Retail Food Price Modelling Project

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Executive Summary

This research was undertaken on behalf of Defra under *Invitation to Tender Number 24580* to provide further research into modelling UK retail food price inflation. It follows from previously-commissioned work on retail food inflation delivered to Defra in November 2011 comprising the majority of the current research team. In the previous research, the team developed an econometric model to estimate the impact of world commodity prices on UK food inflation while accounting for a range of wider factors that may impact on world and domestic retail food prices and, more specifically, the magnitude of the world-retail price transmission effects. The estimates from the model were then used to forecast the impact of developments on world commodity markets as well as other factors influencing price transmission such as exchange rates and oil prices on UK retail food inflation.

The context for the previous research on forecasting retail food inflation in the UK was the exposure to shocks emanating from world markets, in particular following the world price 'spikes' of 2007-2008 and 2011. This was a period of considerable price volatility on world markets involving not only agricultural commodities but also oil, both of which were reflected in volatile domestic retail food inflation. The issue of high and volatile food inflation was not confined to the UK, though the experience of food inflation in the UK was more intense than in many other European Union (EU) countries. Since then, however, the challenges facing the UK food system and the exposure of UK consumers to these challenges have changed, particularly following the UK's decision to exit the European Union. Given the uncertainty that will be involved in the UK's departure from the EU and the range of alternative trading arrangements that may replace the current trade regime, it is desirable to renew the effort in understanding how the UK food sector (from the farm level through to final consumers) will be affected by these new trade arrangements.

To address these issues, the framework initially conceived and delivered under the previous research contract had to be significantly revised. In addition to accommodating more recent data in the econometric model, an innovative feature of the revised food inflation model is the creation of new price indices to reflect specifically what the UK imports and from where. Employing a readily-available world commodity price index, as done in the previous research, is not fit for this specific purpose for two reasons. First, as a portmanteau measure of prices on world commodity markets, it does not reflect the price of what the UK actually imports. Specifically, it ignores that the UK purchases a significant quantity of its food and agricultural products from the EU which are subject to the EU's common trade policy and hence prices differ from those on world markets. Second, since the UK's exit from the European Union is likely to involve fundamental changes to international trade measures with potentially both EU and non-EU countries, import prices are likely to change. Hence, it will be necessary to reflect agricultural and food import prices from different sources, including changes to any tariff and non-tariff measures that are applied. Furthermore, changes to the geographical source of UK food imports will also have implications for other data series that impact on domestic food prices, most obviously exchange rates. In particular, it necessitated the creation of an effective exchange rate that reflects the composition of agricultural and food trade that is potentially different from that applicable in the past.

These newly-created agricultural-food price and appropriately-weighted effective exchange rate indices form key inputs into the revised framework. There are also a number of other new features to the current research. In particular, since a large part of the UK's agricultural and food trade relates to processed food products, we create bespoke price indices that reflect the importance of products produced at

different stages of the food chain. Specifically, we develop models that are based on (a) prices (and effective exchange rates) of agricultural commodities only and (b) a model that includes processed and manufactured food as well as raw agricultural commodity prices and the appropriately weighted exchange rates. While the 'all-product' model is our primary focus, the 'agriculture-only' model is useful because it facilitates a direct comparison of UK import prices with the prices of agricultural products on international markets. The distinction is important with implications for food price transmission in the UK.

In this report, we present the results and insights from this new research. After setting out the context and objectives of the current project, we present an update to the previous food price inflation model (which we label 'Defra I') with more recent data to assess its current validity. Following this, we present the derivation of the new price and effective exchange rate indices which form the main new inputs into the revised modelling (labelled 'Defra II'). It should be noted that, due to the nature of the new data we are working with, and the intention of differentiating between trade with EU and non-EU countries, the specification of the Defra II econometric model differs from the Defra I specification. After an explanation of its structure, estimates of the new model are presented. The results from the econometric model confirm the important role played by domestic factors (including non-agricultural costs (such as labour and energy) and domestic agricultural output prices) as well as international factors (import prices and exchange rates) in determining UK retail food inflation.

A major output of the project is the creation of a bespoke Excel-based modelling tool referred to as the 'Scenario Tool Exeter Food Inflation' (*STEFI*). This tool uses the econometric outputs developed in Defra II to deliver estimated effects of alternative post-EU exit trade scenarios on retail food prices. *STEFI* is user-friendly and has been developed specifically for use within Defra to calculate the dynamic effects of a wide range of scenarios with the option to build-up sequentially the effects in combination with factors such as non-tariff barriers and exchange rates. Finally, in the last two sections of the report, results of two special studies are presented. The first is an analysis of retail food price inflation for different income deciles of the UK population. The second investigates whether the entry of discounters into the UK retail food sector since 2010 may have altered the transmission of agricultural and processed food prices. Our investigation of these issues are tentative in nature and suggest the need for further research to identify the impact of new trade arrangements on different income groups and how the changing structure of the food sector may impact on the transmission of prices through the food supply chain to retail.

Taken together, the revised retail food inflation model that is contained in this report represents a substantial development of previous modelling and provides Defra with the flexibility to assess the retail food price effects that may come about as the UK's trade arrangements with the European Union change and trade arrangements with non-European Union countries develop.

Retail Food Price Modelling Project

1. Context and Objectives of Current Research

Context

Around 40 per cent of UK food and agricultural supply is currently imported and EU partners account for around 70 per cent of trade in this sector. This would imply that the post-Brexit implications of changes in the pattern of trade and the changes in the structure of trade policy are likely to have significant effects on participants throughout the food supply chain from farmers through to retailers. Consumers, particularly those in low-income categories who spend a large proportion of their income on food, will be directly affected by the cost changes that may arise. As the experience of the world commodity price shocks of 2007-2008 and 2011 illustrated, the UK was particularly exposed to events on world markets giving rise to levels and volatility of retail food price inflation that was higher than in most other EU Member States (Lloyd *et al.*, 2015): exposure to world market events may increase, contingent on post-Brexit trade arrangements.

As reported elsewhere (e.g. HM Treasury Report (2016) and (2018)), the potential impact of Brexit on the UK economy could be significant. The most recent Treasury assessment (HM Treasury, 2018) indicates that agri-food trade will be one of the sectors most affected by the UK's departure from the EU: for example, with the 'modelled' White Paper option, economic activity in the agri-food sector would fall by 2 per cent, which compares with the results for the manufacturing sector of -0.1 per cent. While the trade models used for these estimates account for both imports and exports, the research reported here complements these estimates by focussing more on issues related to the drivers of retail food prices in the UK and the potential effect on food inflation. Specifically, the over-riding aim of the research is the development of a tool that will facilitate the assessment of potential changes in UK trade arrangements with the EU and non-EU countries on retail food inflation.

Underpinning the development of this tool to address the food price outcomes of alternative post-Brexit scenarios is an econometric framework that: (i) accounts for a range of factors that determine retail food prices including a range of macroeconomic factors such as exchange rates, labour costs *etc*; (ii) accommodates the appropriate time series properties of the data and; (iii) accounts for the dynamic nature of the determinants of retail food prices.

Addressing the potential impact of post-Brexit trading arrangements on UK retail food prices also requires the derivation of detailed price indices that more accurately reflect the UK's trade regime in food and agricultural products covering: (i) what food and agricultural products we buy and from where; (ii) that these price indices are derived at an appropriately disaggregated level to facilitate the incorporation of changes to tariff and non-tariff measures under alternative post-Brexit scenarios; and (iii) reflecting the importance of exchange rates to UK food and agricultural trade, the derivation of an effective exchange rate index that is weighted by what we import and from where.

An important dimension of this new research is to acknowledge that a considerable proportion of the UK's imports are in semi-or fully-processed food, with the European Union accounting for the majority of these imports. Data on price indices that reflect the specific nature of what form of food and agricultural products the UK imports (from raw commodities through to fully-processed food) and which reflect the geography of the UK's sourcing of these products is not available and has to be constructed. In sum, to deliver an appropriate framework and scenario-modelling tool to assess the potential impact of new trade arrangements following Brexit requires deriving new price and exchange rate indices that can be incorporated in an appropriately-specified econometric model.

Main Objectives

In the context set out above, the overarching objectives of this research are as follows:

- Since the original food price forecasting model (delivered by the research team and used by Defra) is not sufficiently equipped to address a range of Brexit-related issues, the research involves the creation of new price indices reflecting the UK's trade in food and agricultural products with particular reference to imports of semi- and final processed foods with sufficient geographical aggregation to accommodate the effects of alternative sourcing of the UK's agricultural and food imports. In this context, the newly developed price indices will form a major input into the updated econometric model that can therefore be employed to address the potential price impacts following the UK's departure from the EU, and be sufficiently detailed to derive estimates of the price effects as the UK seeks alternative trading arrangements.

- To develop appropriate econometric models of retail food prices based on sound theoretical foundations that can be employed to address the potential impact on UK food prices under various post-Brexit scenarios. This econometric model will be a significant extension of the model previously developed by the team and which was based on a previous commission from Defra, and subsequently published in a leading peer-reviewed journal (Davidson *et al*., 2016). The new specification arises from the specific challenges in addressing potential Brexit-related outcomes on UK food prices as detailed in the *Invitation to Tender* document (Reference 24580). The new model also exploits the newly-derived import price and effective exchange rate indices.

- The development of an Excel-based tool (the Scenario Tool Exeter Food Inflation, *STEFI*) that can be employed to address Brexit-related options as reflected in changes in the price indices (reflecting changing sources of imports and trade barriers that may apply) to assess potential future paths of UK retail food prices. The purpose of this food price scenario-modelling platform is to equip potential non-specialists with the means to address alternative future trade scenarios in a readily-amenable form that will not require specific econometric expertise or programming skills. The food price platform will simply require the user to specify alternative trade scenarios and any trade barriers that arise from the geography of future trade arrangements.

- To explore potential extensions of the econometric framework to account for food price impacts across different income deciles and the extent to which price relationships may have changed following the increased presence of discounters in the food retail sector since 2010.

2. Relation to Previous Research

As discussed above, the development of the original retail food inflation model in 2011 (which we label as 'Defra I') centred around issues relating to volatility on world commodity markets and how these events could impact on the UK food sector and, in particular, on retail food inflation. The purpose of that research was to develop an econometric model that would be used to estimate price transmission coefficients that measure the effect on domestic retail food prices of changes in world markets, while accounting for other factors that may also affect domestic food inflation. This econometric model was used to forecast retail food prices for different scenarios of the underlying determining variables.

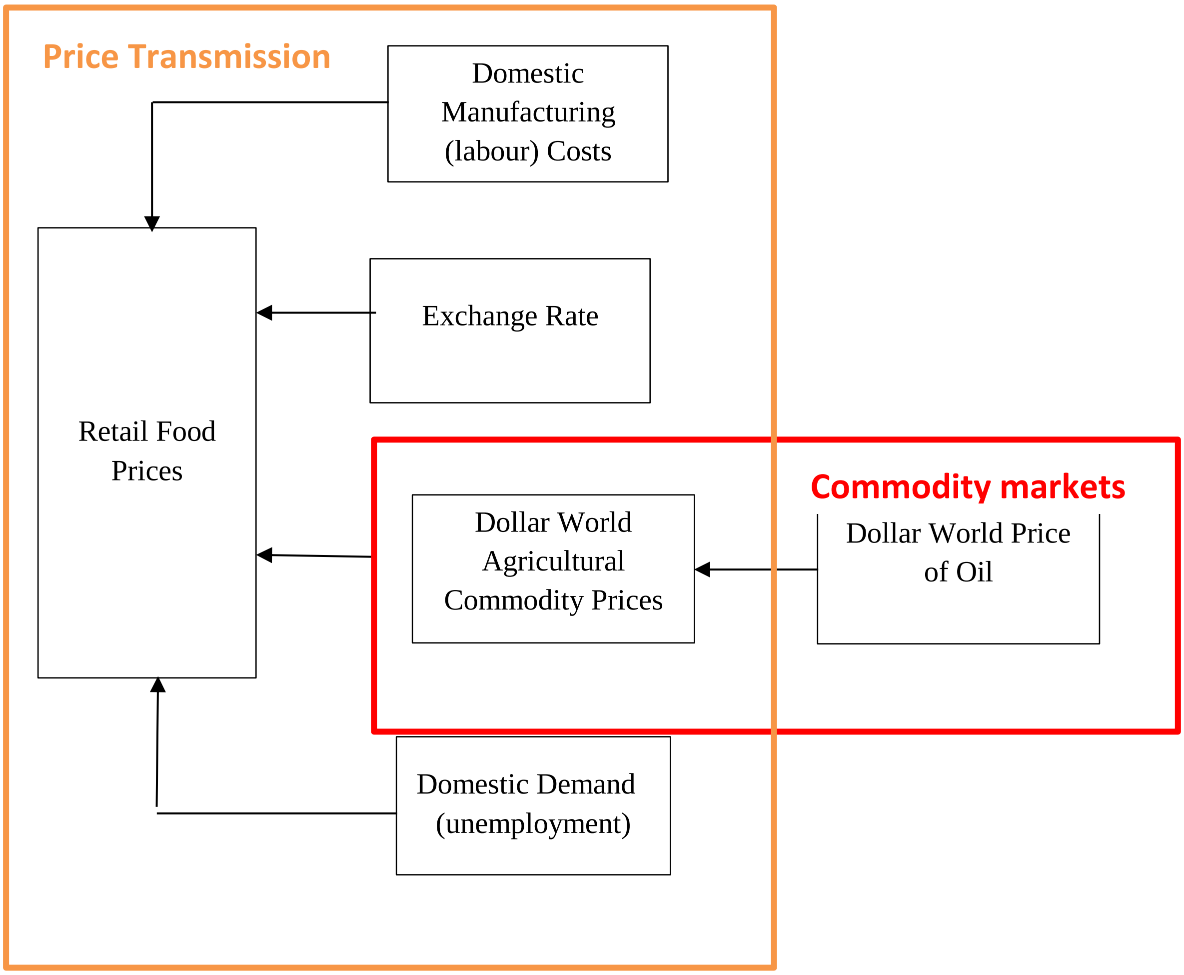
The Defra I model comprised a system of seven equations: one equation for food prices and each of its determining factors (such as agricultural input costs, exchange rates *etc*.) and was estimated with monthly data from January 1990 to December 2010.

