Anomalous Weather and Supply Chains

Abstract: We explore the potential resilience of supply chains that are characterised by imperfect competition at successive stages in the face of anomalous weather shocks. Using a simple theoretical model of successive oligopoly, we show how the price spread at each stage of the supply chain adjusts to potentially ameliorate or accentuate the impact of anomalous weather shocks, contrasting with the perfectly competitive case in which price spreads remain constant. In this theoretical set-up, the direction and extent of the change in the price spreads varies depending on how the vertical chain is characterised. Focussing on banana supply chains in three importing countries (the UK, US and France) and employing bespoke temperature and precipitation data in exporting countries we find that price spreads typically fall in response to anomalous weather shocks though this varies by stage and by country, potentially reflecting differences in national supply chains. For example, in the UK, in response to typical (one standard error) temperature shocks, retail-wholesale spreads fall by as much as 7 per cent; in the US, by around 5 per cent; but in France, these spreads are constant. Overall, the retail stage plays a key role in all countries. We also explore whether the change in spreads varies during crises periods: focussing on the period between the commodity crises of 2007-2011, the behaviour of spreads in face of shocks does vary compared with the data period as a whole, most notably over shorter time horizons though, again, this varies across countries.

THIS VERSION: 25th August 2024

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With increasing concerns relating to the resilience of supply chains, recent research has focused on the impact and propagation of exogenous shocks originating in supply (natural disasters), demand (COVID-19) or policy arenas (trade policy) on the price and availability of intermediates in the final products used by consumers; Baldwin and Freeman (2022) provide an overview of emerging issues. There has also been a concurrent increase in attention on the effect of extreme weather on economic activity (see, for example, Dell *et al*., 2014, Kotz *et al*., 2022 and Bilal and Känzig, 2024). However, scant attention has been paid to the impact of extreme weather impacts on supply chains, one exception to this being Zappalà (2023) who highlights the vulnerability of agriculture and food supply chains relative to (more complex) manufacturing supply chains. In this paper, we address the wider policy issue of who bears the burden of such shocks via a theoretical and empirical investigation of the distributional impacts of anomalous weather patterns on the mark-ups (price spreads) at different stages in a specific agricultural-food supply chain. While related more broadly to the issue of pass-through, we focus on the main mechanism that underpins price transmission when supply chains (and in particular, specific stages within supply chains) are characterised by imperfect competition. This mechanism, which determines the extent of price transmission, depends on the elasticities of mark-ups (or price spreads) that - controlling for other factors that determine changes in margins - absorb or exacerbate the impact of exogenous shocks or policy changes. In contrast, perfectly competitive firms passively pass on such shocks leaving price spreads unaffected. This standard result forms a baseline against which we can identify the presence and impact of imperfectly competitive pricing in the supply chain.

While there have been some studies that address the issue of imperfect competition in the context of a single stage supply chain, our main theoretical contribution is to address how changes in mark-ups at multiple stages respond in the face of common exogenous shocks. This also differs from the extant literature on global supply chains where issues associated with competition are either largely ignored or constant mark-ups are assumed. Both approaches have the same effect and deny the possibility of the supply chain's role in ameliorating or exacerbating the impact of shocks. The key feature of supply chains we highlight here is the potential impact of competition to mediate these shocks. Specifically, imperfect competition at any stage of the supply chain will impact not only on the mark-up at that stage but potentially at all related stages in the supply chain. Under standard assumptions, we show that imperfect

competition between stages in the supply chain ameliorates the impact of shocks originating in production by reducing spreads. This moderating effect is at odds with the widely (and more populist) held view that imperfectly competitive firms exaggerate the impact of shocks to the detriment of consumers.

We investigate this issue empirically by employing two decades of monthly data in the banana supply chains of three major importing countries (the US, the UK and France). Differences in banana procurement in each country provide useful context and comparison. The focus on banana supply chains enables us to directly track the product from import through to retail as there is little transformation of the imported product as it passes through to the retail stage. Though the technology of the banana supply chain is simple, issues of competition are more complex involving market concentration at the retail stage, the role of (previously more dominant) multinational firms at the intermediate stage and the effects market power that is exerted between stages. In the absence of firm-level price data, we employ price data at retail (p^r), wholesale (p^w) and import (p^i) stages in each of the three countries to measure how indicative spreads between retail and wholesale prices ($s^r = p^r - p^w$), wholesale and import prices ($s^w = p^w - p^i$) and retail and import prices ($s = p^r - p^i$) respond over time to weather shocks in the primary exporting countries that supply each of the three importing countries.

Three points are worthy of note regarding our empirical approach. First, by observing prices at different stages we may distinguish the effects of weather shocks on the overall spread (s) and its components (s^r, s^w) allowing different interpretations of the vertical links between stages of the domestic supply chain in each country. While the explanation of such differences is not our *raison d'etre*, the analysis potentially reveals differences in the competitive nature of interactions between retailers and suppliers both within and across countries. Second, we construct separate measures of anomalous (departure from monthly norms of) temperature and precipitation derived from highly granular observations in the banana growing countries of each importer. Doing so is important since, for a number of historical reasons, each importer obtains its bananas from a largely distinct set of source countries around the globe. Being bespoke to the banana growing areas supplying each importer, the weather shock data are thus better able to capture shocks than generic measures of global weather anomalies. Third, we employ impulse response functions obtained by local projection (Jorda 2005, 2009) to trace out the effect of anomalous weather shocks on the price spreads in the supply chains in these three countries. The approach also provides a convenient way of addressing state dependence *i.e.* whether the responses in the mark-ups at each stage vary in different historical periods.

This issue is motivated by general concerns about the time-varying influence of external shocks on domestic prices but, more directly, to previous policy concerns relating to the links between competition in supply chains and commodity price volatility that has been highlighted by the OECD (OECD, 2012, 2022); a concern has been referred to most recently as 'greedflation'.

Our results show that, in general, supply chains spreads fall in response to these anomalous weather shocks in each of the three countries, though the impacts vary across countries. This is consistent with the theoretical framework we present. As expected, the elasticities of the price spreads also vary depending on the characterisation of the supply chain (*i.e*. competition at distinct stages or direct procurement by retailers) that characterises each country and the type of exogenous shock (*i.e.* high temperatures or excessive rainfall). In most cases, the aggregate retail-import spread (s) declines, with the (semi-)elasticity of the retail-import spread being as high as 7 per cent in response to typical (one standard error) anomalous temperature shocks in the case of the UK. However, there are differences between countries in terms of which spread adjusts to the exogenous shock and whether it is anomalous temperature or precipitation. For example, in the UK, both retail-wholesale and wholesale-import spreads respond to anomalous weather shocks (of temperature and precipitation) declining by 7 and 5 per cent respectively. In the US, the retail-wholesale spread declines by around 5 per cent with an anomalous temperature shock but temperature shocks do not appear to impact on price spreads in France. Focussing on the period associated with the food crises between 2007 and 2011, we find significantly larger differences in responses in this sub-period. However, most of the changes in the behaviour of the spreads occur in the UK and US but these changes relate to a more substantive reduction in the spreads for shorter periods (for example, the decline in the retail-wholesale spread in the UK declines by 20 per cent after 8 months compared with a fall of 3 per cent in the non-crisis period). Interestingly, we find little or no evidence of the 'over-shifting' of weather shocks (consistent with 'greedflation') in any country in this crisis period.

Overall, the results highlight three headline insights relating to the impact of exogenous shocks on supply chains. First, the changes in the margins we observe are consistent with imperfectly competitive behaviour in the face of exogenous weather shocks. Specifically, market structure ameliorates the impact of exogenous weather shocks as prices pass through the supply chain; spreads tending to decline in the face of exogenous weather shocks once other factors that impact on the spreads are controlled for. Second, the nature of this effect varies across countries, by different stages in the supply chains and is contingent on the source of the anomalous weather shock; this points to where the effects of imperfect competition matter in

the supply chain and countries' different exposures to anomalous weather shocks. Finally, there is evidence that the impacts on the spreads are state dependent; focussing on the period between the commodity crises between 2007 and 2011 when there was concern about the role of firms in the food sector impacting on price volatility, the response of spreads in this period typically differ from those of the data period taken as a whole. Findings suggest that imperfect competition at different stages of the supply chains acts to insulate consumers from price shocks rather than amplify their effect where, overall, it is likely the retail sector where most of the evidence of declines in spreads appears.

The paper is organised as follows. In Section 2, we summarise the research themes with which our analysis connects. In Section 3, we summarise issues of imperfect competition that relate to food supply chains and competition in banana supply chains more specifically. Note that if we assume perfect competition or imperfect competition with constant margins - a common feature of theoretical supply chain models (Antràs, 2015) - the possibility of shocks impacting on changes in spreads between different stages in the supply chain is denied. We extend this section by presenting a theoretical framework that focuses on the impact of shocks on margins at different stages in the supply chain when imperfect competition can exist at one or more stages in the supply chain. In Section 4, we set out our empirical strategy and present our bespoke measures of anomalous weather patterns that form the basis of the exogenous shocks that impacts on the supply chains in each of the three countries. In this section, we also highlight our approach to state dependent responses relating to potential changes in the elasticities of the margins in the 2007-2011 period. The main results are reported in Section 5 along with some checks to gauge the robustness of the key findings. Section 6 presents the main conclusions arising from the analysis.

2. Related Literature

This paper connects three distinct strands on research relating to the effects of competition on pass-through in commodity chains, market power and inflation and the recent literature on the economic consequences of extreme weather. We do not refer to the recent literature on global supply chains where issues of competition are largely ignored nor to the literature on the propagation of shocks since these do not focus on changes in margins within supply chains (for example, Carvelho *et al*., 2020)). One exception to note is Acemoglu and Tahbaz-Saleh (forthcoming) who have recognised this issue but deal with competition in the supply chain as

a bilateral bargaining issue between firms at different stages and with a two-part tariff. Doing so ensures that supply chain distortions associated with double marginalisation do not arise.

Price Transmission in Imperfectly Competitive Markets

Our focus on measuring the elasticity of margins in supply chains ties to the extant literature on price transmission. The theoretical aspects of price transmission in the presence of imperfect competition have been consolidated by Weyl and Fabinger (2013). When market power matters, the main mechanisms giving rise to under- or over-shifting of cost changes relates to the interaction between the extent of market power and the curvature of the demand function. But in determining the distributional impacts of exogenous shocks, the important issue relates to the elasticities of firms' margins. While most of the theoretical and empirical work on price transmission relates to firms competing in a single stage, we focus on multiple stages in supply chains where the competition issues can arise at all stages. In the case we present below, in face of an exogenous shock, the change in the margin at any stage in the supply chain depends, not only on the competition at a given stage but also competition at the related stage in the supply chain. In this context, assuming a single stage approach will likely miss an important feature of competition within and across stages in the supply chain and miss the potential distributional impacts of margin changes for firms competing at different stages.

