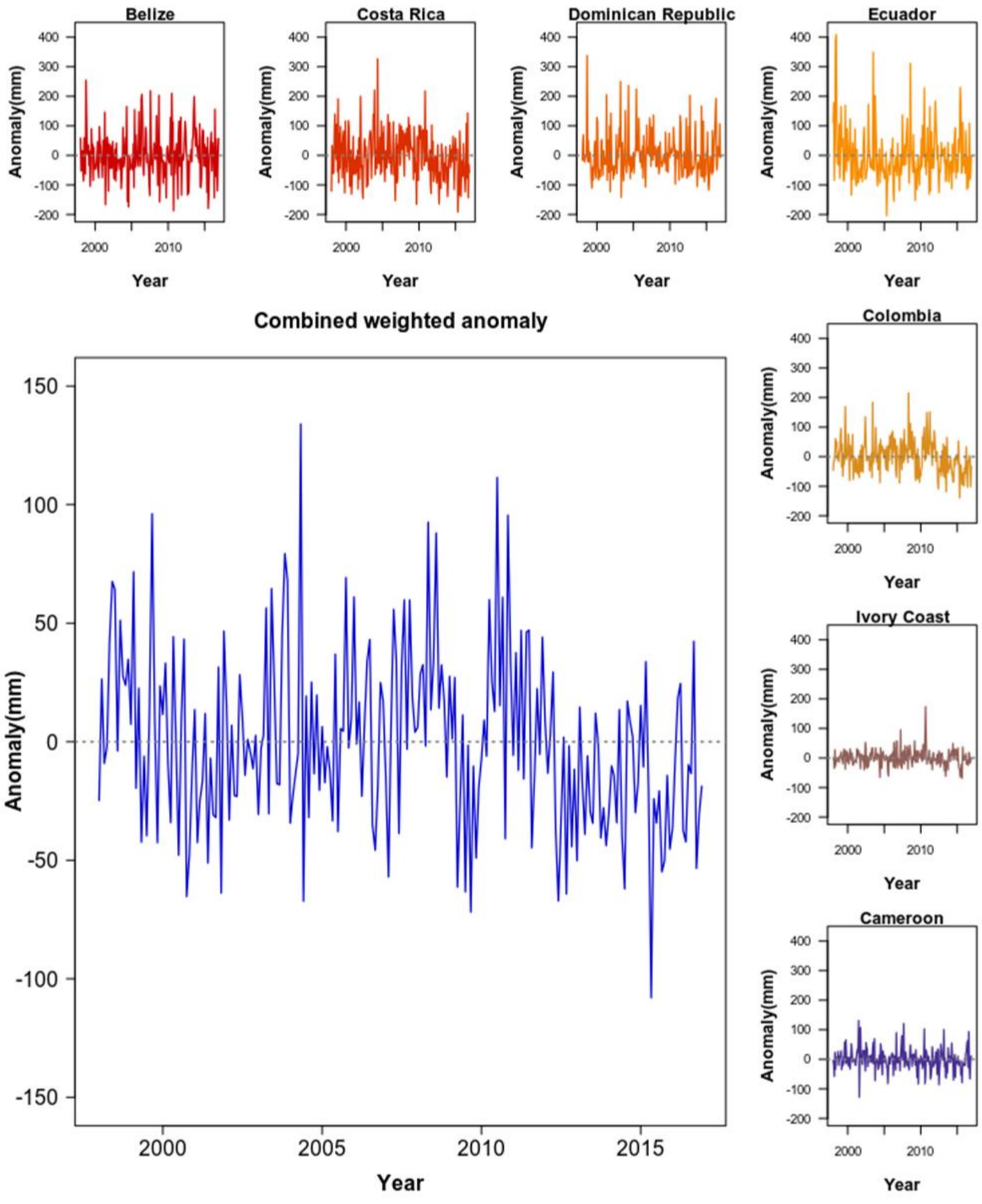
Ronayne, D. Which impulse response function? Warwick Economics Research papers No.971 Department of Economics, University of Warwick. (2011)

Varma, V. and Bebber, D.P. Climate change impacts on banana yields around the world. *Nature Climate Change* **9**, 752-757. (2019)

Supplementary material

We report the weather anomaly data for the UK; the same process was applied for other countries but reflecting different weights reflecting sources of supplies for specific countries.


Belize
Costa Rica
Dominican Republic
Ecuador
Colombia
Ivory Coast
Cameroon
Combined weighted anomaly
Anomaly(°C)
Year
2000
2005
2010
2015
2
1
0
-1
-2



Belize
Costa Rica
Dominican Republic
Ecuador
Colombia
Ivory Coast
Cameroon
Combined weighted anomaly
Anomaly(mm)
Year