In Figure 1, we present a summary of the underlying (or long-run) structure of the Defra I model. As shown in the figure, the model contains two separate long-run relations (represented by orange and red boxes). Each represents an underlying economic equilibrium that is embedded in the overall model. The first is the price transmission relation that defines the factors that affect retail prices in the UK. These are primarily domestic in nature and reflect influences on the demand for food (unemployment) and other costs that may impact on the functioning of the food chain (e.g. labour costs). Influences from the world market are also included; most obviously, world commodity prices but also exchange rates since, with world commodity prices being denominated in US dollars, changes in the value of sterling relative to the US dollar could also have a clear impact on domestic retail food prices.

Domestic agricultural prices are included in the overall model but do not explicitly appear in the price transmission relation illustrated in the figure. This is not because they are unimportant but because they share the same long-term trend as international commodity prices. This means that for practical purposes, only international domestic prices are required to predict the long-run evolution of retail food prices. Domestic agricultural prices are however used to predict short-term food prices since their month-on-month behaviour is different to that of world agricultural prices.

Given the concerns associated with the links between high world oil prices and world agricultural prices, world oil prices are also included in the econometric model. Oil price impacts both on the level and volatility of world food prices owing to the reliance on oil in the agricultural sector and because of the link with biofuels. To incorporate oil prices, we therefore define a second equilibrium relation between international agricultural commodity prices and the price of oil (both of which are expressed in US dollars), implying that the effect of oil prices in the model is mediated through the international commodity prices, as illustrated in Figure 1.

Figure 1: Schematic Outline of the Defra I Price Transmission Model.



In technical terms, the econometric model is a co-integrated vector auto-regression estimated in error correction form, in which the two long run (co-integrating) relations described above (i.e. those governing price transmission and linkages between international commodity markets) are embedded (see Davidson *et al*. 2016 for details).[1] Models of this sort exploit the time series properties of the data and efficiently accommodate dynamic behaviour. Importantly, the co-integrating property gives rise to models whose parameters are more accurate than in the standard case and readily facilitates the estimation of short and long-run economic relationships from time series data.

A summary of the key price transmission elasticities obtained from the Defra I model (1990-2011) is presented in Table 1. Each coefficient represents the estimated eventual effect on food prices of a 1% change in each variable, holding the other variables constant. For example, the transmission elasticity of world commodity prices (0.622) indicates that a 1% increase in world commodity prices (as measured by the FAO World Food Price Index) would lead to an eventual increase of 0.622% in UK food prices (as measured by the Food CPI) other things remaining constant. Given that it is usual to express the

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[1] A co-integrating relation represents the statistical counterpart of the economic equilibrium (or 'long-run' relation) discussed in the main text (and illustrated in Figure 1). Each co-integrating relation contains parameters (estimated from the data) that measure the eventual or 'long run' effect of a change in one variable on another. In Defra I, there are two such long-run relations, one characterising price transmission and the other the relation between (dollar denominated) international commodity prices.

effect of a 10% change rather than a 1% change, this implies that a 10% increase in world commodity prices is estimated to lead to an eventual 6.2% increase in UK food prices, other factors in the model held constant. As the estimates in the table indicate, the retail price of food was most responsive during the sample period to changes in the world commodity prices, the price of oil and the exchange rate. Responses reported in the table are based on relationships that are statistically significant at the 5% level with the exception of the demand proxy (unemployment), the significance of which was more marginal (15% level).

Table 1: Summary of Transmission Coefficients from Defra *I*
(Eventual percentage effect on UK food prices of a 1% change)

Determining Variable	Long-Run Elasticity
World Commodity Prices	0.622***
Exchange Rate	-0.496***
Manufacturing Costs	0.270**
Unemployment	-0.146
World Oil Prices	0.635***

'***'s denote confidence at the 99 per cent level and
'**' confidence at the95 per cent level respectively.

3. Updating the Defra I Model

The first key objective of the current project was to update the data used in Defra I and to re-run the model with the same specification. This was conducted to give an indication of the performance of the model and whether the nature of the determinants of UK retail food prices had changed over time. Moreover, since 2011, concerns with commodity price spikes have subsided and world commodity prices have fallen significantly. It is also likely to be the case that the strong linkage between the world price of oil and commodity prices had weakened compared with the late 2000s. In the initial stages of this project, we therefore updated the data used in Defra I to June 2016 and estimated the model with the identical specification using monthly data from 1990-2016; the updated transmission elasticities are presented in Table 2 along with the previous estimates provided for comparison.

Table 2: Summary of Transmission Coefficients: Updating Defra I
(Eventual percentage effect on UK food prices of a 1% change)

Determining Variable	Long-Run Elasticity Defra I 1990(1) – 2010(12)	Long-Run Elasticity Updated Defra I 1990(1) – 2016(6)
World Commodity Prices	0.622***	0.411***
Exchange Rate	-0.496***	-0.288***
Manufacturing Costs	0.270**	0.380***
Unemployment	-0.146	0.019
World Oil Prices	0.635***	0.513***

'***'s denote confidence at the 99 per cent level and
'**' confidence at the95 per cent level respectively.

Overall, the drivers of retail food prices continue to hold though the estimates of the transmission elasticities have changed in most cases. For example, using more recent data the estimates imply that a 10% change in world commodity prices leads to an eventual increase in UK food prices of 4.11%, keeping other factors fixed, down from 6.22% estimated in the earlier period. Referring to the estimates in the table it is clear that variables that relate to international factors (world commodity prices, world oil prices and the exchange rate) have all decreased in terms of their direct influence on UK retail food prices. Transmission of domestic manufacturing costs has increased while the impact of demand factors (i.e. unemployment) continued to be an insignificant determinant of retail food price. Specifically, the estimates imply that a 10% increase in manufacturing costs leads to a 3.8% rise in UK food prices, other factors held constant, up from 2.7% estimated in the earlier period, while the response to changes in unemployment is effectively zero.

The changes in the relative importance of domestic compared with international factors on retail food prices is likely to reflect the changes in world markets since 2011. The commodity price spikes in world food markets that characterise the earlier period reflected a confluence of factors ranging from low stocks, weather variations, potential spillovers from financial markets and the responses of governments across many countries through the use of trade policy to ensure domestic price stability. Furthermore, world oil prices were a major factor in determining food prices, both domestically and internationally, partly because oil prices impacted on the cost of inputs but also with regard to the relationship between oil prices and the amount of land used for biofuels. To a large extent, these factors have now dissipated: world commodity prices are now lower and, given the decline in world oil prices, the strong links between biofuels and oil are less of a concern.

Accounting for the changes in the responsiveness to domestic factors is more difficult to pinpoint however as both domestic factors (unemployment and manufacturing costs) are consistent with changing patterns of food consumption. Specifically, the rise in the importance of manufacturing costs may reflect consumer trends towards more processed foods in the shopping basket, while the lack of any discernible effect from unemployment could be the result of the emergence of hard discounters and the competitive response of established retailers more generally.

Taken together, the results reported in Table 2 are consistent with international factors having less importance on retail food prices in recent years, an unsurprising result given the absence of commodity price spikes in the post 2011 data. Note however that the statistical significance of the international factors is still strong (all international factors are significant at the 1 per cent level) so that it is the magnitude rather than the existence that has changed in recent years.

Looking ahead at the results from the new food inflation model we outline below, the relative role of domestic compared to international factors is also apparent. In the revised specification, the long-run elasticities relating to domestic variables dominate the role of import prices. This is consistent with the results for the updated Defra 1 model: international factors are important determinants of UK retail food prices but their relative importance compared with domestic factors have declined in the context of less volatile global markets.

4. Specification of the Revised Model

The Defra I model and its updated version is therefore a useful tool for assessing the effects of shocks emanating from world markets, which was its original purpose. However, to address issues associated with the UK's departure from the European Union and alternative trade arrangements that may emerge, it is less directly useful. This is because, as noted above, being an indicator of commodity prices on world markets, the world commodity price index that is used in Defra I does not adequately capture the composition and origin of the food and agricultural products the UK actually imports. What is required is a series that measures UK import prices more accurately, and its creation represents one of the principal inputs into the revised model. In addition, we also aim to extend the modelling framework to accommodate imports of semi- and highly-processed foods (rather than the raw unprocessed commodities measures by the FAO's World Food Index that was used in Defra I) as they account for a significant proportion of UK imports, particularly from the European Union. We detail the derivation of these new price indices in Appendix 2.

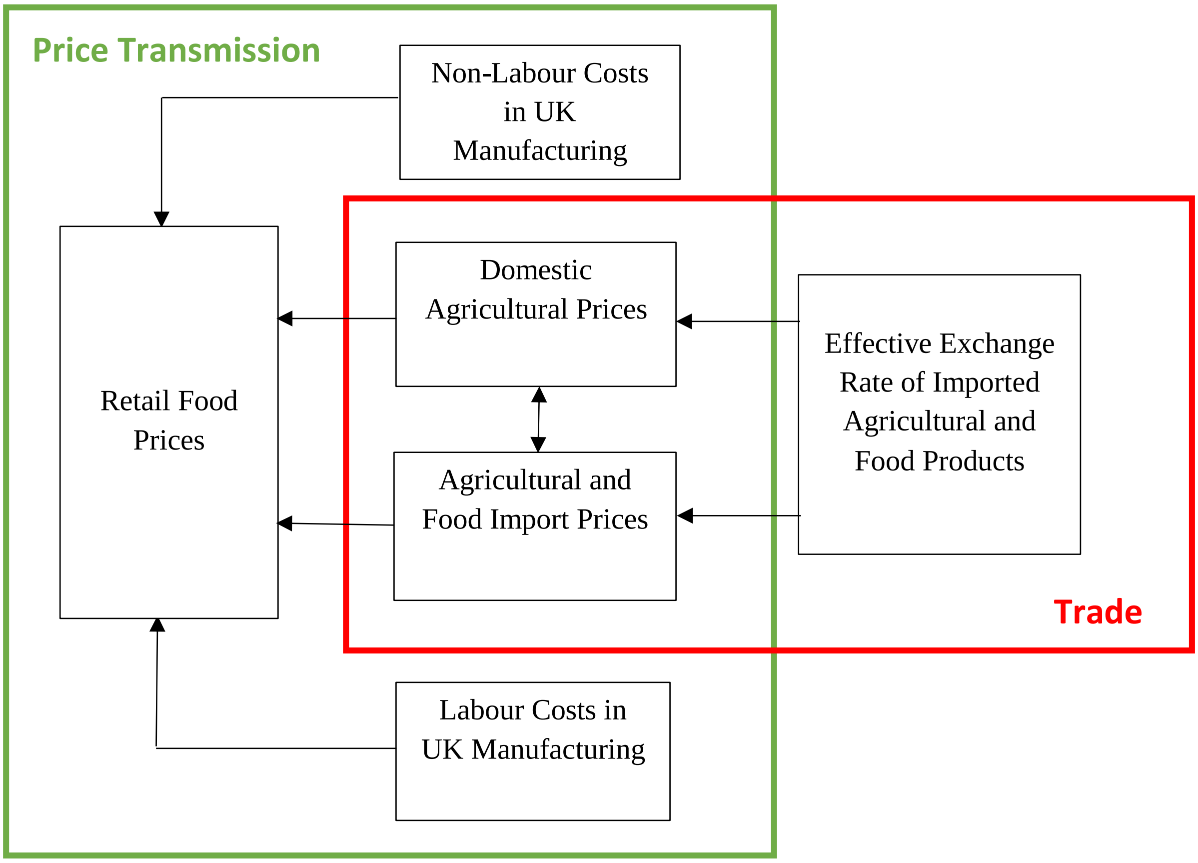
In specifying the new model, we retain the econometric approach adopted in Defra I, namely the co-integrated vector autoregressive (C-VAR) framework. Furthermore, as previously, we also specify two long-run (co-integrating) relations: one defining price transmission that relates to the domestic food chain and accounts for a range of costs that processors/retailers would have to incur in addition to the price of food imports and; a second one that characterises the relationships between domestic agricultural prices and how they are tied to international factors, namely import prices from the UK's main sources of agricultural and food imports and (effective) exchange rates. An outline of the model specification is detailed in Figure 2.[2]

In much the same way as in Defra I, the price transmission (green) box details the factors that determine domestic retail prices. These represent the costs associated with the production of retail food and include domestic agricultural prices, the price index of agricultural and processed food imports, and two components of costs in UK manufacturing, namely labour and non-labour (fuel and raw materials). Note that both domestic and international prices appear in this relation. This is because they potentially

[2] Note that in the empirical analysis we have two variants of the setup outlined in Figure 2. The first is a model that incorporates all agricultural and processed food imports; the second focuses on agricultural imports only. While attention focusses on the former, more general model, the latter (agriculture only) model is useful for comparative purposes, as discussed in Section 6.

relate to different products (for example, tropical and processed goods are included in the import price measure but do not enter from the measure of domestic agricultural prices).