Since margins can potentially change in face of exogenous shocks or policy changes, the main interest is the distributional effects that are a consequence of these shocks. Assuming constant margins, as often assumed in the international economics literature or with perfect competition, these distributional effects between stages in the supply chain are set aside. As noted by Gauge and Göuel (2022*),* issues relating to distributional effects within food supply chains is an important omission from extant research. More generally, there has been only limited empirical work that relates to this issue.[1] In their review of how mark-ups respond to changes in trade policy, De Loecker *et al.* (2016) show that margin changes depend both on tariffs that impact on output prices but also on intermediate prices; their results show that firms' margins can increase despite the procompetitive effect due to trade liberalisation owing to the relatively greater decline in intermediate prices. Based on a similar framework but accounting for input: output linkages, Curzi *et al.'s* (2021) results relating to the French food industry also highlight the importance for accounting for competition at the intermediate stage. However, while these

[1] More generally, the empirical literature on price transmission that has focussed on food and agricultural markets has been surveyed by Lloyd (2017).

papers acknowledge the importance of intermediates, they do not directly observe intermediate prices that relate specifically to costs for the retail stage. More recently, Melo *et al*. (2021) note that taking a 'whole' chain perspective occludes changes within a supply chain. Focussing on the liquefied gas market in Brazil, their results show that -in response to tax changes- retail price changes were consistent with 'over-shifting' while distributors' margins were 'under-shifted', consistent with differences in the changes in margins at each stage of the supply chain. Taken together, these recent papers highlight the significance of accounting for different stages in supply chains to account for the distributional impact of exogenous shocks.

State Dependence

We also address whether the response of margins at each stage to exogenous shocks is state dependent. While there has been a long-standing literature on the time-varying aspects of price-cost margins, there has been recent concerns that, in the face of shocks, firms' margins have been changing (more specifically, increasing) to take advantage of sector-specific and economy wide shocks. A summary of recent concerns linking competition to inflation can be found in OECD (2022), Haskell (2023), among others and has been referred to as 'greedflation'.[2] In the analysis below, we address whether the changes in the margins between stages in the supply chain varied in the context of previous commodity price crises of 2007 and 2011. We note the concerns linking competition in food supply chains to commodity price spikes as highlighted by the OECD (2012, 2013) and we investigate if the anomalous weather shocks had a differential impact during and following these crises.

Climate Change

This paper also relates to the recent strand of research on the impact of anomalous weather on economic outcomes, particularly the links between agriculture and extreme weather arising from climate change. Dell *et al.* (2012, 2014) provided an early overview of the issues involved. Much of this research has addressed the links between weather variations and (locally impacted) agricultural output; see, for example, Deschènes and Greenstone (2007), Mendelsohn and Massetti (2017) and Ortiz-Bobea (2021). In contrast, Jones and Olken (2014) focus on weather variations and exports. More recently, there has been work on extreme weather on world commodity prices (see Ubilava (2017) and Guittarez (2018)). Cashin *et al*. (2017) tie changes in commodity prices due to anomalous weather patterns to inflation and

[2] An earlier analysis by Chirinko and Fazzari (2000) also addressed the links between inflation and market power.

economic activity across developed and emerging economies. De Winne and Peersman (2021) examine the link between commodity market shocks due to anomalous weather on inflation across Eurozone countries. Faccia *et al*. (2021) and Kotz *et al*. (2022) also focus on price stability issues. Although this stream of research on the economic impact of weather variations has expanded, there has been a significant gap in considering supply chain impacts. Estimating the impact of global commodity prices due to weather anomalies, Peersman (2022) reports that unit profits decline to absorb these shocks; a one per cent increase in international commodity prices results in a fall in unit profits of 0.05 per cent but there is no specific delineation of food supply chains. A notable recent exception is Zappalà (2023); using input: output tables, he shows that agricultural supply chains are most vulnerable to localised weather shocks. Our results, which provide evidence of the distributional impact on firms' margins within a single food supply chain, offers an illustration of this more widespread finding.

3. Competition in Supply Chains

Market Structure

Although the fixed proportions technology linking stages in the banana supply chains considered here are significantly different from more complex supply chains in the manufacturing sector (Baldwin and Freeman, *op. cit*.), market structure issues in the banana supply chains are nevertheless complex. This reflects two main aspects. First, although there are some common features, market structure that characterises the procurement and distribution of bananas differs across countries with respect to varying degrees of concentration at the retail level, differences in the role of intermediaries including multinational firms and the extent of vertical control exercised by retail chains. Second, there have been notable changes in the structure of banana supply chains in recent years at both the intermediate and retail stages. Most obvious in this regard has been the changing role of multinational firms who traditionally have dominated banana procurement and distribution (and, in some cases, owned plantations in exporting countries) but their role in banana trade has diminished significantly in recent years. The main multinationals (Chiquita, Dole and del Monte) were typically vertically integrated controlling production, distribution and marketing and accounted for around 65 per cent of global banana exports in the 1980s; by 2013, their market share had dropped to 37 per

cent (FAO, 2014).[3] Although these multinationals are diversified across different fruit supply chains, the largest share of revenue relates to bananas (EU Commission, 2014).

As the role of multinationals has diminished, other competition issues have emerged. Most obvious has been the growing concentration of retail chains: in the UK, the five leading retail food chains account for around 80 per cent of food sales; in France, the five-firm concentration at the retail level is around 60 per cent and there has been increasing concern about concentration in the US food retailing sector. The reduced dominance of multinational intermediaries coupled with high levels of concentration in the retail sector impacts on competition in two ways. First, it increases the negotiating power of these retail chains vis-à-vis upstream suppliers which has given rise to increasing concerns about unfair trading practices (BASIC, 2015) and a recognition that retail chains capture a significant proportion of value in the banana chain. BASIC (2015) reports that the retail stage accounts for around 40 per cent of total value across several EU countries. Second, retail chains have been increasing vertical control of banana supply chains as many now directly procure from exporting countries, circumventing the role of intermediaries. This has been particularly notable in the UK where Tesco (the largest retail food chain) recently became the second largest importer of bananas after the multinational Fyffes, despite having commenced direct procurement only in 2010. Other retail chains have followed suit, making direct procurement an important recent development in the UK banana supply chain[4]. In addition, as the role of multinational firms has diminished, there has been the entry of new intermediaries (e.g. Winfresh in the UK, Compagnie Fruitière in EU Member States) though the significance of their role has varied across countries. Though multinationals still play a more dominant role in the US market, similar changes relating to direct procurement have also occurred. Taken together, there have been considerable changes in concentration at retail and intermediate stages and vertical coordination which, in turn, will potentially impact on how margins will change following exogenous shocks.[5]

[3] Reflecting the changing role of multinational firms, there has been consolidation as witnessed by the merger between Chiquita and Fyffes to be a significant player in global banana trade in part because of the pressure to promote synergies in supplying different national markets (EU Commission, 2014).
[4] Despite the high levels of concentration in the UK food retail sector, banana prices have often been lower in the UK compared with other EU countries due to a price war between retail chains (BASIC, 2015).
[5] Concerns over competition in the world banana sector has attracted attention for some time. See, for example, Deodhar and Sheldon (1995) and Anania and Scoppola (2014); McCorriston and Sheldon (1996) addressed issues relating to price transmission in the UK banana market relating to the trade reforms that characterised the EU banana sector in the late 1980s.

In this context, detailed pricing information relating to firms at different stages in the supply chain is opaque and not disclosed by firms.[6] In the absence of firm level data, we employ unit value data collected at retail, wholesale and import stages of the supply chain in three major importing countries sourced from the UN FAO. This data is monthly and indicative of market conditions. Specifically, while arrangements between retailers and suppliers may reflect contracts, prices can nevertheless be flexible reflecting market conditions (UNCTAD, 2016).[7] Similarly, in the overview of unfair trading practices in the EU banana sector, it has been noted that 'banana prices are traditionally negotiated between suppliers and customers on a short-term basis, following a weekly rhythm' (BASIC, 2015). Though contract prices are not available, it is reasonable to assume that the unit value data we employ will reflect different competitive practices and varying conditions under which bananas are traded. In a review of unfair trading practices in the EU banana sector, it has been noted that 'prices and contracts are mostly negotiated on a short-term basis at national level, but even the biggest traders point out the imbalance of their negotiating power with retailers' (BASIC, 2015, p.6). More specifically, the EU Commission noted that 'prices may be based on different price formulas for different durations and may encompass different levels of services to the customers. This is all the more so with wholesalers, which also source bananas on a weekly basis and on spot markets' (EU Commission, p. 70, 2014). Note that, in this context, the exercise of buyer power is often related to leonine contract arrangements (which allows buyers to cancel contracts when margins are 'insufficient') or changes in the quantities purchased which will be reflected in unit values (which is the data we utilise) rather than price quotations. As such, we make the reasonable assumption that the prices we observe at each stage and the changes due to exogenous shocks will be reflective of changes in margins at different stages in the supply chain.[8]

Taken together, we focus on two characterisations of the supply chains in each of the countries we cover. One is where we have a supply chain with intermediate firms where the spreads are retail prices minus wholesale prices for the downstream stage and wholesale minus import prices for the upstream stage. We detail in the theoretical framework below how competition

[6] The EU Commission's investigation into the EU banana market noted the 'significant complexity and lack of transparency' in this market (EU Commission, 2014).
[7] An alternative interpretation of the links between contracts and prices is that the contracts are based on a formula approach and are updated to reflect market conditions (EU Commission, 2014). Note that in the econometric framework below, we allow spreads to respond to shocks with a lag which will reflect this formula-based approach.
[8] The EU Commission has also noted the existence of price wars for bananas between retail chains. It notes, '…price wars at the retail level [have] as significant impact on UK retailers' procurement strategies, with the result that there is an intense focus on price when purchasing bananas at the retail level'. (EU Commission, p. 6, 2014).

at each stage can impact on the changes in the spreads at alternative stages of the supply chain. The alternative characterisation of competition in the supply chain is where retail firms are characterised by vertical coordination where the spread is between retail and import prices only. Though, in principle, this spread for retail firms may be larger than the spread between retail and wholesale prices, as we show below, it also can influence the adjustment of the spread in response to exogenous shocks. By covering both characterisations of the spreads in the supply chains and the impact of shocks, we are agnostic as to the 'correct' characterisation as both are informative in different ways on how firms in the supply chain respond to shocks and the distributional impact between firms at different stages.[9, 10] In the theoretical framework below, we allow for these two characterisations and how spreads will change in each case[11].

4. Theoretical Framework

The focus of the framework we adopt highlights how spreads will change following exogenous shocks. Specifically, we aim to identify the main determinants of the relative change in spreads contingent on two characterisations of the supply chain: one where there is vertical control by retail chains (*i.e.* the spread between retail and import omitting the role of intermediaries) and the other where intermediaries have a role and the focus is on changes in the spreads between the retail and wholesale stage and the wholesale and import stage. These characterisations of the supply chain will form the basis for the specification and interpretation of the results from the econometric model. Note that since the import price we observe relates to the export price plus carriage, insurance, freight and trade duties which we assume to be a constant proportion, the import price can effectively be interpreted as relating to export supply and thus links directly to the issue of unfair trading practices in banana supply chains noted above.

Changes in Spreads with Wholesale Sector

We outline a model of successive oligopoly where there is potentially imperfect competition at each stage of the supply chain and where the intensity of competition is allowed to differ across

[9] In the EU commission's decision on the Chiquita/Fyffes merger, it characterised the banana supply chain as multinational importers supplying both wholesalers and retail chains and wholesalers supplying larger retail chains and the 'non modern' retail channel (EU Commission, 2014).