Figure 2: Schematic Outline of the Defra II Price Transmission Model



In addition to the price transmission relation, we specify a second equilibrium relation that accounts for the links between domestic agricultural output prices and international factors *i.e.* the newly-constructed index price of agricultural and food imports and the correspondingly geographically-weighted effective exchange rate. In Figure 2, this is represented by the trade (red) box. There are two dimensions to the inter-relationships identified in the trade equation that are important in determining retail price transmission. First, as the effective exchange rate changes (predominantly the $:£ and €:£) so will the price of agricultural and food trade imports into the UK. Depreciation (appreciation) of Sterling increases (decreases) the price of these imports in the UK. Similarly, domestic agricultural prices will change in response to movements in the effective exchange rate reflecting that the price of UK output has changed to foreign purchasers. Specifically, depreciation (appreciation) of Sterling will increase the overseas demand for UK domestic output, exerting an upward pressure on its price in the UK. As a result, depreciation (appreciation) of Sterling increases (decreases) the prices of agricultural and food products in the UK market. Second, import prices will not only impact directly on retail food prices but also indirectly via an impact on domestic agricultural prices. Specifically, as the price index of agricultural imports rises, domestic agricultural prices will rise too, reflecting the relatively open nature of the UK agricultural and food market. Note that the price of domestically produced agricultural output might also influence the price of directly comparable imports (although not world markets), hence the two-way nature of the arrows linking these two in Figure 2.

The nature of the links between the variables in the second equilibrium relationship means that domestic agricultural prices may also be influenced by the demand both within the UK and in other countries. The variable that measures domestic agricultural prices covers all output whether it competes with imports as inputs into the domestic food industry or output that is exported to other countries. This will have a bearing on the relationship between the exchange rate and domestic output prices as the exchange rate will also influence the UK's competitiveness in world markets.

These relationships are summarised in Table 3. In the price transmission model, each factor represents a cost (either directly or indirectly) in supplying retail food and thus are positively related to food prices. In the trade model (the red box in Figure 2), which describes the relationships between domestic agricultural output prices, import prices and the effective exchange rate, an increase in import prices would be expected to raise domestic agricultural output prices reflecting the 'small' open economy nature of the UK food and agricultural sector. An appreciation (depreciation) in the effective exchange rate leads to a reduction (increase) in domestic agricultural output prices.

Table 3: The Relationships between the Model's Variables

Price Transmission Model	
UK retail food prices (r_t) are determined by :	Expected sign
UK agricultural output prices (p_t)	+
Domestic labour costs (d_t)	+
UK manufacturing input costs (m_t)	+
Import prices of agricultural and food products (i_t)	+
Trade Model	
UK agricultural output prices (p_t) are determined by:	
Import prices of agricultural and food products (i_t)	+
Effective exchange rate for agricultural and food imports (a_t)	-

Differences between Defra I and II

As is evident from Figure 1 and 2, while there are many similarities between the specifications of Defra I and II, there are also some key differences. Importantly, the role and definition of the exchange rate is different across specifications. In Defra I, the exchange rate related to the US$/£ exchange rate as an international determinant of domestic retail prices and, as such, it appeared in the first (price transmission) equilibrium relation directly. In essence, its role was to convert dollar-denominated world market prices into £ Sterling. In the new model, the role of the exchange rate is different and, in this case, appears in the second (trade) equilibrium relation. There are two reasons for this.

The first is a practical reason: since the new import price indices are already priced in £ Sterling, there is no need to directly include the exchange rate in the price transmission relationship. Clearly however, exchange rates play a vital role in domestic food prices. In Defra II we specify a second ('trade') relation that shows the link from exchange rates into import prices and, by extension, price relationships between import prices and domestic agricultural prices. As the exchange rate depreciates, the Sterling-denominated import price index will rise and, in turn, increase domestic agricultural prices. Hence the effect of exchange rates in Defra II is mediated through import prices and domestic prices, both of which are priced in Sterling. Taken together, a depreciation in the exchange rate increases retail food prices via the consequent rise in import prices and domestic agricultural prices, both of which appear in the price transmission relationship. This, in turn, has the implication that the magnitude of the exchange rate effect and the role it plays in the newly-specified model will differ from the exchange rate effect as detailed in Defra I.

The second reason to treat exchange rates differently in Defra II is because, for the purposes at hand, we require an *effective,* rather than a single bilateral exchange rate. Recall our aim is to reflect the geography of food and agricultural imports, so the exchange rate should relate to where imports are sourced from, suitably-weighted to reflect the currencies of the UK's major trading partners for food and agricultural imports. The construction of the effective exchange rate (involving different variants depending on whether it relates to agricultural imports or agricultural and manufactured food imports) is also detailed in Appendix 2.

There are two other differences in the final specification of Defra I and II to note. The first is that Defra II explicitly incorporates domestic agricultural output prices in the price transmission relationship whereas Defra I did not. Domestic prices were omitted from Defra I because over the 1990-2011 sample period, domestic agricultural prices and world commodity prices possessed the same long-run trend, implying that, from a statistical viewpoint, world commodity price trends were sufficient to model the long run behaviour (although both world and domestic prices played a role in the short-run only part of Defra I. With the longer data period, and given the increased role of domestic factors, the results show that both domestic agricultural prices and import prices play roles in determining the long-run trend (and short run changes) in retail food prices, and so both are included in Defra II. The second difference is that the price transmission relation in Defra II does not contain any explicit demand proxy, although as noted previously the effect of shifts in demand were small and only marginally significant in Defra I. More detail on this is given in the following sub-section.

Alternative Specifications

As part of the modelling exercise, a large number of alternative specifications of the revised retail food price model were explored. Investigation focussed most notably on versions of the econometric model with oil prices, various demand proxies (the unemployment rate, the number of unemployed and the job vacancy rate) and other costs in the food chain (both input and output costs). The variables considered are listed in Appendix Table 1. Detailed results of the work on a demand proxy formed a section in the interim report, *Data and Model Specification*. In principle, demand shifters, such as aggregate earnings or unemployment may influence the demand for food and thus food prices. Extensive testing could not establish an empirical link using the available measures, echoing the findings obtained in the development of Defra I. Few empirical measures of demand are available at the monthly frequency and thus it is possible that the findings reflect this. However, it should also be noted that food accounts for a relatively small share of total consumer expenditure, suggesting that cost factors are likely to dominate the formation of retail food prices. Since statistically significant effects using the available demand proxies could not be found, the final specification of the model is that portrayed in Figure 2, which will therefore be the version of the model that we will focus on in the discussion below.

5. Data Issues

Context

As set out above, the creation of new price indices that reflect the product composition and origin of imports was an essential part of the current Defra project. Note that this is more than just an issue about more representative data. Given that the world commodity price index is unlikely to accurately reflect what the UK procures and from where, the estimate of price transmission, which is calculated directly from the data, will most likely give an inaccurate estimate of the price transmission effect. The sources of imports will also have implications for the measurement of the exchange rate: rather than using the US dollar commodity price index and hence include only the US$/£ exchange rate in the model, the more relevant measure of the exchange rate is an effective exchange rate suitably weighted with the weights reflecting the geography of where the UK procures agricultural and food imports. The effective exchange rate will therefore be an appropriately-weighted basket of currencies vis-à-vis UK sterling. This is particularly pertinent given that a large proportion of the UK's food and agricultural imports are sourced from the European Union and thus priced in Euros not US dollars.

Data Coverage

The trade data was sourced from the HMRC database (https://www.uktradeinfo.com/Statistics/). While trade data are available at a highly disaggregated level, we worked with a relatively high level of commodity aggregation at the HS two-digit level (e.g. meat, cereals, sugar *etc*.) and identified eight suppliers classified at a regional level. The issue of aggregation is important as the data we have can be disaggregated to any commodity at the six-digit level and by any single country. It was useful to keep a relatively high level of aggregation, however, the more disaggregated the data become (by commodity and country), the more likely it is that null entries would be encountered. Given that the price indices we created comprise unit values (value divided by volume), trade must take place for a price to be calculated. Highly detailed product classifications at the individual country level thus confound the creation of price indices, particularly at the monthly frequency (reflecting, for example, seasonal issues).

Country Aggregation

HMRC provides import data by country although for practical reasons we aggregated by geographical regions which can be downloaded directly from the HMRC website. The regions are:

- European Union
- Non-European Union suppliers split between
    - Asia and Oceania
    - Eastern Europe
    - Latin America and the Caribbean
    - Middle East and North Africa
    - North America
    - Sub-Saharan Africa
    - Western Europe excluding the EU.

Product Aggregation

The commodity groups (called chapters in the HMRC classification system) that we used are from the first four sections of the 99 sections into which HMRC classify all imports. These represent the sections covering agricultural and food imports. The chapters that comprise the first four sections of the HS2 classification are presented in Box 1 below.

We excluded the chapters in these sections that are not food or beverages, namely Chapters 05 (products of animal origin, not elsewhere specified or included), 06 (live trees and other plants; bulbs, roots and the like; cut flowers and ornamental foliage), 13 (lac; gums, resins and other vegetable saps and extracts), 14 (vegetable plaiting materials; vegetable products not elsewhere specified or included), 23 (residues and waste from the food industries; prepared animal fodder) and 24 (tobacco and manufactured tobacco substitutes). This leaves 18 chapters.

Given the broad nature of some of the commodity categories, we split Chapter 17 (sugars and sugar confectionery) and Chapter 18 (cocoa and cocoa preparations) corresponding to their raw and processed constituents to give the 20 groups listed in Table 4. The designation of 'raw' and 'processed' chapters is in concordance with the FAO's Food Price Index that essentially relates to raw (unprocessed or with limited processing) commodities and therefore allowed us to compare directly the newly-derived import price index for the UK with an 'off-the-shelf' world commodity price index.

Box 1: HS2 Product Classifications

SECTION I
LIVE ANIMALS; ANIMAL PRODUCTS

01 Live animals.
02 Meat and edible meat offal.
03 Fish and crustaceans, molluscs and other aquatic invertebrates.
04 Dairy produce; birds' eggs; natural honey; edible products of animal origin, not elsewhere specified or included.
05 Products of animal origin, not elsewhere specified or included.

SECTION II
VEGETABLE PRODUCTS

06 Live trees and other plants; bulbs, roots and the like; cut flowers and ornamental foliage.
07 Edible vegetables and certain roots and tubers.
08 Edible fruit and nuts; peel of citrus fruit or melons.
09 Coffee, tea, mate and spices.
10 Cereals.
11 Products of the milling industry; malt; starches; inulin; wheat gluten.
12 Oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruit; industrial or medicinal plants; straw and fodder.
13 Lac; gums, resins and other vegetable saps and extracts.
14 Vegetable plaiting materials; vegetable products not elsewhere specified or included.

SECTION III
ANIMAL OR VEGETABLE FATS AND OILS AND THEIR CLEAVAGE PRODUCTS; PREPARED EDIBLE FATS; ANIMAL OR VEGETABLE WAXES

15 Animal or vegetable fats and oils and their cleavage products; prepared edible fats; animal or vegetable waxes.

SECTION IV
PREPARED FOODSTUFFS; BEVERAGES, SPIRITS AND VINEGAR; TOBACCO AND MANUFACTURED TOBACCO SUBSTITUTES

16 Preparations of meat, of fish or of crustaceans, molluscs or other aquatic invertebrates.
17 Sugars and sugar confectionery.
18 Cocoa and cocoa preparations.
19 Preparations of cereals, flour, starch or milk; pastry cooks' products.
20 Preparations of vegetables, fruit, nuts or other parts of plants.
21 Miscellaneous edible preparations.
22 Beverages, spirits and vinegar.
23 Residues and waste from the food industries; prepared animal fodder.
24 Tobacco and manufactured tobacco substitutes.

Table 4: Commodity Groups and Corresponding HMRC Chapter Classifications

Commodity Group label	HMRC Commodity Chapters (HS Level codes)	Raw or Processed
01	Live Animals (HS01)	Raw
02	Meat and Offal (HS02)	Raw
03	Fish. (HS03)	Raw
04	Dairy Produce (HS04)	Raw
07	Edible Vegetables (HS07)	Raw
08	Edible Fruit (HS08)	Raw
09	Coffee, Tea, Mate (HS09)	Raw
10	Cereals (HS10)	Raw
11	Products of Milling Industry (HS11)	Raw
12	Oilseeds (HS12)	Raw
15	Animal of Vegetable Fats (HS15)	Raw
16	Preparations of Meat, Fish etc. (HS16)	Processed
1701	Sugars (17.01)[1]	Raw
1702	Confectionery (17.02, , 1703 and 17.04)[2]	Processed
1801	Cocoa (18.01 and 18.02)[3]	Raw
1802	Cocoa Preparations (18.03, 18.04, 18.05 and 18.06)[4]	Processed
19	Preparations of Cereals, Flour (HS19)	Processed
20	Preparations of Vegetables (HS20)	Processed
21	Miscellaneous Edible Preparations (HS21)	Processed
22	Beverages, Spirits and Vinegar (HS22)	Processed

Source: HMRC

Notes: [1] 1701 Cane or beet sugar and chemically pure sucrose, in solid form. [2] 1702 Sugars, including lactose, maltose, glucose or fructose in solid form; sugar syrups without added; flavouring or colouring matter; artificial honey, whether or not mixed with natural honey; caramel; 1703 Molasses; resulting from the extraction or refining of sugar; 1704 Sugar confectionery (including white chocolate), not containing cocoa. [3] 1801 Cocoa beans; whole or broken, raw or roasted; 1802 Cocoa; shells, husks, skins and other cocoa waste. [4] 1803 Cocoa; paste; whether or not defatted; 1804 Cocoa; butter, fat and oil; 1805 Cocoa; powder, not containing added sugar or other sweetening matter; 1806 Chocolate and other food preparations containing cocoa.

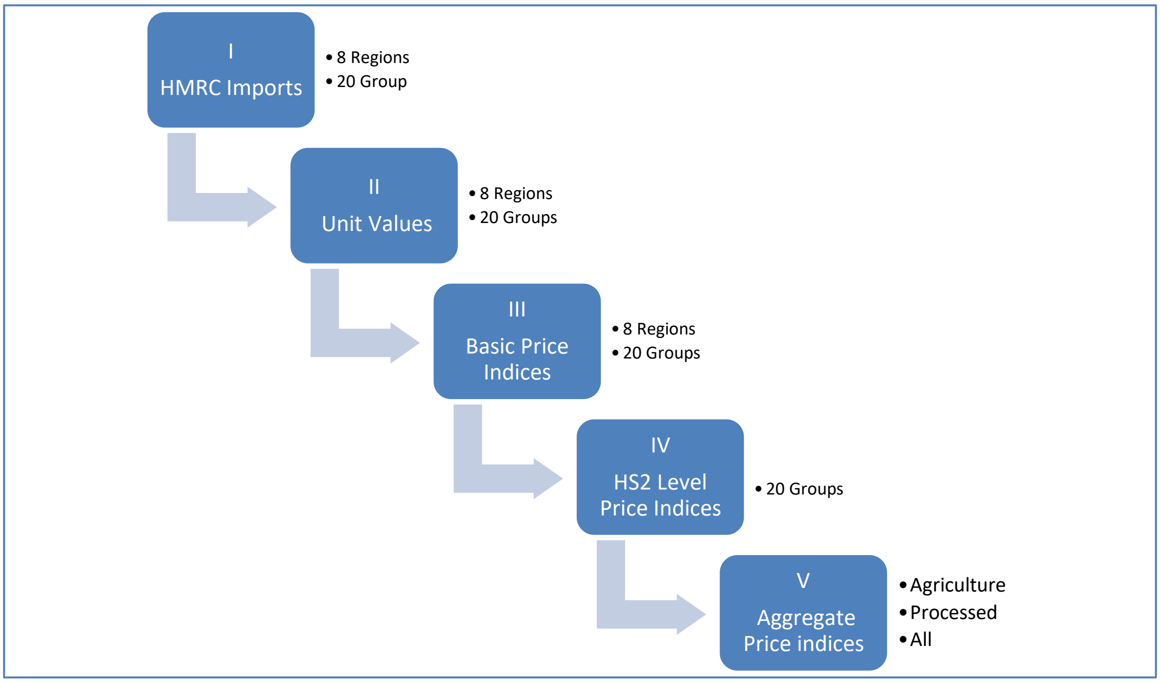
Import Price Indices

A key objective of the data construction exercise was to create indices of aggregate import prices based on highly granular (eight regions and 20 HS2 commodity groups) import data obtained from HMRC. In all, there were five steps to the process that creates the import data, which is summarised in Figure 3 (see Appendix 2 for details). In Step I, the value and volume of imports from the 8 regions in each of 20 groups covering commodities, food and beverages imported into the UK were assembled from the HMRC online database. Given the monthly frequency of the data, spanning 264 observations from 1996(1) to 2017(12), this represents a total of (264 × 20 × 8 =) 42,240 observations for import values and a similar number for import volume. In Step II, each value series was divided by the corresponding volume series to yield unit value series at monthly frequency. This gives (8 × 20 =) 160 unit value series, each containing 264 monthly observations. In Step III, we created basic indices of unit values by region for each of the 20 product groups that are relative to the unit value in the chosen base year. In Step IV, the regional price indices were aggregated to form price indices of each of the 20 groups imported into the UK. These represent the average price (in £ sterling) of imports into the UK in the 20 commodity, food and beverage groups taking into account the geography of trade. While useful in themselves, these series were combined to form aggregate price series weighted by the value share of trade. We created three such aggregate series that reflect: (i) the import price of agricultural commodities imported into the UK; (ii) the import price of processed food and beverages; and (iii) an all commodities food and beverages index. Econometric models are developed using (i) as a direct comparator to Defra I, and (iii) for extending its coverage to agricultural and processed food imports.

In terms of the basic unit of analysis, this is by region-commodity group. Should we wish in future work to increase the granularity of the analysis (for example, split North America into constituent countries), it will be possible to do so. Each step in the figure will remain; however, the detail within the boxes will be increased.

Figure 3: Creation of the Import Price Indices - A Five Step Process

Revised Price Indices

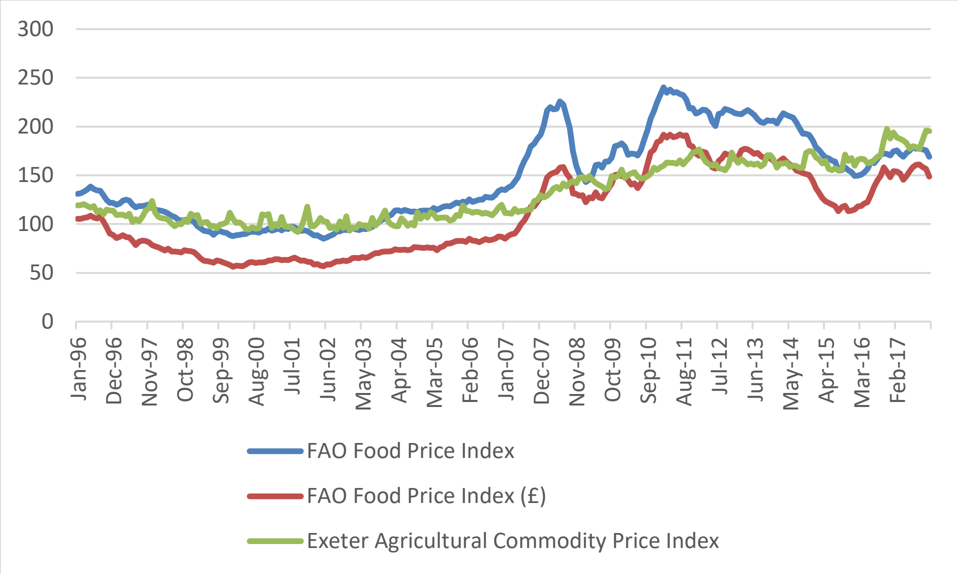


Agricultural Commodities

We begin by showing the price index for unprocessed agricultural commodities (as detailed in the commodity group classifications defined in Table 4) in Figure 4. This is labelled as the Exeter Agricultural Commodity Price Index in the figure. As noted above, the construction of this series is in close concordance with definitions of product coverage reported in more generally available 'world' agricultural price indices, such as the FAO Food Price Index, which is also shown in Figure 3 (priced in both $ and £). When comparing the series, it is important to note that each series is benchmarked to its value in a common base year, so that differences between the series indicate how each series was changing relative to its value in that base year, and should not be taken as an indication of the absolute level of price differences.[3]

[3] As a result, the fact that one series may lie above another does not suggest that prices were lower in absolute terms in that series; merely, that it was lower relative to its value in the base year than another series. In other words, we should not expect the Exeter series to lie above the FAO series, even though EU prices are generally higher than those on world markets.

Figure 4: Exeter Agricultural Commodity Price Index Compared with FAO World Food Price Index (priced in US Dollars and Sterling)



With this caveat in mind, there are some notable features arising from a comparison between the Exeter and FAO series. The Exeter price index appears to be more stable than the FAO price series, irrespective of the denominator currency. Most notably, the Exeter index does not exhibit the spike in prices in 2008 that is evident from the FAO food price indices. This is also true of events around 2011. This is likely to reflect that as a 'world' price index, the FAO series is essentially an indicator price that does not reflect the geography of the sourcing of UK agricultural imports, in that the UK sources a large proportion of its imports from the EU, in which prices are typically more stable (although higher in absolute level).

To see whether differences in the variability of the Exeter and (dollar based) FAO series is due to the influence of fluctuations in the value of £ relative to the $, Figure 4 also presents the FAO Food Price Index converted into £ Sterling at prevailing nominal exchange rates. As is clear from the figure, accounting for the currency differences does reduce some of the volatility in the FAO price index but does not remove it: the higher volatility of the FAO Food Price is still evident, particularly from the 2008 onwards

These observations are important for three reasons. First, where the UK sources its agricultural imports from is a more appropriate characterisation of how 'exposed' the UK is to events on world (non-EU) markets, particularly given the policy framework that applies to the EU agricultural sector. Second, and by extension, in deriving a more relevant commodity price index, we will have a more appropriate basis to assess outcomes associated with potential changes in trade and agricultural policy regimes post-Brexit. Third, use of the Exeter index will also have a bearing on the size of the transmission effect that is estimated. This is because the coefficient is calculated using the variability of each of the series that it links. Hence the Exeter series, which exhibits distinct dynamic behaviour (in terms of volatility and turning points) to the FAO series, will potentially result in a very different relationship between commodity prices and the retail food price index.

In Figure 5, we report a selection of Exeter price indices for UK imports of specific agricultural commodities with relevant sub-indices from the FAO (priced in $ and £ as above). A comparison reinforces the observations made above. Reflecting the source of UK imports and the corresponding issues relating to EU agricultural and trade policies, the features of the 'Exeter' specific commodity price indices are notably different from world prices as measured by the FAO.

Processed Food and Drink

As set out above we also derive a processed food price index (see Box 1 and Table 4 for the composition of the index). There are several reasons why deriving a specific price index for processed food products is both statistically relevant for estimating price transmission effects and economically important. First, a large proportion of UK imports of food products fall in the processed foods categories. Second, to the extent that the geographical sourcing of these imports differs from agricultural commodities, then the processed food price index will give a more accurate characterisation of UK food trade. Third, since processed foods involve a range of inputs which combine with raw materials to produce the manufactured product, the price index for processed food may exhibit different properties in comparison with the agricultural price index, the latter being more directly influenced by EU agricultural policies, the former also by the costs of manufacturing. Fourth, this may result in the price transmission mechanism being different compared with the transmission between agricultural and retail food prices. Finally, and important for present purposes, to the extent that trade costs vary according to the degree of processing, then this will have relevance for evaluating the potential outcomes for UK retail food prices post-Brexit. This is particularly relevant for the case of non-tariff measures given that barriers relating to health and food safety standards, for example, are known to be particularly high for food processing trade compared with agricultural trade.

Figure 5: Comparison between 'Exeter' Import Price Indices and FAO Food Price Sub-Indices for Selected Commodities.