[10] In 2013, the EU Commission reported market shares for bananas as follows: Fyffes between 40-50 per cent; Chiquita 5-10 per cent; Tesco, 20-25 per cent; with remaining suppliers (e.g. Dole, Winfresh, etc) accounting for between 5-10 per cent (EU Commission, 2014).

[11] In principle, this is an issue endemic to all research involving retail food chains and the agricultural-food supply chains more generally where contracts and various alternative vertical arrangements characterise links in the supply chain and where firm-level prices and details of contracts etc are non-existent.

stages.[12] For simplicity, we assume quantity-setting strategies at each stage of the supply chain. The technology linking stages is further assumed to be Leontief (*i.e.* fixed proportions), a reasonable assumption given that the supply chains relate to the procurement and distribution of bananas. Vertical aspects of competition that impact on prices of upstream firms are embedded in the framework via the derivation of the inverse derived demand function facing intermediaries; although downstream firms take the wholesale price as given, the price that firms in the intermediate stage can charge will be determined by the extent of competition at the retail stage via the slope of the inverse derived demand function which is contingent on competition between retailers. Competition at the intermediate stage also impacts on the wholesale price. We also endogenise the import price as importers decide how much to import and where the inverse derived demand function facing importers relates to demand from the wholesale stage. Note that we allow for the possibility that import prices capture a terms of trade effect. Although constant costs are commonly assumed in deriving pass-through effects, as Ritz (2023) notes, rising costs can be an important determinant of the impact of exogenous shocks and alter the ranking on the impact of competition on pass-through.

There are three stages in the supply chain: retail, wholesale and import. Import prices are subject to the anomalous weather shock which reduces quantities exported thus raising the import price. Since we are assuming Leontief technology, the change in quantities at this stage apply at all three stages. We start the framework backwards, by defining profit maximisation at the retail stage and then determine the perceived inverse derived demand functions that apply at the previous upstream stage. Since $Q^r = Q^w = Q^m$, we use Q throughout where the superscripts relate to retail (r), wholesale (w) and import (m) respectively.

The intensity of competition at each stage is given by a conjectural variation parameter which is widely used to account for the extent of competition.[13] Specifically, from firms' first-order conditions, we will have:

$$q_i p'(Q) = q_i p'(Q)\left[\frac{\delta q_i}{\delta q_i} + \frac{\delta Q_{-i}}{\delta q_i}\right]$$
$$= q_i p'(Q)\theta_i$$

which, when aggregated over n-symmetric firms, gives:

[12] Recent papers that have addressed pass-through in vertically-related markets where competition at each stage matter include Adachi and Ebina (2014) and Adachi (2020).
[13] See, for example, Weyl and Fabinger (2013) for the use of the conjectural variation parameter to account for the intensity of competition when addressing pass-through issues.

$$Qp'(Q)\theta$$

where θ=θ_i/n. If the stage is competitive, then $\theta = 0$; if Cournot, $\theta = 1/n$; if monopoly, $\theta = 1$.

Retail Stage

Profit for a representative retail firm is given by:

$$\pi_i^r = (p^r(Q^r) - p^w)q_i^r \quad (1)$$

with the first-order condition given by:

$$\frac{\delta\pi_i^r}{\delta q_i^r} = p^r(Q^r) - p^w + p_r'(Q^r)q_i^r\theta_i^r = 0 \quad (2)$$

After aggregating, we have:

$$p^r(Q^r) - p^w + p^{r\prime}(Q^r)(Q^r)Q^r\ \theta^r{=}0 \quad (3)$$

Wholesale Stage

We follow the same procedure as above but with some amendments. As before, we capture competition at the wholesale stage by the competitiveness parameter which is now given by:

$$\theta^w = \frac{\theta_i^w}{n^w} \quad (4)$$

We assume that wholesale firms take the import price, p^m, as given.

The inverse demand function facing wholesale firms is given from (3) above; this is the *inverse derived demand* function:

$$p^w = p^r(Q^r) + p^{r\prime}(Q^r)Q^r\ \theta^r \quad (5)$$

Note that because of the inclusion of θ^r, the derived demand facing wholesale firms depends on the extent of competition at the retail stage and will determine the slope of the derived demand function. As competition gets less intense, the inverse derived demand function becomes steeper since $p^{r\prime}(Q^r) < 0$.

Profits for a representative wholesale firm is given by:

$$\pi_i^w = (p^w(Q^r) - p^m)q_i^w \quad (6)$$

Maximising profits and aggregating gives:

$$p^w(Q^r) - p^m + p^{w\prime}(Q^r)Q^r\theta^w \tag{7}$$

Import Stage

For the importing firm, the derived demand relates to the inverse derived demand function from the wholesale sector. This is given by re-arranging (7) as:

$$p^m = p^w(Q^r) + p^{w\prime}(Q^r)Q^r\theta^w \tag{8}$$

where the slope of the inverse derived demand function is conditional on the intensity of competition at the wholesale stage (and, by extension, competition at the retail stage).

Profits for a representative importing firm are given by:

$$\pi_i^m = (Q^w) - c^m(Q^w) - \tau)q_i^m \tag{9}$$

Note that, for the case of importing firms, the cost of imports (c^m) is also related to the quantities exported (Q^w); this captures potential terms of trade effects associated with the large country assumption. τ is the anomalous weather shock that impacts on import prices.

Maximising profits and aggregating gives:

$$p^m(Q^w) - c^m(Q^w) + p^{m\prime}(Q^w)Q^w\theta^m - c^{m\prime}(Q^w)Q^w\theta^e \tag{10}$$

where θ^m relates to the sales of competing firms at the import stage and θ^e is the aggregate conjecture that relates to procurement decisions vis-à-vis export suppliers. The former more commonly acts as a summary measure of seller power while the latter relates to buyer power and has the same interpretation as the conjectures relating to sales: as $\theta^e \to 1\ (\to 0)$, we have monopsony (perfect competition) in procurement.

Changes in Margins between Retail, Wholesale and Import Stages

To derive changes in the margins at each stage, we need to derive the relative changes in pass-through at each stage where pass-through is defined (generically) as:

$$\frac{dp^k}{d\tau} = p'\ \frac{dQ}{d\tau}, \qquad \text{for } k = r, w \text{ and } m.$$

Note that the source of the anomalous weather shock (τ) determines the change in quantities that apply equally at all stages in the supply chain (hence $dQ \equiv dQ^{r,w,m}$). Implicitly differentiating (10), we have:

$$\frac{1}{p^{m\prime}[1+\theta^w(1-\varepsilon^w)-\frac{c^{m\prime}}{p^{m\prime}}(1+\theta^e)-\frac{c^{m\prime\prime}}{p^{m\prime}}(Q)Q\theta^e]} \tag{11}$$

where $\varepsilon^w \equiv -Q\frac{p^{w\prime\prime}(Q)\theta^w}{p^{w\prime}(Q)}.\frac{p^{w\prime\prime}(Q)\theta^w}{p^{w\prime}(Q)}$ relates to the (perceived) super-elasticity of the derived demand function (i.e. the change in the slope of the demand function) and which is the main feature relating to the demand function which may result in over-shifting of exogenous shocks or policy changes. Note that (11) deviates from the standard assumption of constant marginal costs and where $\frac{c^{m\prime\prime}}{p^{m\prime\prime}}(Q)Q\theta^e$ relates to the perceived super-elasticity of the (perceived) import supply function. To highlight the main insights, assume linear demand and cost functions *i.e.* $p^{m\prime\prime}$and $c^{m\prime\prime}$ equal zero. We can then derive the change in spreads at each stage.

Consider first of all, the characterisation of the supply chain where we have retailers, intermediaries and importers. The change in the wholesale-import spread (S^w) is given by:

$$\frac{dS^w}{d\tau} = \frac{(p^{w\prime}-p^{m\prime})}{p^{m\prime}}\left[\frac{1}{[1+\theta^m-\frac{c^{m\prime}}{p^{m\prime}}(1+\theta^e)]}\right] \tag{12}$$

and the change in the retail-wholesale margin (S^r) is given by:

$$\frac{dS^r}{d\tau} = \frac{(p^{r\prime}-p^{w\prime})}{p^{w\prime}}\left[\frac{1}{[1+\theta^m-\frac{c^{m\prime}}{p^{m\prime}}(1+\theta^e)]}\right] \tag{13}$$

Alternatively, and as discussed above, there has been a tendency for retail chains to procure directly thus circumventing intermediaries and the wholesale stage.[14] In this case, the change in the spread will relate to the retail and import prices (S) and is given by:

$$\frac{dS}{d\tau} = \frac{(p^{r\prime}-p^{m\prime})}{p^{m\prime}}\left[\frac{1}{[1+\theta^m-\frac{c^{m\prime}}{p^{m\prime}}(1+\theta^e)]}\right] \tag{14}$$

Insights

There are several insights that arise from equations (12)-(14). First, note that with the Leontief technology and the nature of the links in the supply chain, [.] is common to changes in the spreads between all stages. Second, competition throughout the supply chain influences the change in the margin at each stage. At the import stage, the change in quantities resulting from the weather shock is directly determined by θ^m and θ^e. Assuming constant import costs ($c^{m\prime} = 0$), then as $\theta^m \longrightarrow 1$, the impact of the exogenous shock on spreads will therefore

[14] Note that when there is direct procurement by retailers, the size of the retail margin will now increase but since the issue of double marginalisation is ameliorated, the change of the margin will now be different since it will not depend on changes in the margin at the intermediate stage.

decline. But also note from equations (5) and (8) that the slopes of the derived demand functions are determined by the extent of competition at the subsequent stage and therefore indirectly impact on the changes in the spread at each stage. So, for example, as market power at the retail stage increases, this serves to increase the slope of the perceived inverse derived demand function at the wholesale and import stages; this would have the effect of increasing the (negative) response of the spread at each stage in face of anomalous weather shocks. Taken together, competition throughout (or at any stage of) the supply chain will determine the changes in the spreads in response to exogenous shocks.

The term $\frac{c^{m\prime}}{p^{m\prime}}$ relates to the slope of the import supply function and is equivalent to the terms of trade effect in the trade literature. This term captures the effect that, as the intermediate price rises in the domestic market, import costs fall. Note that -and as with Ritz (*ibid.*)- if θ^m is sufficiently low or if θ^e sufficiently high, then the impact of the exogenous weather shock could be to increase spreads.

Contingent on the factors highlighted by the term [.] and assuming [.]<1, the changes in the spread between each stage will be given by the slopes of the inverse (derived) demand function. Since with imperfect competition the slopes of the perceived inverse derived demand functions are steeper at the subsequent upstream stage, this means that the spread should fall because of the weather shock. As the intensity of competition increases at any stage, the inverse derived demand functions become steeper; in the linear case, this would imply a greater change in the margins due to exogenous shocks. However, in the absence of imperfect competition, the slopes of the inverse (derived) demand functions would be identical resulting in the change in the spread being zero. This represents the perfectly competitive baseline.