Figure 5 (a): Meat

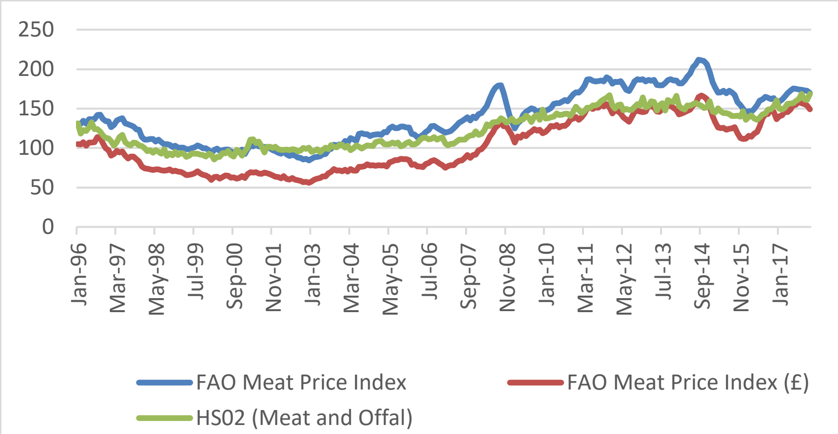


Figure 5 (b): Dairy

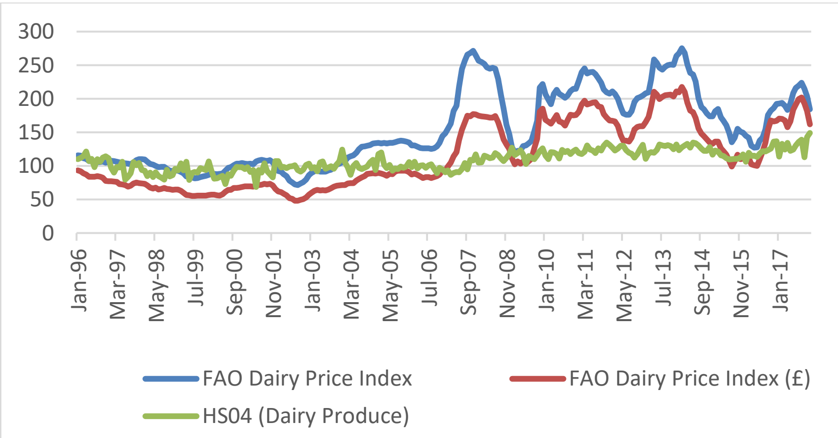
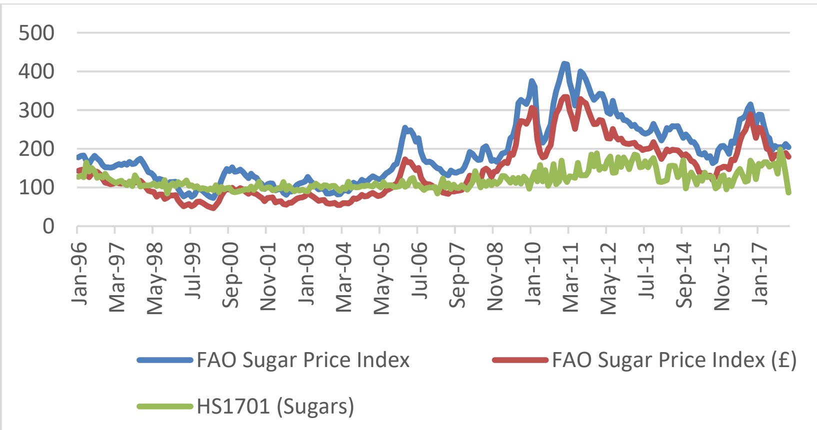
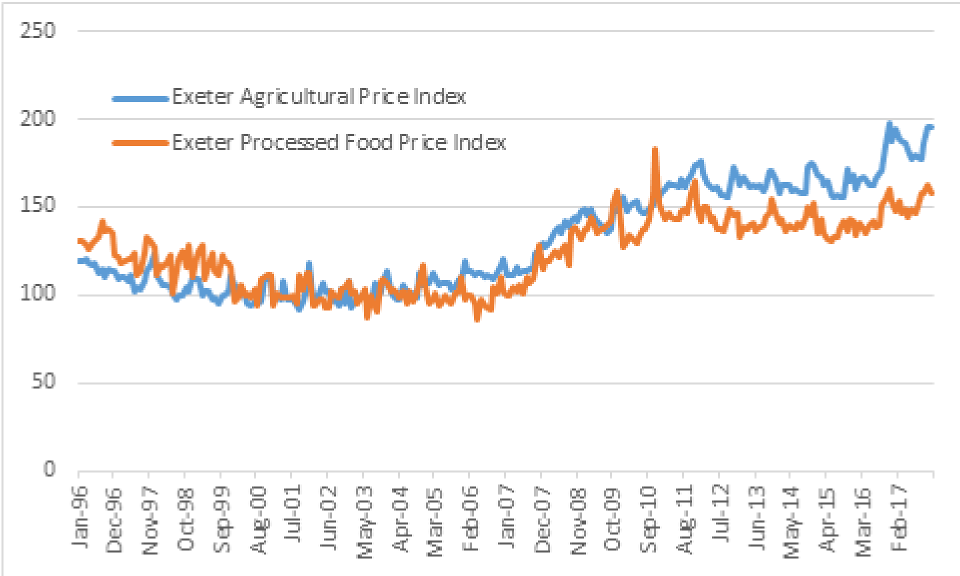


Figure 5 (c): Sugar



The Exeter price index for processed food is presented in Figure 6. For comparison, we also include the Exeter agricultural commodity price index as detailed above. Again with the caveat that the index relates more to the properties of the underlying dynamics of prices rather than price levels, the comparison of the price indices presented below suggest that processed food prices are more stable than agricultural commodity price indices. As noted, this will reflect the geographical sourcing of UK food imports and also the costs associated with processing: a common feature of the dynamics of food prices in downstream stages of the food chain is that prices exhibit less volatility. To the extent that agricultural commodities represent a low proportion of value added in the food processing sector, it is therefore of no surprise that the processed food price index is less volatile than the agricultural price index.

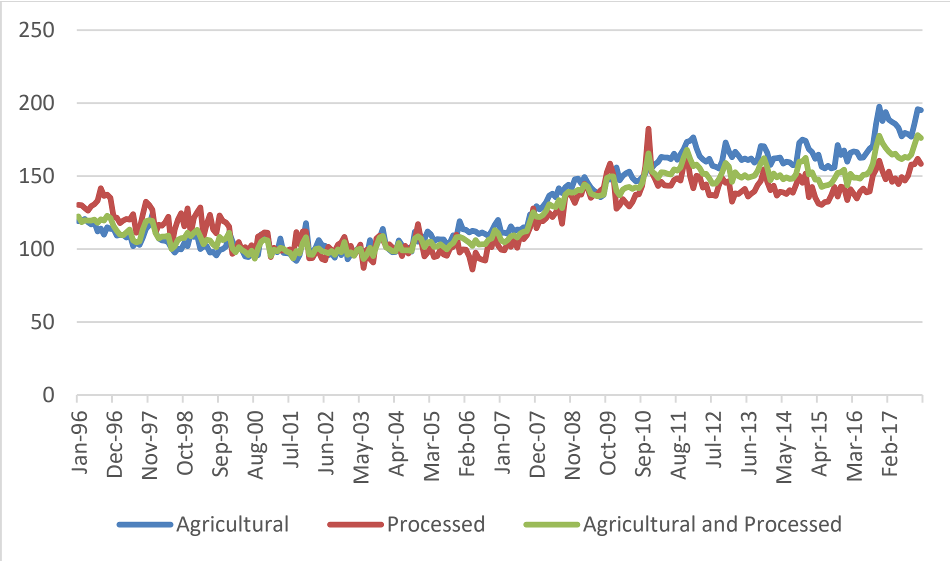
Figure 6: Processed Food Price Index Compared with Agricultural Commodity Price Index.



Agricultural and Processed Food and Drink

Finally, by appropriately weighting the sub-groups across all commodity groups as presented in Table 4, we can derive an overall 'Exeter' food price index which is presented in Figure 7. We include the comparison between the aggregate import price index and the corresponding agricultural and processed food price indices detailed above.

Figure 7: ‘Exeter’ Food Price Indices for Agricultural, Processed and All Food Imports.



Effective Exchange Rates

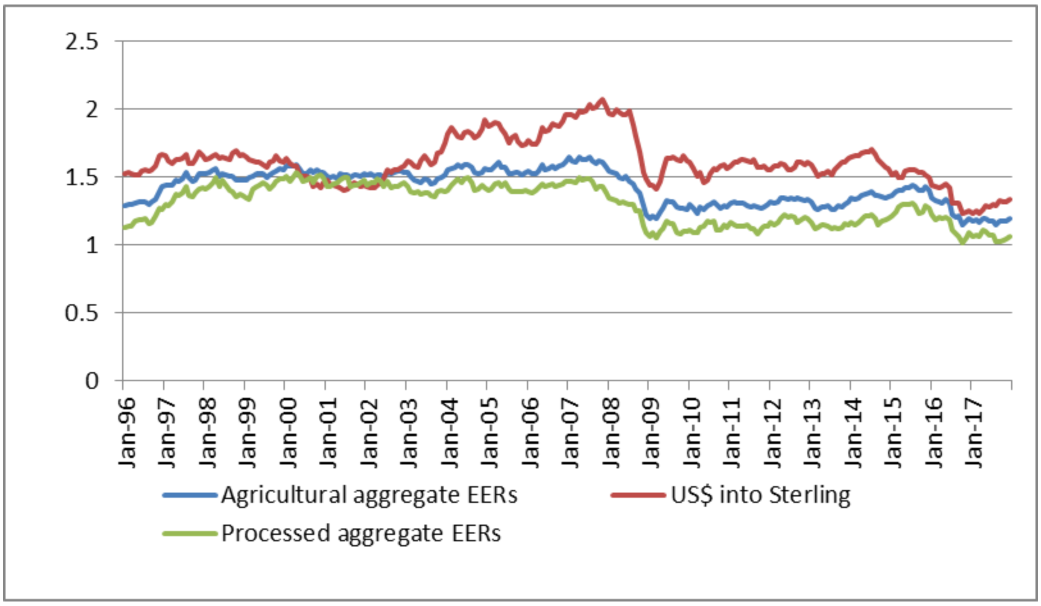
Owing to the importance of imports of food and drink to the UK food chain, exchange rates are an important determinant of domestic retail food inflation. Results from previous work (see Davidson *et al*., 2016) confirmed the important role played by the (US$:£) exchange rate on domestic food prices. As set out in Section 4, exchange rates also feature in the current specification, but need to be measured appropriately for the purposes at hand. Specifically, since the emphasis in the current model is on the source of imported commodities, we will need to incorporate an *effective* exchange rate, where the weights reflect the relative importance of key currencies used to purchase UK agricultural and processed food imports. This difference has implications for: (i) the interpretation of the exchange rate and how it is specified in the model; (ii) how the exchange rate is measured; and (iii) the effect of alternative trade agreement scenarios (future changes to the geography of UK food and agricultural imports will change the importance of each currency in the effective exchange rate).

We therefore created an effective exchange rate which reflected the basket of exchange rates associated with where the UK sources its imports from. Although effective exchange rates are available from external sources (e.g. from the Bank of England, the Bank for International Settlements or the IMF), none of these were suitable for the purpose at hand. This is because the weights on these publicly-available effective exchange rate indices specifically exclude agricultural and food trade. By reflecting the trade in manufactured goods (and, in some cases, trade in services also), such series misrepresent the costs of UK food trade. This made creation of a bespoke effective exchange rate series necessary.

Ideally, an effective exchange rate should weight the basket of currencies used by source of imports. However, since we are dealing with regions, we could not apply single country exchange rates; also, since we are aggregating across sub-commodity price indices, no single weighting can be applied since the import weights on grains, for example, will differ from that for beverages. Setting aside the regional aggregation for the moment, one way to deal with this is to create an effective exchange rate index corresponding to each commodity chapter and then subsequently apply the same weights to the j=1, . . .20 effective exchange rates that have been derived for the import price index. However, we had to make compromises in the number of bilateral weights that should be included and we needed to make some decisions to make the derivation functional. To this end, we assume that trade with EU partners was denominated in Euros, and that trade with non-EU regions was denominated in US dollars.

Details of the construction of the effective exchange rate series are given in the Appendix 2. For illustrative purposes, we report the effective exchange rates relating to UK trade in raw commodity imports and processed food imports in Figure 8. For comparison, we also show the US$:£ exchange rate that was used in the previous version of the food inflation model. The base period (2002-2004) is the same as that used in the derivation of the agricultural and processed food import price indices.

Figure 8: Effective Exchange Rates and the US$:£ Exchange Rates



Other Data Requirements

The import price indices and effective exchange rate indices constructed above represent pre-requisites that form the basis of the econometric model of UK retail food prices with the aim of assessing the potential impact of UK trade arrangements post-Brexit. However, as noted in Section 3 on the specification of the model, there are other factors that determine the rate of retail food price inflation. These primarily relate to domestic variables and, specifically, include factors that influence costs throughout the vertical food chain, including domestic agricultural prices, costs at the manufacturing level (excluding labour costs), and labour costs. These measures are however readily available from public sources and did not require construction. A key issue in selecting the additional variables was that the data had to have the same frequency as retail food inflation and the other variables in the econometric model: this was a potentially limiting factor with reference to some variables (particularly in relation to demand factors that, in principle, could be more accurate measures of demand for food but which are not available on a monthly basis). A full list of the potential variables, sources and presentation of the data is provided in Appendix 1.

6. Model Selection, Results and Interpretation

Overview

In this section, we highlight some important aspects of the estimation of the model that is set out in Figure 2. We estimated two versions of the model described in Figure 2: the first used the newly-derived import price index for raw agricultural products (and, associated with this, the appropriately-weighted 'agricultural products only' effective exchange rate); the second version used an import price index constructed from both raw agricultural products and manufactured food products (together with an appropriately-weighted 'all products' effective exchange rate, as detailed in Section 5). These price indices (and the effective exchange rate series) are the only ways in which the two versions of the model differ but since they relate to a very different characterisation of UK food trade, and to the structure of the vertical domestic food chain, it is anticipated that the results from each version will vary.

Given that the 'all products' model encompasses a broader range of inputs, it is this model that will be used to produce the final estimates of price transmission for the UK and for calculating the food inflation impacts of alternative post-Brexit scenarios. The 'agriculture only' import price model is more similar to the Defra I Model and hence its primary purpose will be to facilitate comparison. Aside from the differences in the import price indices and the effective exchange rates, all other variables in both specifications are the same. The results from the 'agriculture-only' model are reported in Appendix 5.

Econometric Methodology

To estimate the parameters of the model, we adopted a Co-integrated Vector Auto-Regression (C-VAR) model. Technical details relating to this econometric approach are given in Davidson *et al.* (2016) so the following merely provides a sketch of the econometric methods. A more extensive discussion of the details of model specification, model selection and statistical properties of the model are reported in Appendix 4.

In general terms, the C-VAR is given by standard vector auto-regression, namely:

$$\mathbf{x}_t = \mathbf{\Phi}_1\mathbf{x}_{t-1} + \mathbf{\Phi}_2\mathbf{x}_{t-2} + \ldots + \mathbf{\Phi}_p\mathbf{x}_{t-p} + \mathbf{\Psi}\mathbf{D}_t + \boldsymbol{\varepsilon}_t \qquad (1)$$

where $\mathbf{x}_t$ is a vector of I(1) variables containing the UK retail food price index ($FCPI_t$) and a set of sterling-denominated input costs that are likely to play a role in the price transmission process: the price of domestically produced agricultural output ($DAOPI_t$) and the non-agricultural costs of food production, namely, domestic labour costs (DLC_t), and non-labour manufacturing costs ($UKMIC_t$). Given that the UK imports a high proportion of its agricultural and food products, many of which are not produced domestically, we also include the price of agricultural and food imports ($IMPAM_t$). These five variables form the price transmission relations portrayed in Figure 1, which is expressed mathematically as the *Price Transmission Equation* below. Note that this equation does not include an explicit exchange rate variable since all variables are denominated in sterling. Thus, in the absence of augmentation, exchange rate effects would work through the prices of domestic and imported agricultural and food products indirectly.

As discussed in Section 2, exchange rates enter the model via a second equilibrium relationship in the system, described by the *Trade Equation* below. Recall that this describes how changes in the effective exchange rate of food imports affects the price of food imports directly and, in so doing, allow us to incorporate exchange rates into a price transmission model denominated solely in domestic currency. Given that the price of imported food is likely to affect, and be affected by, the price of domestically produce food, this second equilibrium relationship is formed of three variables, namely, the price of domestic and imported food and the effective exchange rate of food imports ($EERAM_t$).

The two economic equilibria can now be described mathematically as:

Price Transmission Equation

$$\log(FCPI)_t = \beta_{11}\log(\text{DAOPI})_t + \beta_{12}\log(\text{DLC})_t + \beta_{13}\log(\text{UKMIC})_t + \beta_{14}\log(\text{IPAM})_t \qquad (2a)$$

Trade Equation

$$\log(DAOPI)_t = \beta_{21}\log(\text{EERAM})_t + \beta_{22}\log(IPAM)_t \qquad (2b)$$

To re-cap, (2a) is the price transmission equation and corresponds to the price transmission relationships identified in the green box in Figure 2. Equation (2b), the trade equation, expresses the relationships among domestic agricultural products, imports and the effective exchange rate. This corresponds to the red box in Figure 2. Economic reasoning along the lines summarised in Table 1 suggests that all the coefficients in (2a) are positively signed, reflecting that costs into food chain increase retail prices. In the trade equation, 2(b), economic theory posits a positive relationship between the price of imports and domestic agricultural price (hence $\beta_{22} > 0$) reflecting that international and domestic prices have a tendency to move together over the longer term, other factors remaining constant.

The effect of the effective exchange rate in (2b) is expected to be negative. To recall, exchange rates impact on the price of both imported goods and domestic production. Other things held constant, a depreciation of Sterling against other currencies will make imports more expensive to UK consumers and UK produced products cheaper to foreign consumers. So, a depreciation of the effective exchange rate for agricultural and food imports leads to an increase in the demand for domestic agricultural production from purchasers overseas and hence an increase in its price in the long-run, other factors held constant. As such, $\beta_{21} < 0$ implies that domestic agricultural prices rise (fall) with an depreciation (appreciation) of the exchange rate.

Model Selection and Testing

The process of model search involved the estimation and testing of a wide range of models. The combination of variable choice, lag length, coefficient restrictions and robustness checking resulted in well over 100 candidate C-VARs being evaluated. Since there is no universal criterion for model selection among these candidates, the preferred specifications were selected on the basis of principally two criteria: economic plausibility and statistical adequacy. The econometric model was subject to a rigorous range of formal tests; the results from these formal tests confirm the existence of the two long-run equilibria in the data of the form described by equation (2a) and (2b). This approach to identification and statistical adequacy of the estimated model confers a good degree of confidence in the results that are obtained. A detailed discussion of the issues relating to model selection can be found in Appendix 5.

Interpreting Model Estimates: Long-Run Elasticities and Impulse Response Coefficients

There are principally two outputs from the C-VAR model. The first are the long-run elasticities contained in equations (2a) and (2b) that describe the long-run effect of one variable on another, holding other variables constant. For example, the estimate of β_{11} in equation 2(a) measures the percentage effect of a one per cent change in the domestic price of agricultural output on the retail prices of food, holding other factors included in the model fixed. Hence, if β_{11} is estimated at 0.25, this means that a one per cent increase (decrease) in domestic agricultural output is associated with a 0.25% increase (decrease) in the retail price of food, other factors held constant. Coefficients in (2b) have a similar interpretation and describe the *ceteris paribus* (other things held constant) effect on domestic agricultural prices. Hence, if the estimate of β_{22} is 1.20, this means that a one per cent increase (decrease) in the prices of agricultural and food imports is associated with a 1.2% increase (decrease) in the retail price of food, other factors held constant. Coefficients less than unity imply the relationship is inelastic, those greater than unity, that the relationship is elastic.

There are three facets to this interpretation that are worthy of note. First, it is the *long-run effect* that is being measured, and hence each elasticity quantifies the effect at the end of the adjustment process. The elasticity does not indicate how long the adjustment takes nor the nature of the adjustment process, it simply measures the eventual effect. Second, estimates of the long-run elasticities are predicated on the *ceteris paribus* clause and, as such, explicitly ignore any indirect effects that that are mediated through other variables. Third, coefficients in the second equilibrium relation measure the effect of changes to import prices and the effective exchange rate on domestic agricultural output and not retail food prices. Hence, in order to assess the effect of changes to the effective exchange rate on retail prices, we need another measure that will estimate this link. Fortunately, this is accomplished by the second key set of outputs from the C-VAR, the impulse response coefficients.

In contrast to the long-run elasticities, which measure the *long-run effect* keeping other variables held fixed, impulse response coefficients measure the *dynamic effect* of a shock to one variable on another and incorporate knock-on and feedback effects among the variables in the system. In this regard, the impulse response coefficient is akin to the total effect of a change, whereas the long-run elasticity measures the partial effect. Furthermore, rather than deliver a single coefficient, the impulse response function traces the effect of a change throughout the adjustment process and thus is informative about the speed and nature of dynamic adjustment, not just the long-run effect.

Given their construction, impulse response functions are useful to address the 'what if'-type questions posed in scenario analysis where the object is to provide an estimate of the effect of a shock (or set of shocks) that takes into account dynamic interactions of the variables under consideration (i.e. the total effect of a shock or set of shocks). The relevance of this in the context of food price modelling under various trade scenarios is evident, not least because changes to the effective exchange rate indices for example are likely to induce changes across the food system as a whole, involving import prices, domestic agricultural prices and potentially other food production costs. Consequently, we will use the coefficients from the impulse response function as the principal measure of responsiveness and measure the effect of 10% changes in each of the variables. Figures will also be produced to describe the impulse response functions which deliver the dynamic effects (over 36 months) of changes in the variables on food prices.

We will begin however by reporting the long-run elasticities. These are useful in their own right because they represent the coefficients (such as β_{11} and β_{22}) of the equilibrium equations (2a) and 2(b). Notwithstanding the relevance of using the impulse response functions to gauge the effects of shocks of food price drivers on food inflation, the elasticities are useful in understanding and confirming the economic intuition behind the inclusion of each of the variables. Results are provided for (i) the model containing imports of only agricultural products and (ii) the model containing imports of agriculture and processed food imports.

Results: (i) Long-Run Elasticities using the Import Price Index for Agricultural Products

The specification with the import price index for agricultural commodities is presented in Table 5 below. This specification is 'closest' to the Defra I model insofar as the import structure relates to unprocessed agricultural commodities, given that this was the main characteristic of the world price index used in previous research. Table 5 consist of two panels of long run elasticities. In the top panel, the coefficients represent the long-run transmission elasticities of retail food prices with respect to each source of cost and represents the empirical estimates of equation 2(a) in the 'agricultural imports only' model. The bottom panel shows the results for the second relation, equation 2(b), showing the long-run elasticity of domestic agricultural output prices with respect to import prices and effective exchange rates in the agricultural imports-only model. All the elasticities are statistically significant at the 5% level of significance, as indicated by the *p*-values reported in the table.

In the top panel, which shows the coefficients of the price transmission relation, the results summarise how costs are passed through the vertical food chain. All elasticities are less than unity, as would be expected given that any one component represents a fraction of the retail good. In terms of the magnitude of the relevant elasticities, retail food prices are most sensitive to changes in labour costs, with an elasticity of 0.256. Hence the model estimates that a 10% increase in labour costs increases retail food prices in the long run by 2.5%, other factors held fixed. Agricultural prices (whether domestic or imported) are also important drivers of retail food prices with domestic agricultural output prices having a higher transmission elasticity relative to the import price index (0.242 and 0.162 respectively). In other words, the model estimates that a 10% increase in domestic agricultural prices increases retail food prices in the long-run by 2.4%, other factors held fixed; a 10% increase in import prices of agricultural products increases retail food prices in the long-run by 1.6%, other factors held fixed. The larger response to domestic food prices is consistent with the importance of domestic production in retail food. Taking both together, these *ceteris paribus* elasticities suggest that changes in domestic and imported agricultural commodities are slightly more important drivers of retail food prices compared with labour costs. Other (non-labour) manufacturing input costs such as energy are also important, the estimated elasticity being 0.143.

The bottom panel of Table 5, which describes the elasticities of the trade relation, shows that domestic prices sensitive to the agricultural import price index and the effective exchange rate with the transmission elasticities being 0.906 and -1.44 respectively. Hence, for example, a 10% increase in the price of agricultural imports leads to a long-run increase in domestic agricultural prices of around 9%. While not one-for-one (owing to differences between domestically produced imports agricultural products), the relationship is indicative of the close links between the UK and international commodity markets. The response of domestic agricultural prices to changes in the effective exchange rate are even larger, such that a 10% depreciation of Sterling against the trade weighted basket of currencies leads to a 14% increase in domestic agricultural prices. These estimates highlight the sensitivity of domestic agriculture to international factors[4].

Note that there are two underlying mechanisms that can account for the strength of the relationship between effective exchange rates and domestic output prices. First, as Sterling depreciates, this increases the cost of agricultural and food imports which, in turn, increases the demand for domestic output hence driving up prices. Second, the depreciation of Sterling will also make UK agricultural

[4] If instead we re-cast the relationship reported in the bottom panel of Table 5 in terms of the agricultural import price index rather than domestic agricultural output prices, in order to measure the effect a percentage increase in the effective exchange rate on import prices, the elasticity would be (0.906/-1.44 =)-0.694. This is less than unity but consistent with estimates of effective exchange rate elasticities reported in the literature (e.g. Gilbert, 1989).

exports cheaper in world markets; this gives an additional kick to the demand for domestic output which therefore also contributes to the strength of this relation.

Table 5: Estimates of Long-Run Elasticities: Model Using Agriculture-Only Import Prices and Effective Exchange Rates

Elasticity of UK retail food prices ($FCPI_t$) with respect to:	
Index of UK agricultural output prices (*DAOPI*$_t$)	0.242 (0.001)
Domestic labour costs (*DLC*$_t$)	0.256 (0.000)
UK manufacturing other input costs (*UKMIC*$_t$)	0.143 (0.050)
Import price index for agricultural products (*IPA*$_t$)	0.162 (0.012)
Elasticity of UK agricultural output index (*DAOPI*$_t$) with respect to:	
Import price index for raw agricultural products (*IPA*$_t$)	0.906 (0.006)
Effective exchange rate for raw agricultural imports (*EERA*$_t$)	-1.440 (0.000)

Numbers in parentheses are *p*-values and indicate the significance level of a hypothesis test evaluating the zero null. Hence a *p* value of 0.05 means that the coefficient is statistically different from zero at the 5% significance level (i.e. with 95% confidence).

Results: (ii) Long-Run Elasticities using Import Price Index for Agricultural and Manufactured Products

In Table 6, we present the results for the model that uses the import prices and effective exchange rate series that relate to agricultural commodities and processed foods. Otherwise, the specification is the same as that reported in Table 5. Coefficient estimates are very similar in the first (price transmission) relation, (e.g. the long run elasticity of retail food prices with respect to domestic agricultural prices is 0.236 in Table 6 compared with 0.242 in Table 5). Given that most of the variables in the price transmission relation are identical, the similarity is unsurprising, although a larger difference in the import price coefficient might have been expected given the importance of manufactured food in retail prices. The estimate in Table 6 suggests that the *ceteris paribus* effect of a 10% increase in the prices of agricultural and food imports is to increase retail food prices by 1.7% in the long run, compared to 1.6% when considering the prices of agricultural products only.

Overall, even though we are accounting for a wider range of imports (as the price index now accounts for imports of processed food as well as raw agricultural imports), domestic factors still have the most dominant impact on UK retail prices. The coefficient on the import price index increases (albeit marginally, from 0.162 per cent as reported in Table 5 to 0.168 per cent as reported in Table 6). Other manufacturing costs have become (marginally) less important though domestic labour costs more so. The latter may reflect that despite accounting for semi- and highly processed food imports, these products still enter the food chain and still reflect costs borne in the retail food sector.

Greater differences are apparent in the second (trade) relation. As expected, inclusion of processed foods imparts a larger impact on domestic output prices than with purely agricultural output (with an elasticity of 1.170 compared to 0.906). Hence the model estimates suggest that the *ceteris paribus* effect of a 10% increase in import prices for agricultural and food imports is 12% compared to 9% for agricultural only prices. Similarly, the effective exchange rate elasticity increases (from 1.440 to 1.847). These results demonstrate that domestic agricultural output prices are more sensitive to international factors when specified with a price index that includes a broader set of products. Given that these products include processed food as well as raw commodities, and it is the former which represents a growing proportion of imports, the results are consistent with a heightened role for international factors.