Although our empirical strategy does not explicitly identify the role of competition, the framework outlined above gives some insights into the interpretation of the results. In the face of exogenous weather shocks, the change in the spreads -under reasonable conditions- will be negative if imperfect competition acts to ameliorate the impact of shocks on consumers. If the changes in the spreads are not significantly different from zero, this would imply that imperfect competition -at any stage- does not influence the effect of the exogenous shock (either that imperfect competition is not an issue or that less competition at one stage is offset by more

competitive behaviour at a related stage[15]). Lastly, if the terms of trade effect are sufficiently strong and outweighs the influence of other factors, spreads could potentially rise in face of exogenous shocks.[16]

4. Empirical Approach

Econometric Specification

To gauge the effects of the weather shocks on the price margins at each stage of the supply chains, we estimate the impulse response function using local projection methods (Jordà, 2005, 2009; Jordà and Taylor 2024). Each impulse response function measures the dynamic effect of an exogenous weather shock on the price spreads at each stage in the food chain, controlling for other factors that influence retail and wholesale prices. In a correctly specified model, impulse responses generated from local projection are asymptotically equivalent to those generated by vector autoregression (Plagborg-Moller and Wolf, 2021) yet offer more flexibility and tractability since by estimating the impulse response coefficients directly, rather than deriving them through inversion of the VAR, they circumvent the dynamic restrictions embedded in a VAR, features that account for the emerging popularity of the method in the applied literature (Brugnolini, 2018).

Local projection proceeds by estimating a set of h regressions in which dependent variable is successively updated over a H period horizon ($h = 0,1,2, \ldots H$) for a fixed set of the explanatory variables. Given that each regression is estimated separately, the impulse response function is formed from the coefficient of each explanatory variable in these $H + 1$ regressions. Our focus is on the effect of exogenous weather shocks on price spreads between stages of the banana supply chain, so it is the coefficients on temperature and precipitation (denoted by $\vartheta_{1,h}$ and $\vartheta_{2,h}$ respectively in the specifications below) that form the impulse responses of interest.

Consider first the base specification for the local projection model where we have a supply chain comprising retailers, intermediaries and importers. The cumulative change in the log of retail-wholesale price spread (or 'long difference') between period $t-1$ and $t+h$ is given by:

[15] For example, less competition at the retail stage implies a steeper slope of the inverse derived demand function facing the wholesale stage; but a competitive wholesale stage results in the perceived marginal revenue function of the wholesale stage lying closer to the inverse derived demand function.
[16] In principle, the terms of trade effect that increases margins could cancel the impact of competition in reducing margins this giving a misleading impression that the intensity of competition throughout the supply chain did not matter.

$$s^r_{t+h} - s^r_{t-1} = \alpha^r_{1,h} + \vartheta^r_{1,h} Temp_t + \vartheta^r_{2,h} Temp_t + \sum_{j=1}^{J} \beta^r_{1,j,h}\, Temp_{t-j} + \sum_{j=1}^{J} \beta^r_{2,j,h}\, Precip_{t-j} + \sum_{j=1}^{J} \beta^r_{3,j,h}\, \Delta s^r_{t-j} + \sum_{j=0}^{J} \beta^r_{4,j,h}\, s^w_{t-j} + \sum_{j=0}^{J} \beta^r_{5,j,h}\, c_{t-j} + \sum_{j=0}^{J} \beta^r_{6,j,h}\, er_{t-j} + \sum_{j=0}^{J} \beta^r_{7,j,h} ur_{t-j} + \beta^r_8 T_t + \varepsilon^r_{t+h} \quad (15)$$

with the corresponding specification for the wholesale-import price spread given by:

$$s^w_{t+h} - s^w_{t-1} = \alpha^w_{1,h} + \vartheta^w_{1,h} Temp_t + \vartheta^w_{2,h} Temp_t + \sum_{j=1}^{J} \beta^w_{1,j,h}\, Temp_{t-j} + \sum_{j=1}^{J} \beta^w_{2,j,h}\, Precip_{t-j} + \sum_{j=1}^{J} \beta^w_{3,j,h}\, \Delta s^r_{t-j} + \sum_{j=0}^{J} \beta^w_{4,j,h}\, s^w_{t-j} + \sum_{j=0}^{J} \beta^w_{5,j,h}\, c_{t-j} + \sum_{j=0}^{J} \beta^w_{6,j,h}\, er_{t-j} + \sum_{j=0}^{J} \beta^w_{7,j,h} ur_{t-j} + \beta^w_8 T_t + \varepsilon^w_{t+h} \quad (16)$$

Finally, for the case where we have direct procurement between retailers and export countries, the change in the retail-import margin is given by:

$$s_{t+h} - s_{t-1} = \alpha_{1,h} + \vartheta_{1,h} Temp_t + \vartheta_{2,h} Prec_t + \sum_{j=1}^{J} \beta_{1,j,h}\, Temp_{t-j} + \sum_{j=1}^{J} \beta_{2,j,h}\, Precip_{t-j} + \sum_{j=1}^{J} \beta_{3,j,h}\, \Delta s_{t-j} + \sum_{j=0}^{J} \beta_{4,j,h}\, c_{t-j} + \sum_{j=0}^{J} \beta_{5,j,h}\, er_{t-j} + \sum_{j=0}^{J} \beta_{6,j,h} ur_{t-j} + \beta_7 T_t + \varepsilon_{t+h} \quad (17)$$

where, $h = 0,1\ \ldots, H$.

All explanatory variables enter the specifications contemporaneously and with a common lag J based on the AIC. As Montiel Olea and Plaborg-Møller (2021) show, the lag-augmented local

projection framework readily facilitates inference with standard critical values and circumvents the need to correct standard errors for serial correlation in the regression residuals. For each case, the anomalous weather shocks relate to a one standard deviation in the variable of interest.

As mentioned above, the coefficients $\vartheta_{1,h}$ and $\vartheta_{2,h}$ in (15)-(17) for $h = 0,1 \ldots, H$ represents the impulse response functions following weather shocks. With the cumulative specification and spreads expressed in logs the impulse response coefficients measure the growth rate in spreads between $t-1$ and $t+h$ as a result of the shock in period t. Jordà and Taylor (2024) advocate the cumulative specification owing to its superior small sample performance.

Also included in the models are controls to account for factors driving price spread in the supply chain other than weather shocks. Note that for each stage in the supply chain, we include other food chain costs c_t but vary the measure employed with the aim of reflecting the different activities of each stage. Specifically, for the price spread between retail and wholesale, manufacturing costs are used; for the price spread between wholesalers and importer, oil prices are used to proxy for the costs of distribution between stages. In the case of the retail-import margin, we use both manufacturing costs and oil prices as the additional cost controls. To reflect global events that may impinge on the supply to each country, we use the US dollar exchange rate (er_t). To capture demand side changes, the monthly unemployment rate, ur_t is also included.

Following the theory set out in Section 3 showing that competition at each stage impacts on the adjustment of the margins at the other vertical stage, we also include the related spread as a control. So, for the retail-wholesale (wholesale-import) price spread, we include the wholesale-import (retail-wholesale) spreads respectively. Finally, to capture changes in the spread over time due to competition and/or technological change, we include a time trend (T_t).

State Dependence

As noted in Section 2, there has been concern that imperfect competition in supply chains has influenced the impact of shocks during crisis periods (OECD, *op. cit.*). In an extension to the above specifications, we also account for state dependent responses to address whether the changes in the margins in response to exogenous shocks differ in periods of crises in commodity/food retailing markets.[17] State dependence is straightforward to execute in the local

[17] To clarify, our focus is on whether the response in the spreads changed during this crisis period where the cause of the food crisis related to a number of factors, not necessarily an increase in the

projection framework and we follow Ramey and Zuchary (2018) in amending the specifications as detailed in (15)-(17) by including indicator variables to allow the coefficients estimated during the commodity crisis, 2007 to 2011, (denoted A below) to differ from those estimated over the rest of the sample (denoted B).

Collecting the controls together in $\boldsymbol{X}_t$ and defining an indicator variable $I_t = 1$ during 2007(1) to 2011(12); zero otherwise we estimate the state dependent version of (15) –(17):

$$s^r_{t+h} - s^r_{t-1} = I_t\left[\alpha^r_{A,1,h} + \vartheta^r_{A,1,h}Temp_t + \vartheta^r_{A,2,h}Temp_t + \boldsymbol{\beta}_A(L)\boldsymbol{X}_t\right] + (1 - I_t)\left[\alpha^r_{B,1,h} + \vartheta^r_{B,1,h}Temp_t + \vartheta^r_{B,2,h}Temp_t + \boldsymbol{\beta}_B(L)\boldsymbol{X}_t\right] + \varepsilon^r_{t+h} \quad (18)$$

and the specification for the wholesale-import price spread is given by:

$$s^w_{t+h} - s^w_{t-1} = I_t\left[\alpha^w_{A,1,h} + \vartheta^w_{A,1,h}Temp_t + \vartheta^w_{A,2,h}Temp_t + \boldsymbol{\beta}_A(L)\boldsymbol{X}_t\right] + (1 - I_t)\left[\alpha^w_{B,1,h} + \vartheta^w_{B,1,h}Temp_t + \vartheta^w_{B,2,h}Temp_t + \boldsymbol{\beta}_B(L)\boldsymbol{X}_t\right] + \varepsilon^w_{t+h} \quad (19)$$

Finally, we estimate a set of regressions for the retail-import margin:

$$s_{t+h} - s_{t-1} = I_t\left[\alpha_{A,1,h} + \vartheta_{A,1,h}Temp_t + \vartheta_{A,2,h}Temp_t + \boldsymbol{\beta}_A(L)\boldsymbol{X}_t\right] + (1 - I_t)\left[\alpha_{B,1,h} + \vartheta_{B,1,h}Temp_t + \vartheta_{B,2,h}Temp_t + \boldsymbol{\beta}_B(L)\boldsymbol{X}_t\right] + \varepsilon_{t+h} \quad (20)$$

where, $h = 0,1\ \ldots, H$.