In summary, both specifications of the model, whether including agricultural or agricultural and processed imports, tell a very similar story. In terms of the *ceteris paribus* effects reported in this section, both models indicate that retail food prices are as responsive to domestic labour costs as domestic agricultural product prices. Indeed, in both models retail prices are more responsive to labour costs, albeit marginally so. Other manufacturing costs and import prices play an important but somewhat secondary role. The results also highlight the sensitivity of domestic agricultural prices to international factors and suggest that the latter play a more important role when the data includes a more complete spectrum of agricultural and food imports. Given that a growing proportion of imports that enter the UK are in processed forms, and that these manufactured imports are likely to be subject to future trade measures, this sensitivity may play a key role as a result of the UK's departure from the EU. However, given the *ceteris paribus* nature of the price transmission elasticities a more complete picture of the impacts on domestic and international factors on retail food prices requires interactions between the variables to be accommodated. With this in mind, attention now turns to the impulse response analysis.

Table 6: Estimates of Long-Run Elasticities: Model Using Agriculture and Food Import Prices and Effective Exchange Rates

Elasticity of UK retail food prices ($FCPI_t$) with respect to:	
Index of UK agricultural output prices ($DAOPI_t$)	0.236 (0.001)
Domestic labour costs (DLC_t)	0.306 (0.000)
UK manufacturing other input costs ($UKMIC_t$)	0.135 (0.055)
Import price index for agricultural and manufactured food products ($IPAM_t$)	0.168 (0.009)
Elasticity of UK agricultural output prices (i_t) with respect to:	
Index of import price index for agricultural and manufactured food products ($IPAM_t$)	1.170 (0.003)
Effective exchange rate for agricultural and manufactured food imports ($EERA_t$)	-1.847 (0.000)

Numbers in parentheses are *p*-values and indicate the significance level of a hypothesis test evaluating the zero null. Hence a *p* value of 0.05 means that the coefficient is statistically different from zero at the 5% significance level (i.e. with 95% confidence).

Results: (iii) Impulse Response Functions

Reporting long-run elasticities is a useful means for summarising how individual variables may impact on the dependent variable and to highlight the statistical significance of each of the variables; they are also an important check detailing whether relationships between variables in a complex model are consistent with economic intuition. However, as explained above, the elasticities are *ceteris paribus* in nature meaning that they are premised on other influences remaining unchanged. In a vector autoregressive framework as we have here, shocks in one variable will potentially have an impact on other variables so that the 'final' effect of the variable of interest will depend on how all variables adjust to a shock and, given the inherent lags in the responses, will take some time to fully evolve. While both elasticities and impulse response functions indicate the long-run effects, results from impulse response analysis incorporate these knock-on and feedback effects at each point in the adjustment process and so give a more realistic estimate of what might actually happen following a shock to one of the variables (and hence measure the total effects of a change rather the partial effects). Furthermore, impulse response analysis allows us to estimate the effect of exchange rates on domestic retail prices, something that the partial elasticities do not.

Given the similarity of numerical estimates in the specifications used for Tables 5 and 6, we confine the impulse response analysis to the model using data for agricultural and food import prices hence the impulse response coefficients reported in this section relate to the version of the model reported in Table 6. Results for the agricultural only model are reported in the Appendix 5.[5] Figure 9 presents the impulse response function of food prices over a 36 month period to 10 per cent shocks in (i) import prices and (ii) the effective exchange rate and (iii) domestic agricultural prices. In Figure 9(i), the impulse response given a shock in the import price index on retail food prices is shown. The results imply that the net result of a 10 per cent rise in the import price index will be to increase retail food prices in the long run by 1.8 per cent once all the indirect effects have worked through. As can be seen, adjustment is a gradual process that unwinds over a long period. The full effect materialises over a 3 year period; in the shorter term (3 months), the 10 per cent rise in the import price index is predicted to increase retail food prices by around 0.36 per cent. Note that the shock to import prices has a permanent impact; this arises due to strong trends in the underlying data series which means that a temporary shock manifests as a step-change in import prices. In response, food prices settle at a new higher level that does not fall unless import prices fall.

In Figure 9(ii), we show the impact of a shock to the effective exchange rate. The plot implies that the effect of a 10 per cent rise (appreciation) in the effective exchange rate is to decrease retail food prices by around 0.6 per cent in the short term (3 months) culminating in a long-run decrease of 2 per cent once all the indirect effects have worked through. A 10 per cent depreciation would have the opposite effect, resulting in a 2 per cent increase retail food prices in the long run. These results imply that the exchange rate effect imparts a slightly stronger impact than an equivalent change in import prices alone, a result that is likely to reflect that the exchange rate impacts on exports as well as imports. The relatively strong impact arising from exchange rate effects is consistent with the insights from Defra I.

[5] Numerical estimates of the import price and effective exchange rate effects in the agriculture only model are slightly smaller than those reported in Figure 9 and Table 7 which relate to the sum of agricultural and manufactured food price imports. This is consistent with the theory of price transmission that the further up the supply chain, the impact of price shocks is weaker. It should be borne in mind, however, that even though the estimates from the two specifications of the import price indices are relatively close, the scenarios to which they will be used will give different insights (and quantitatively different results) given the range of tariffs and non-tariff measures that affect trade in processed food products.

Figure 9: Impulse Response Functions of Retail Food Prices for Alternative Shocks (Based on Econometric Results Reported in Table 7)

Figure 9(i): 10% increase in Import Prices

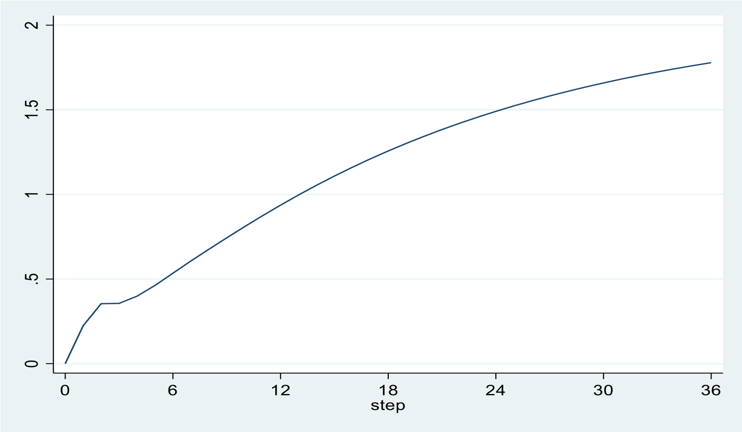


Figure 9(ii): 10% Appreciation in Effective Exchange Rate

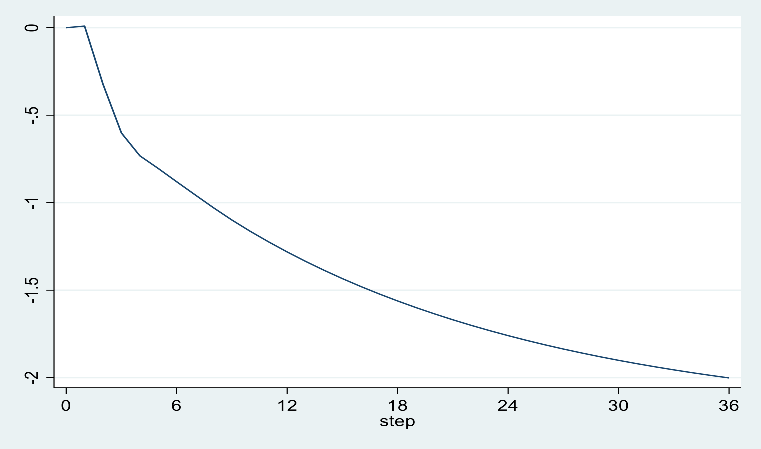
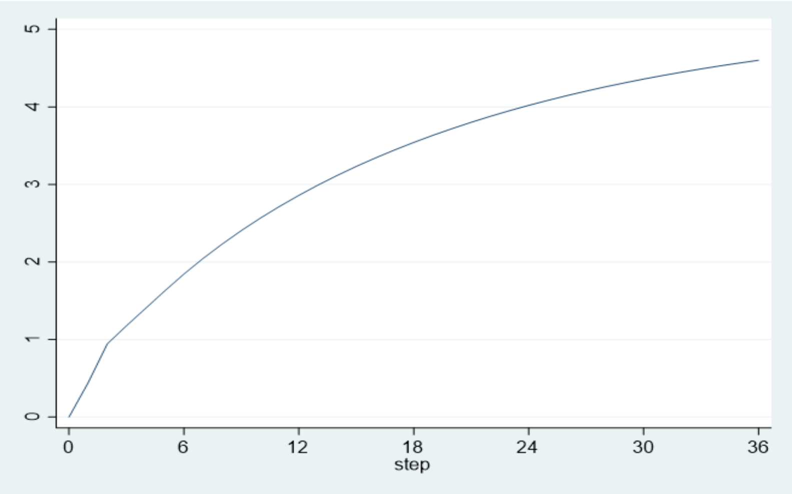


Figure 9(iii): 10% increase in Domestic Agricultural Prices



In Figure 9 (iii), the effect of an increase domestic agricultural output prices. As is evident, this also increases food prices; in this case, retail food prices rise in the short term by 1.2 percent rising to a level 4.6 per cent higher in the long run, more than double the effect of an equivalent change in import prices. While larger than may have been expected it is consistent with the fact that domestic output represents a larger share of UK retail food than imports.

The observation that domestic agricultural output prices are more influential in the price transmission process than import prices may also point to an additional dynamic interaction following shocks to domestic prices that are absent or at least weaker following shock to import prices. While explanations are inevitably conjectural, the finding may simply reflect the different composition of products that are domestically-produced and imported. For example, whereas changes in the prices of domestically-produced dairy and beef may lead to import prices for these products rising, the same would not occur for non-indigenous products (such as cocoa and bananas). This is not to say that domestic prices affect world prices, but the evidence certainly points to the prices of the products that the UK imports responding in this way. On this point, recall from Table 6 the long-run elasticities (which measure the effects keeping other factors fixed) with respect to domestic and import prices (0.246 and 0.168 respectively) differ somewhat less than the long-run impulse response coefficients, indicating that domestic prices have stronger knock-on effects into retail prices than import prices.

For ease of exposition, we also summarise the dynamic effects of the variables plotted in Figure 9 (and the other variables included in the model) in Table 7, labelling the impulse response coefficients at 3, 12 and 36 months following a 10 per cent shock as the short, medium and long run effects.[6] Focussing on the long-run effects, it is evident that domestic agricultural prices consistently play an important role as a driver of retail food prices. Manufacturing costs (whether labour or other costs such as energy and raw materials) also play important roles. Estimates presented in the table suggest that these costs have larger effects than food import prices or effective exchange rates, underlying the importance of the costs that impact on the food chain in UK food prices. This, of course, is not to infer that international costs do not matter; they do. But the role of domestic factors has increased and this observation is consistent with the evidence reported in Table 2 with reference to the updated Defra I model.

Table 7: The Estimated Dynamic Response of Food Prices (%) to a 10% Change 3, 12 and 36 Months following Specific Shocks

Variable being shocked by 10%	Effect on Food Prices (%)		
	Short-run (3 months)	Medium-run (12 months)	Long-run (36 months)
Domestic Agricultural Prices ($DAOPI_t$)	1.18	2.86	4.60
Domestic Labour costs (DLC_t)	0.35	1.24	2.29
Domestic (non-labour) input costs in UK manufacturing ($UKMIC_t$)	0.00	1.22	2.74
Agricultural and food import prices ($IPAM_t$)	0.36	0.94	1.78
Effective Exchange Rate $EERAM_t$	0.60	1.28	2.00

[6] The choice of 3, 12 and 36 months is somewhat arbitrary. All impulse response functions are plotted throughout the forecast horizon in the figures above, so the table merely offers a useful summary of the estimates based on the impulse response coefficients at the 3, 12 and 36 month horizons.

7. Extension: Food Prices and Income Deciles

The potentially disparate impact of high food prices across different income groups is a well-known observation in the economics literature. Engel's Law suggests that, since lower income groups spend a higher proportion of their disposable income on food products, the impact of high food prices on lower income groups will be more significant compared with high income groups that spend a lower proportion of their income on food. In this section, we explore the potential for different income deciles to be impacted differentially by changing food prices. However, the focus of the mechanism via which food prices may have an impact across different income deciles is distinct from the well-known Engel effect; specifically, since the weights on the composition of individual food groups may vary across income deciles, for a given change in any of the factors that may affect price transmission throughout the food chain, the transmission mechanism itself may vary across income groups. For example, if one income group spent a high proportion of their food expenditure on specific forms of food from a specific geographic region and the composition of food expenditure for a different income group relied on different categories of food from an alternative geographic source, a change in the import price index will be transmitted differentially across these income groups. This inflation transmission effect is in addition to the Engel effect and, as far as we are aware, has received only limited attention in the economics literature to date.

We provide some insights into addressing this issue. To do so, however, required addressing a number of challenges primarily relating to constructing retail food price indices for each income decile that will replace the more readily-available economy-wide average retail food price index that has been used in the model estimates above. Following the construction of the new income decile-specific price indices, we then re-estimated the econometric models as set out above and explored the extent to which the transmission elasticities vary across income groups. We confine the results to the lowest and highest income deciles, and also note other socio-economic dimensions where the impact of retail food price effects may be identified with suitably-constructed data series.