Data

Our primary objective is to estimate changes in the spreads at each stage of the supply chain to anomalous shocks in temperature and precipitation in the growing areas of the countries from which bananas are sourced in the three importing counties we consider. Retail price data is the unit value of prices at the retail stage. Although these data do not delineate different retail

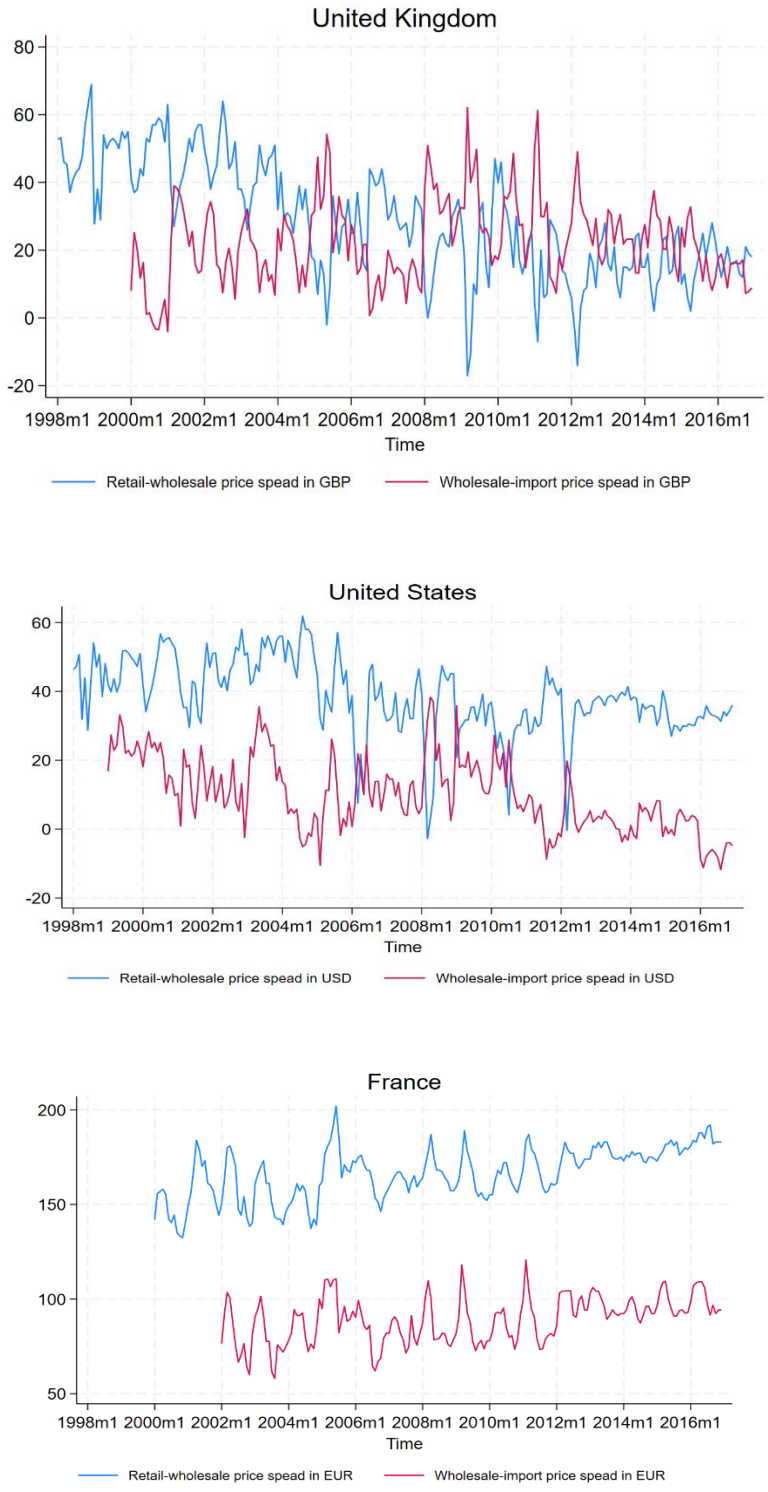
variability of anomalous weather patterns. Indeed, the standard deviations of the temperature and precipitation anomalies were relatively unchanged during this crisis period,

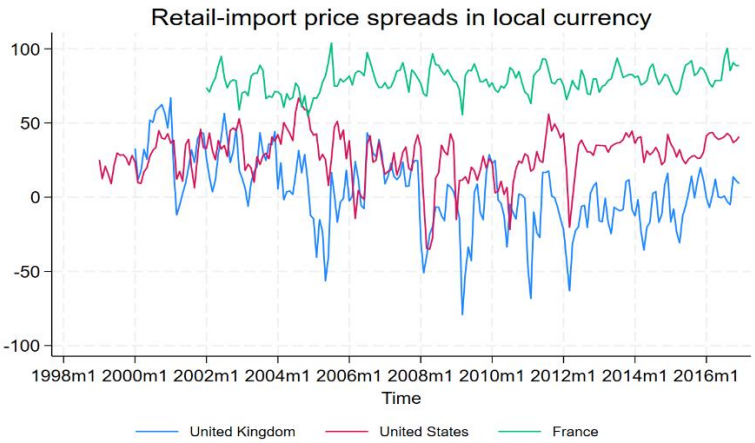
chains, they are indicative of the prices available in national retail outlets in each country. Our import price data is also specific to each of the countries we cover; variations in this price relate essentially to export prices since the differences between country-specific import prices and export prices reflect only carriage, insurance and freight and trade duties, which we assume to be constant in logs. For intermediate prices, we use wholesale stage prices as reported by the UN FAO. While it may be argued that these prices do not reflect actual prices agreed between multinationals and retail chains, we take the wholesale price to be reflective of a benchmark via which upstream and retail firms will negotiate and are thus representative of competition at the intermediate stage for the banana supply chain as a whole.

We begin by displaying the dynamics of the spreads for the US, the UK and France (in local currencies) in Figure 1. For the top three plots in the figure, we have the retail-wholesale and wholesale-import spreads for each of the three countries; in the final plot, we show the retail-import price in each country. The most obvious observation from Figure 1 is how the behaviour of the spreads differ across all three countries. For France, the retail-wholesale spread is greater than the wholesale-import spread and both spreads are relatively constant. For the US, both spreads are highly variable with a notable decline in the wholesale-import spread in the latter third of the time period. The retail-wholesale spread is consistently higher than the wholesale-import spread though the average of the spread is lower from 2011 onwards. However, the behaviour of the UK spreads differs from the US and French cases. First, the spreads are more volatile but, second, the retail-wholesale spread lies below the wholesale-import spread from 2011 onwards, a feature that is likely to reflect the intensity of competition in the UK retail food sector following the entry of discounters in 2010.

In the final segment, we report the retail-import spreads for the three countries (in local currencies). Again, the differences across the three countries are apparent. In France, the spread is fairly constant over the whole data period; for the US, the spread is volatile but has been decreasing over time; in the UK, the spread has also been decreasing particularly from 2011 onwards. Taken together, the characteristics of the spreads are likely to reflect differences in the functioning of the supply chains in each of these three countries and gives a basis for comparing how the impact of exogenous shocks will vary across these countries.

Figure 1: Retail-Wholesale and Wholesale-Import Price Spreads: UK, US and France



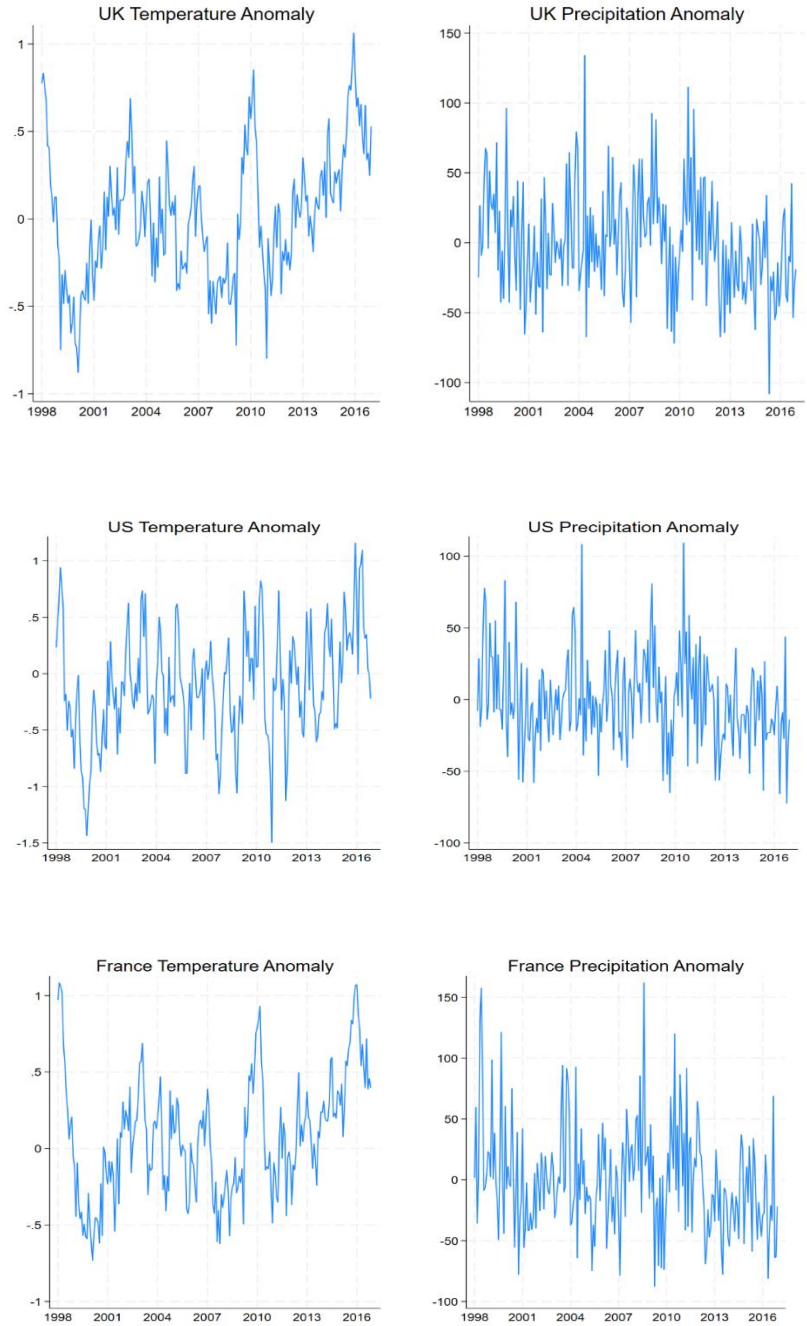


Given that our focus is on the impact of anomalous weather on the spreads in each of these countries, we require weather data that reflects conditions in the growing areas in source countries. To derive the anomalous weather data, we employ detailed gridded weather data relating to banana production in the countries that are the main exporters to the UK, the US and France. Data on monthly temperature and precipitation from 1996 to 2016 for each country that exports bananas were extracted from the CRU TS v.4.01 product (https://crudata.uea.ac.uk/cru/data/hrg/).[3] Data extraction and an elevation-based correction of temperature specific to banana production areas were performed.[8] 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 represent 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 specific import market to derive a single series for temperature and precipitation anomalies. Country-specific exports to each country were sourced from the World Integrated Trade Solution database accessed from the World Bank or from the Food and Agriculture Organisation's *Banana Statistical Compendium*. (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.

Figure 2 presents our measures of anomalous variation in temperature (left-hand side segments) and precipitation (right-hand side segments) weighted measures for each of the three countries. These form the basis of our exogenous shocks. Note that both positive and negative anomalous

weather observations would be anticipated to reduce output (i.e. 'too' hot weather may be just as bad for yields as 'too' cold weather).[18]

Figure 2: Temperature and Precipitation Anomalies: UK, US and France



[18] When we separate positive from negative shocks, we find the same results indicating that the impact of positive and negative anomalous weather variation is not asymmetric.

5. Results

Impact of Temperature and Precipitation Shocks

The cumulative impulse responses of price spreads following one standard error shocks to temperature and precipitation anomalies in the three countries are presented in Figure 3. In the top half of each frame, we show the responses to temperature anomalies; responses to precipitation anomalies in the bottom half. The left hand graphs plot the response of the retail-wholesale spread; in the middle, it is the wholesale-import spread; and the graphs on the right hand side plot the response of the retail-wholesale spread.

Although the theoretical model presented above does allow for the possibility of an increase in spreads, the overall conclusion one draws from the results presented in Figure 3 is that either spreads decrease in response to anomalous weather shocks or, in a limited number of cases, responses are indistinguishable from zero over the 18-month horizon. Evidence suggesting that spreads rise is limited to the wholesale-import spread in the US following a temperature shock but even here the response hugs the zero axis for much of the horizon. Recall that the observation that spreads typically decline is consistent with the mechanism that underpins the impact of imperfect competition when firms are impacted by exogenous shocks. While there is a strong consensus for the amelioration of shocks in each country, where in the chain the adjustment takes place is largely country specific.

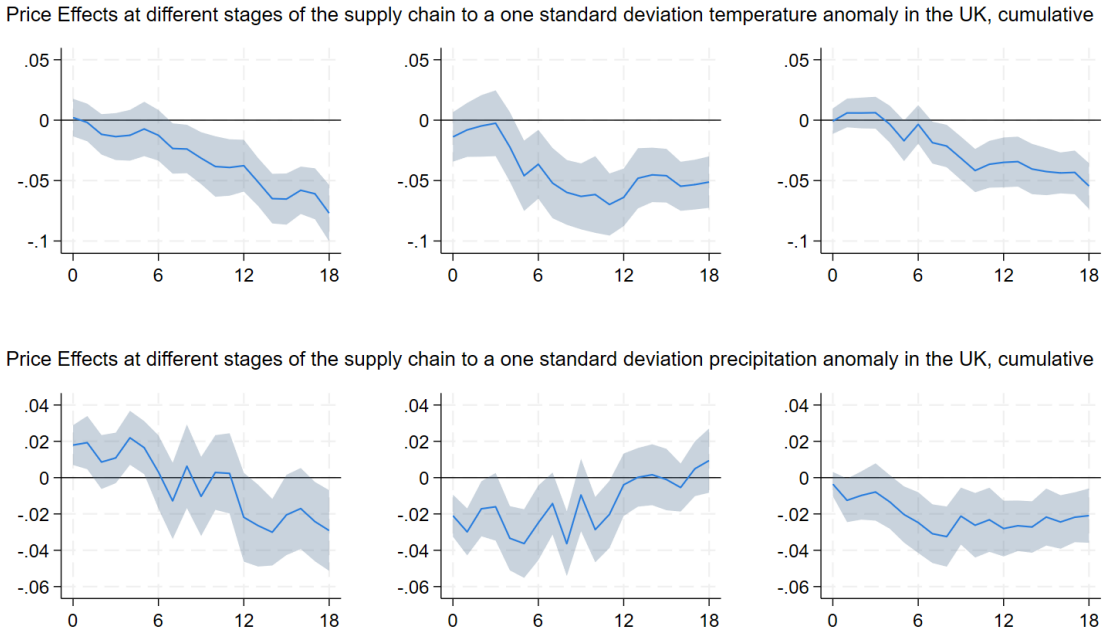
In more detail, for the UK, spreads at all stages decline in response to temperature anomalies- as well as the retail-import spread- and, with the exception of the retail-wholesale spread, show the same pattern of responses in response to precipitation anomalies. The changes in the retail-wholesale spread are marginally greater than the change in the wholesale-import spread (-7 versus -5 per cent) and for the retail-import stage as a whole, around -5 per cent. The declines due to precipitation anomalies are around -2 per cent for the retail-wholesale and retail-import stages but converges to zero for the wholesale-import spread after 18 months. For the US, there are some similarities but overall responses are weaker and more difficult to discern. In relation to temperature shocks, the retail-wholesale spread declines by around 5 per cent which is also true of the retail-import spread but for the wholesale-import case, there is evidence of that spreads increase by 5 per cent, possibly suggesting a terms of trade effect, however the large confidence intervals around the wholesale-import spread in response to both weather anomalies suggest that responses are not well defined over the entire sample period (see below). Finally, in the French case, declines are most apparent in the retail-import spreads where the decrease

is around 5 per cent in response to both temperature and precipitation shocks, with the evidence for adjustment at the retail-wholesale or wholesale-import levels being more modest.

What general insights can one draw from these results? First, reflecting differences in the dynamics of the spreads reported in Figure 1, the responses to weather anomalies vary across the supply chains in each of the three countries. Second, where significant responses are found, they are generally consistent with the role of imperfect competition. Specifically, there is evidence that spreads decline in response to shocks though this can vary by stage in - or characterisation of - the supply chains. Note that if competition characterised every stage in each supply chain, we would not observe the declines in the spreads that are presented throughout the results presented in Figure 3. Further, consistent with the model presented above, stages can respond in different ways and to varying extents in response to these shocks. Finally, as noted, while increasing spreads could be feasible if the terms of trade effect was sufficiently strong (and irrespective of functional form issues), the empirical evidence on this issue is weak.

Figure 3: Cumulative Impulse Responses of Spreads Following Temperature (Top Segment) and Precipitation (Bottom Segment) Shocks

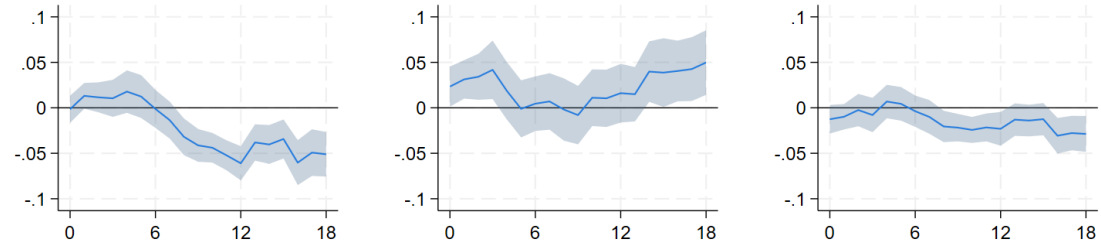
UK



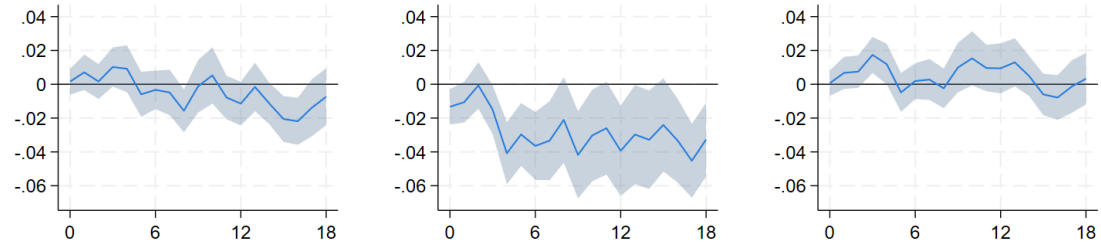
Note: Graphs on the left-hand side show the estimated response of the retail-wholesale spread to a one standard deviation shock in each weather anomaly; graphs in the middle show the response of the wholesale-import spread and graphs on the right hand side show the response of the retail-import spread. The response horizon is 18 months and the grey shading represent 68% confidence intervals.

US

Price Effects at different stages of the supply chain to a one standard deviation temperature anomaly in the US, cumulative

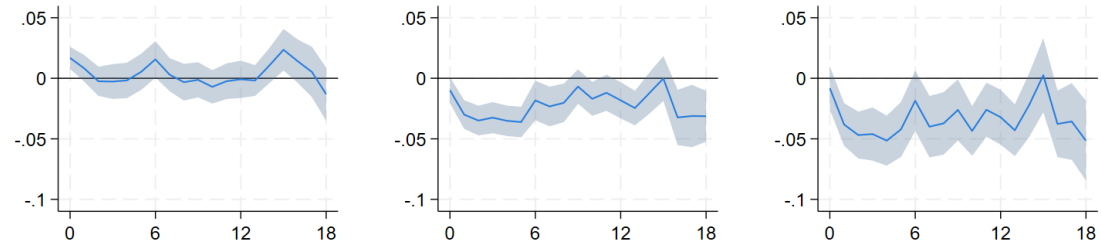


Price Effects at different stages of the supply chain to a one standard deviation precipitation anomaly in the US, cumulative

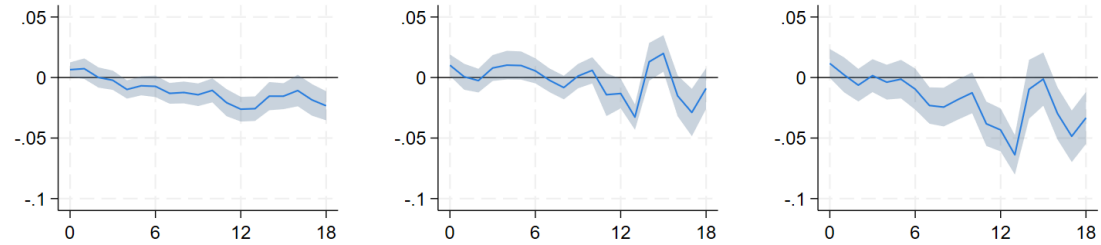


France

Price Effects at different stages of the supply chain to a one standard deviation temperature anomaly in France, cumulative



Price Effects at different stages of the supply chain to a one standard deviation precipitation anomaly in France, cumulative



Note: Graphs on the left-hand side show the estimated response of the retail-wholesale spread to a one standard deviation shock in each weather anomaly; graphs in the middle show the response of the wholesale-import spread and graphs on the right hand side show the response of the retail-import spread. The response horizon is 18 months and the grey shading represent 68% confidence intervals.

State Dependent Impacts

As discussed above, concerns have been raised that, during crises periods, the response of firms in food supply chains may differ from that in 'non-crisis' periods. More specifically, firms have been accused of using their market power to increase their margins during periods of price volatility to their advantage. While the results from the previous section offer little empirical support for this behaviour over the period as a whole, the possibility remains that widening margins may characterise the crises periods in commodity markets[19]. To explore this, we consider the impact of weather shocks between the periods straddling the commodity crises of 2007 and 2011, compared to those estimated over the period as a whole. Figure 5 shows the cumulative impulse responses of the spreads to shocks during 2007-2011 (shaded grey) alongside those for the whole sample period (shaded red) for comparison.[20]

Overall, the impulse responses of price spreads in each the three countries following anomalous temperature and precipitation shocks in the 2007-11 period differ from those estimated during the data period a whole, and in most cases, quite markedly so. Specifically, and in contrast to the concerns regarding widening margins, the tendency for negative responses observed over the full sample is more accentuated in the crisis period, particularly over shorter horizons, the long run (18 month) response being largely similar in most cases.

Take, first, the UK. For both temperature and precipitation anomalies, the retail-wholesale spreads decreases by around 20 per cent in the crisis period compared to the fall of around 3 per cent in the non-crisis period 8 months after the shock. Responses converge thereafter so that within a year, responses have converged to a decline of some five percent. Elsewhere in the chain, spreads are largely similar, pointing to the exercise of power being most keenly exerted by retailers in the crisis period.

For the US, an accentuated decline is most apparent in the retail-import spread, and is common to both temperature and precipitation anomalies. For example, the retail-import spread falls by some 10 per cent after 6 months compared with an effectively zero effect at the same horizon in the non-crisis period. While wholesale-import spreads also show a marked decline to temperature shocks in the crisis period, the response to precipitation shocks is actually less than

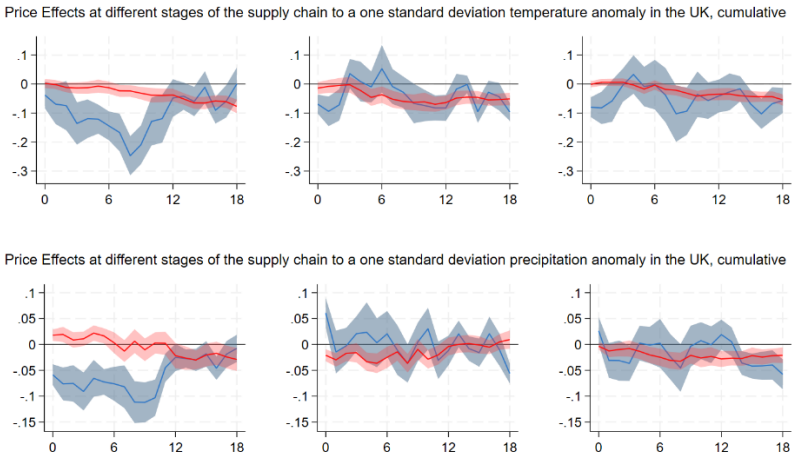
[19] Note that the standard deviation of the weather anomalies were similar in the crisis and non-crisis periods. The focus is whether, due to wider pressures associated with commodity markets, firms respond differently during these periods.

[20] To facilitate comparison the impulses for crisis and whole sample in graph in Figure 5 have been scaled to the same magnitude.

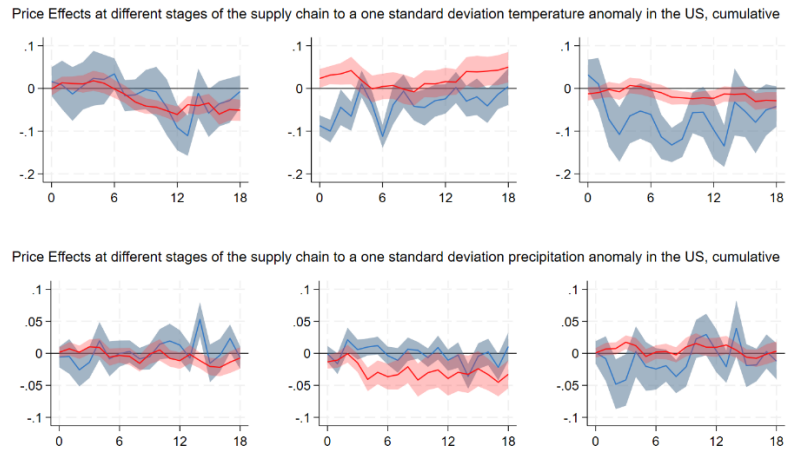
the period as a whole (albeit insignificantly different from zero). Finally, in the case of France, the impact of temperature and precipitation shocks at the retail-wholesale level are considerably more negative in the crisis period (-10 per cent after 3 months in each case). Elsewhere in the chain, the responses are more variable during the crisis period but with many crossings of the axis clear patterns are more difficult to discern.

Figure 4: Cumulative Impulse Responses of Spreads between Commodity Crises Periods, 2007-2011.

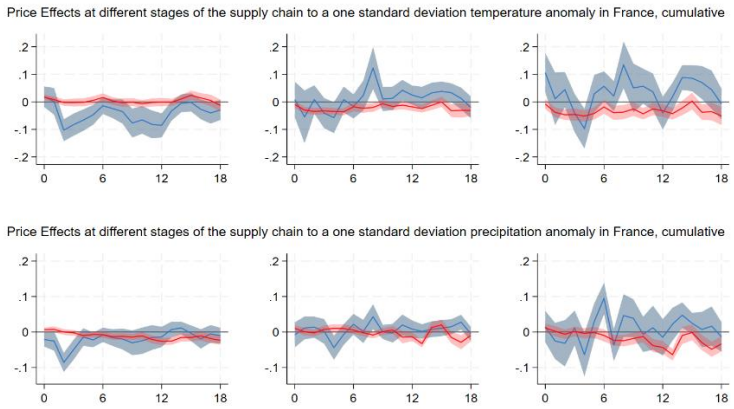
UK



US



France



Note: Graphs on the left-hand side show the estimated response of the retail-wholesale spread to a one standard deviation shock in each weather anomaly; graphs in the middle show the response of the wholesale-import spread and graphs on the right hand side show the response of the retail-import spread. The response horizon is 18 months and the shading represent 68% confidence intervals. Crisis period responses are in grey whereas responses for the whole period are in red for comparison.

There are two main takeaways from the results presented in Figure 4. First, evidence points to state dependent behaviour in the price spreads in response to weather shocks being present in all countries studied. However, the weight of evidence points to the moderating effect of imperfect competition during crises periods, in contrast to the accusation of profiteering that have been expressed (so-called 'greedflation'). Second, the effects are located in different parts of the chain in the three countries we have studied: in the UK and France, it is the retail-wholesale spreads where the effects are most pronounced; whereas in the US it is the retail-import spread. In every case, retail power is implicated, the difference potentially reflecting structural differences in the marketing channels through which banana trade passes in the three countries.

Robustness

As adjuncts to the main analysis presented above, we have explored three related issues: weather measurement, asymmetry and nonlinearity of the impulses responses. Our findings (presented in the appendix) suggest that location-specific weather data matters for the identification of weather shocks but that the specification of the functional form of the shock does not. Specifically, to address the measurement issue, we repeated the analysis using a commonly-applied global measure weather intensity called El Niño Southern Oscillation or ENSO rather than location-specific weather shocks. Based on the monthly deviation of sea

surface temperature from a 30 year historical average, the ENSO anomaly series has been used to determine the impact of weather variations on commodity prices (see Ubilava, 2017 for details). The results using ENSO (where the shocks relate to the positive anomalies as per Cashin *et al.* 2017), show no apparent changes in the spreads at any stage of the supply chains across any of the countries. To the extent that the ENSO anomaly measure is a generic indicator of extreme weather these findings are not particularly surprising but underline the relevance of employing commodity-specific weather data to detect the impact of weather shocks.

To address the issue of asymmetry we also investigated the impact of positive anomalies only using our location-specific temperature and precipitation anomalies. Doing so potentially distinguishes hot from cool and wet from dry weather in banana growing countries, and allows us to focus on concerns associated with rising temperatures and increased flooding. As Appendix Figure 2 shows, while there are some minor deviations, results are consistent with those presented in Figure 3.

Finally, to assess the possibility of important non-linear effects to weather shocks (to better capture the yield response when the temperature or precipitation anomalies were particularly hot or wet) we conducted an additional exercise in which the weather anomalies enter the location projection quadratically. The impulse response function that result are presented in Appendix Figure 3. As with the other aspect of non-linearity, the qualitative findings reported above continue to hold with only minor quantitative deviations. In most cases, the direction of the change in the spreads were negative and while the magnitude of the spread elasticities in some cases varied form those reported above, the main thrust of the findings were unaffected.

6. Summary and Conclusion

The overall aim of this paper was to provide additional insights into the growing literature on the economic impacts of extreme weather; our specific focus has been on how supply chains are potentially impacted and where alternative stages of supply chains may be characterised by imperfect competition. The supply chains we have focussed on related to a single commodity with a simple (Leontief) technology but where competition issues are potentially more complex. The focus on bananas allows us to detail the prices at each stage and make the comparison of supply chains across countries straightforward insofar as there are no significant differences in the commodity that is passed through the vertical stages in each country. Our findings suggest that price spreads within the supply chains differ and we address how these spreads adjust in face of anomalous weather. Our focus on banana supply chains is also

complemented by detailed temperature and precipitation measures that apply across the main exporting countries.

Using cumulative local projection impulse responses, our results show that where spreads do respond to weather shocks, they tend to decline. Importantly, not all spreads adjust with the same chain, a result that points to structural differences in the procurement and distribution of bananas in the three countries. In general, the source of the weather shock matter too, price spreads being more responsive to temperature than precipitation shocks. We also considered whether the response of spreads varied in different time periods, in particular the period spanning the commodity crises of 2007 and 2011. We found evidence that responses across the three supply chains were generally larger than the responses for the period as a whole. We found little or no evidence that price spreads increased during this period, which has typically been the accusation levelled at firms in times of crises.

Taken together, the main insight is that while supply chains will be impacted by extreme weather and on-going climate change in the future, distributional effects can arise within those chains that affect all participants in potentially unexpected ways. The theory and empirical work presented here suggests that where imperfect competition is a feature of the supply chains of interest, firms will be affected by anomalous weather events and, to the extent that spreads decline as a response, the behaviour of firms may potentially ameliorate the impact on consumers. A remaining question relates to the impact of shocks on (small) producers at the banana growing end of the supply chain but this would require bespoke data to address this issue.

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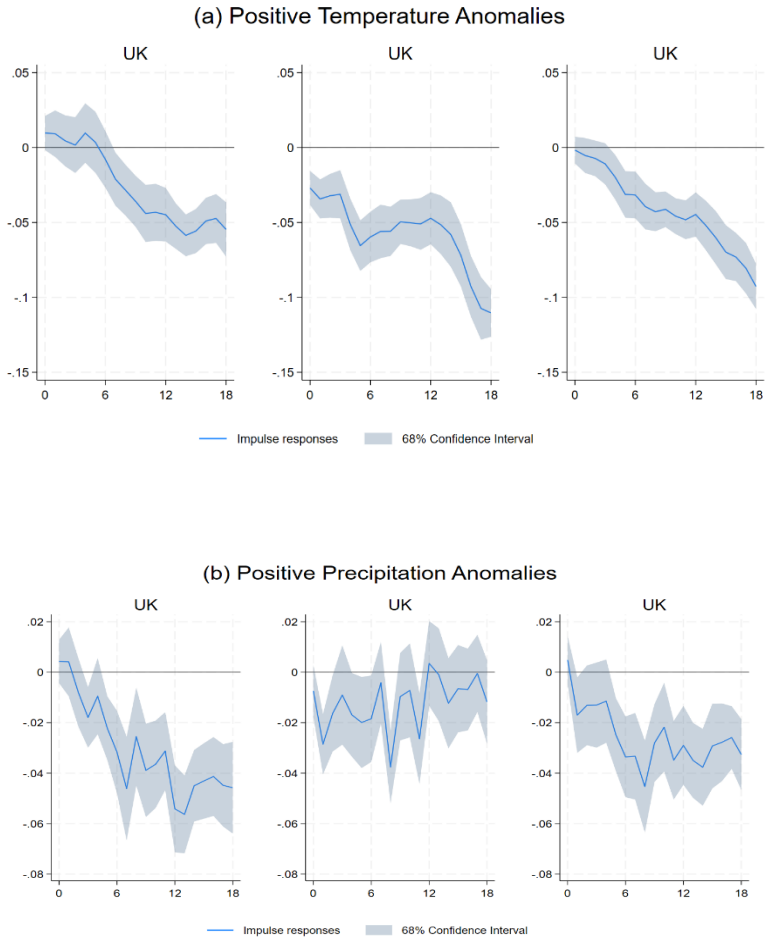
Appendix



Note: In the left-hand side of each segment, we have the retail-wholesale spread; in the middle segment, the wholesale-import spread; in the right hand side segment, the retail-import spread. Also, as with *Cashin et al*. (2017) and Ubilava (2017), our shock relating to ENSO relates to the positive SST anomalies.

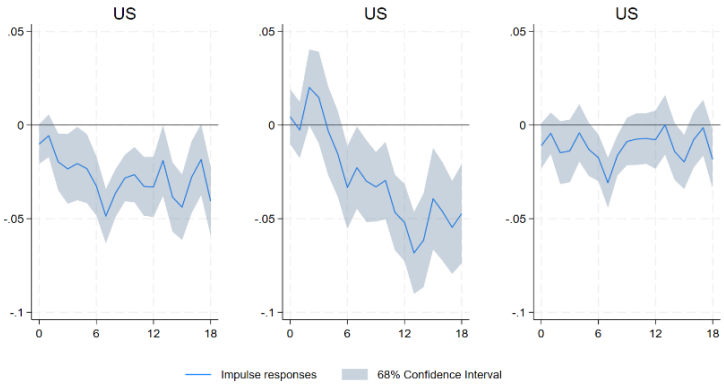
Appendix Figure 2: Cumulative Impulse Responses to Positive Temperature and Precipitation Anomalies

UK

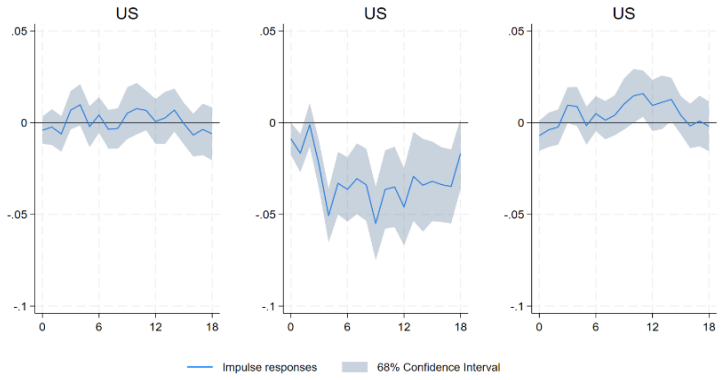


US

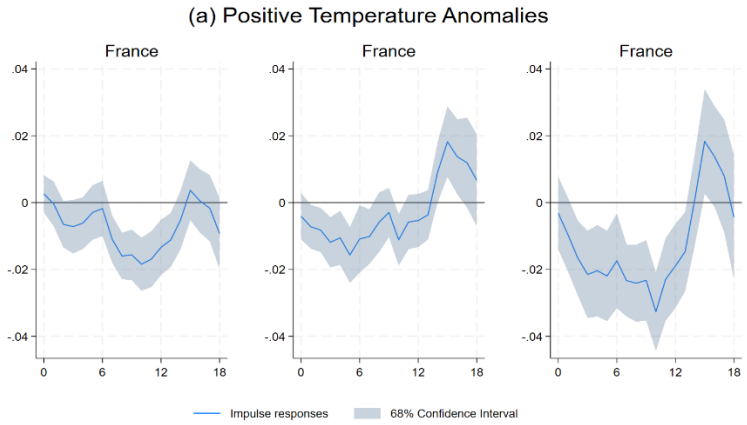
(a) Positive Temperature Anomalies

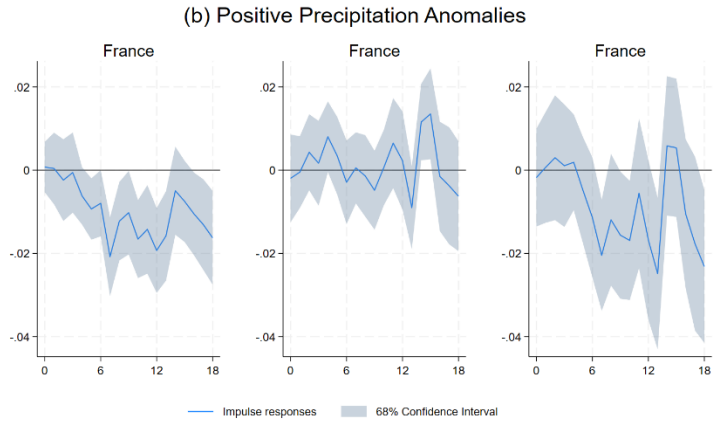


(b) Positive Precipitation Anomalies



France



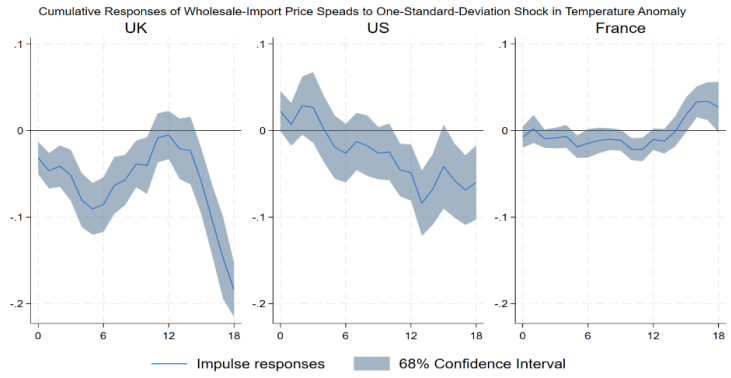


Note: In the left-hand side of each segment, we have the retail-wholesale spread; in the middle segment, the wholesale-import spread; in the right hand side segment, the retail-import spread.

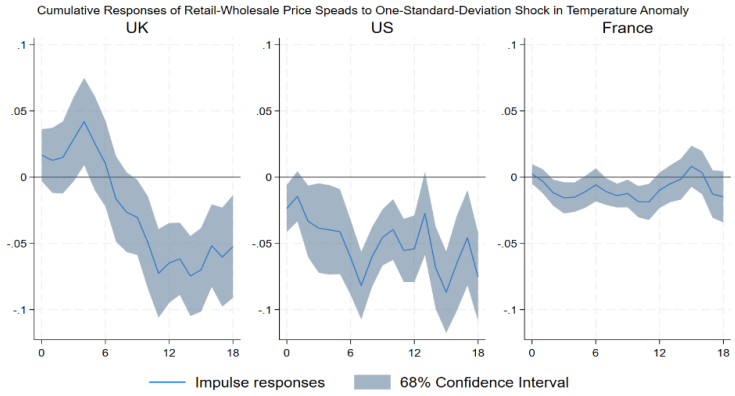
Appendix Figure 3: Cumulative Impulse Responses of Non-Linear Temperature and Precipitation Anomalies

3.1 Shock with Temperature

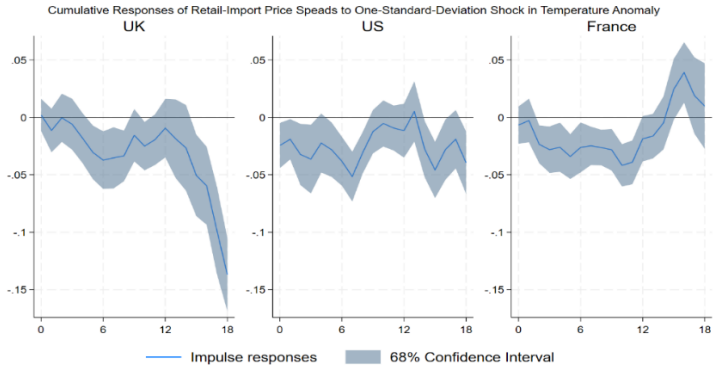
3.1.1. Wholesale Stage



3.1.2. Retail Stage

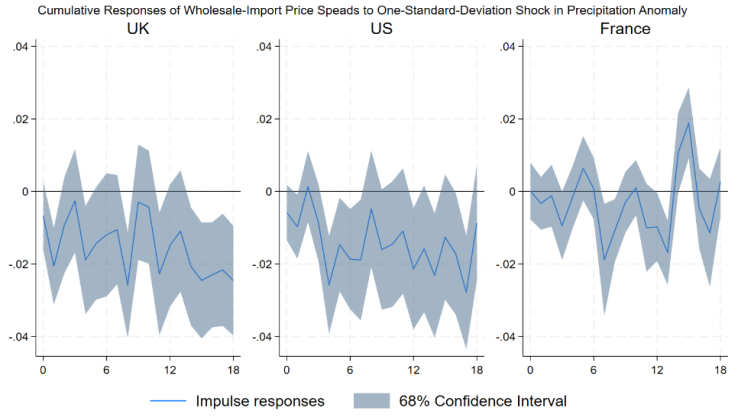


3.1.3. Whole Supply Chain

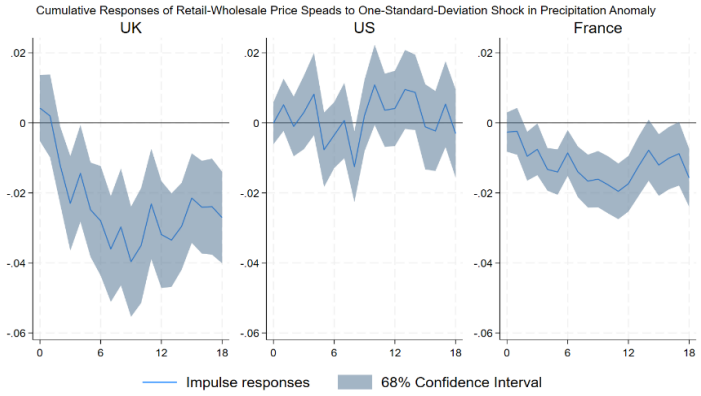


3.2 Shock with Precipitation

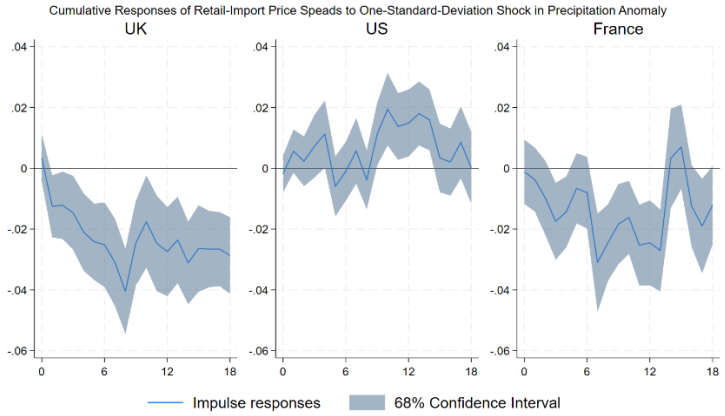
3.2.1. Wholesale Stage



3.2.2. Retail Stage



3.2.3. Whole Supply Chain



Note: In the left-hand side of each segment, we have the retail-wholesale spread; in the middle segment, the wholesale-import spread; in the right hand side segment, the retail-import spread.