Data Issues

There were two main steps in deriving the decile-specific price indices. First, expenditure on dis-aggregated food groups by income decile had to be employed in order to derive the shares of expenditure spent on specific food items. Second, when the shares have been derived, they needed to be matched with the price information used to construct the Retail Prices Index (RPI) for the identical food groups to produce decile-specific price indices.

We sourced income decile food expenditure data from the *Living Costs and Expenditure Survey* published by the Office of National Statistics (ONS). This source provided annual information on expenditure across all goods and services purchased by consumers, one category of which is food expenditure. Within this category (which excludes expenditure on food purchased for consumption outside the home, such as restaurant meals), there are data on consumer spending on specific food groups (such as bread, milk and beef) for each income decile of the UK population. Expressing this expenditure as a share of total food expenditure (where the latter category excludes food away from home), we were able to compute the weights of each food category by income decile. In Table 8, we reproduce the base data source for a given year (2016).

Table 8: Food Expenditure on Specific Food Groups across Income Deciles, 2016 (Weekly Expenditure, £)

	Lowest ten per cent	Second decile group	Third decile group	Fourth decile group	Fifth decile group	Sixth decile group	Seventh decile group	Eighth decile group	Ninth decile group	Highest ten per cent	All house-holds
Bread, rice and cereals	2.60	3.30	4.00	4.80	5.00	5.80	5.70	6.20	7.00	7.00	5.10
Pasta products	0.20	0.30	0.30	0.40	0.40	0.50	0.50	0.60	0.60	0.60	0.40
Buns, cakes, biscuits etc	2.00	2.50	3.10	3.70	3.60	4.00	3.90	4.10	4.90	5.30	3.70
Pastry (savoury)	0.40	0.40	0.60	0.70	0.90	0.90	1.00	1.20	1.20	1.20	0.80
Beef (fresh, chilled or frozen)	0.70	1.10	1.50	1.70	2.00	1.90	1.90	2.10	2.90	3.30	1.90
Pork (fresh, chilled or frozen)	0.40	0.30	0.50	0.50	0.70	0.70	0.60	0.70	0.70	0.70	0.60
Lamb (fresh, chilled or frozen)	0.30	0.40	0.50	0.60	0.60	0.60	0.60	0.50	0.80	0.80	0.60
Poultry (fresh, chilled or frozen)	0.80	1.20	1.50	1.80	2.30	2.50	2.80	2.70	3.50	3.60	2.30
Bacon and ham	0.40	0.70	0.90	0.80	0.90	0.90	0.80	1.10	1.00	1.20	0.90
Other meat and meat preparations	3.40	4.60	5.20	5.70	6.00	6.30	6.70	7.70	7.30	8.50	6.10
Fish and fish products	1.50	1.80	2.00	2.20	2.50	2.80	3.00	3.10	4.00	4.50	2.70
Milk	1.40	1.80	1.90	2.20	2.30	2.50	2.20	2.40	2.30	2.40	2.10
Cheese and curd	0.90	1.10	1.40	1.60	1.90	2.00	2.30	2.60	2.80	3.10	2.00
Eggs	0.40	0.50	0.50	0.60	0.70	0.70	0.80	0.90	0.90	1.00	0.70
Other milk products	1.00	1.40	1.60	2.00	2.10	2.30	2.50	2.70	2.90	3.20	2.20
Butter	0.20	0.30	0.40	0.40	0.40	0.30	0.40	0.50	0.50	0.50	0.40
Margarine, other vegetable fats and peanut butter	0.40	0.40	0.40	0.50	0.50	0.50	0.50	0.50	0.60	0.60	0.50
Cooking oils and fats	0.20	0.20	0.20	0.40	0.30	0.30	0.40	0.40	0.40	0.40	0.30
Fresh fruit	1.60	2.20	2.80	3.00	3.70	3.90	4.40	4.70	5.60	6.40	3.80
Other fresh, chilled or frozen fruits	0.20	0.20	0.30	0.50	0.50	0.40	0.50	0.50	0.60	0.70	0.50
Dried fruit and nuts	0.40	0.40	0.50	0.60	0.70	0.90	0.90	1.20	1.30	1.50	0.80
Preserved fruit and fruit based products	0.10	0.10	0.10	0.10	0.20	0.20	0.10	0.20	0.20	0.20	0.10
Fresh vegetables	1.70	2.20	2.70	3.30	3.90	4.10	5.00	5.20	6.30	6.90	4.10
Dried vegetables	[0.00~]	[0.00~]	[0.00~]	0.10	0.10	0.10	0.00~	0.10	0.10	0.10	0.10
Other preserved or processed vegetables	0.70	0.80	1.10	1.40	1.30	1.60	1.70	2.10	2.30	2.40	1.50
Potatoes	0.40	0.60	0.70	0.80	0.80	0.80	0.80	0.90	1.00	0.90	0.80
Other tubers and products of tuber vegetables	0.90	1.20	1.20	1.50	1.70	1.80	1.60	1.90	2.10	1.90	1.60
Sugar and sugar products	0.20	0.30	0.30	0.30	0.40	0.40	0.50	0.40	0.60	0.50	0.40
Jams, marmalades	0.20	0.20	0.20	0.30	0.30	0.40	0.30	0.40	0.30	0.40	0.30
Chocolate	0.90	1.20	1.50	1.70	1.80	2.00	2.30	2.20	2.70	2.80	1.90
Confectionery products	0.40	0.60	0.60	0.70	0.90	0.80	0.80	1.00	1.00	0.90	0.80
Edible ices and ice cream	0.30	0.40	0.40	0.60	0.70	0.60	0.60	0.70	1.00	0.80	0.60
Other food products	1.10	1.40	1.80	2.10	2.40	2.40	2.80	3.20	3.80	4.20	2.50
Coffee	0.40	0.60	0.90	0.70	0.90	0.80	0.90	1.20	1.10	1.30	0.90
Tea	0.30	0.40	0.50	0.40	0.40	0.50	0.50	0.60	0.60	0.60	0.50
Cocoa and powdered chocolate	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.10	0.10	0.10
Fruit and vegetable juices (inc. fruit squash)	0.50	0.50	0.70	0.90	1.00	1.10	1.10	1.30	1.50	1.80	1.00
Mineral or spring waters	0.20	0.20	0.20	0.40	0.40	0.40	0.50	0.40	0.50	0.60	0.40
Soft drinks (inc. fizzy and ready to drink fruit drinks)	0.90	1.30	1.30	1.80	2.10	2.00	2.10	2.20	2.30	2.30	1.80
	28.70	37.20	44.40	51.90	57.40	60.90	64.10	70.50	79.30	85.20	57.80

Source: Living Costs and Expenditure Survey, 2017.

Our data coverage for the econometric model covers the period, 1996 -2017. Given this almost 20 year time span, it is feasible that tastes and diets may have changed both within and across income deciles. To address this issue, we therefore sourced food expenditure for all years of our data coverage to derive annual weights for specific food groups across each income decile. These annual weights will therefore form the basis of the new income decile price indices employing a chain-linked process to allow for the weights to vary annually.

The next step was to source price data that matches the specific food groups shown in Table 4 above. These data were sourced from the ONS and, for most food groups, are available for the full period. However, in a limited number of cases, there appeared slight changes in the product coverage of the food groups (e.g. relating to the definition of 'other food products') and, in such cases, we applied a concordance across product groups to derive a uniform price series.

Differences in Food Inflation across Income Deciles

The decile-specific food price indices are derived using the combination of chain-weighted annual weights and price series for the main 26 food groups listed in Table 4 above. Due to a re-categorisation of the expenditure data in the late 1990s which provided an amendment to the data series, we constrained the time period of the data coverage to 2000-2017.

To investigate how food inflation may differ across income deciles, we derived the food inflation level for both the lowest and highest income deciles. This comparison is shown in Figure 10. As is evident from the figure, the food inflation experience differs between these two groups: given that the price series is a common input into the derivation of the inflation indices, the difference in food inflation experienced by the poorest and richest deciles arises from differences in the baskets of food that they consume, as measured by the time varying weights that are applied by these income groups over the time period.[7] We also compare the food inflation experiences of the lowest and highest deciles compared to 'all households'. This is presented in Figure 11.

In interpreting these data, when the observations lie above (below) the horizontal axis, this indicates that the lowest income decile faces higher (lower) food inflation than the highest income decile. While there is no particular pattern to these contrasting inflation experiences, the data clearly point to notable differences. The most obvious pattern is that the comparative experience of food inflation across deciles has considerably more variation in the period from 2007 onwards. This period coincided with commodity price shocks on world markets and which were also evident in the 'Exeter' import price indices as reported in Figures 4-6 above. In terms of retail food prices, food inflation in the UK was more volatile in this period (Lloyd *et al*., 2015).

[7] Note that while the data allow us to detect differences in consumption patterns *between* food categories by income decile, the data are not sufficiently detailed to detect differences in quality within food categories.

Figure 10: Differences in Food Inflation Experience between Lowest Income Decile Compared with Highest Income Decile.

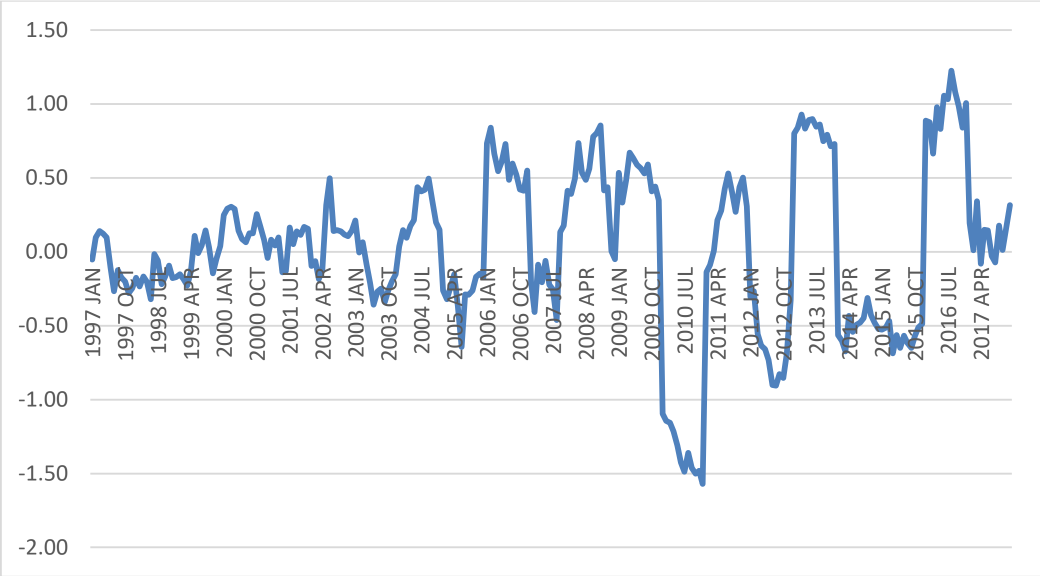
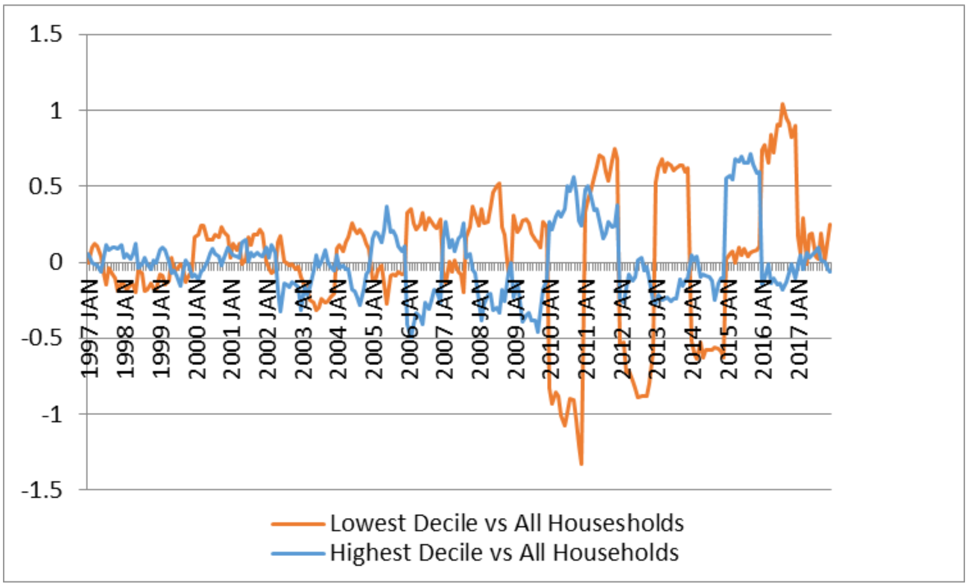


Figure 11: Differences in Food Inflation Experience between Lowest and Highest Income Deciles Compared with All Households



Estimating the Price Transmission Effects by Income Decile

In Table 9, we report the results from estimating the econometric specification with imports inclusive of both agricultural products and processed food imports, as presented in Table 6 above. Bearing in mind the caveat relating to the differences between the partial elasticity effects and the impulse response impacts, we confine the discussion here to the transmission elasticities for ease of comparison across different groups. The key difference with the results presented here is that the dependent variable in each case relates to the income decile-specific price index. A comparison of the long-run elasticities between the lowest and highest deciles indicates close similarities in the magnitude of the elasticities. There are notable difference in the magnitude of the elasticities: for domestic labour costs, the transmission elasticity for the lowest decile is 46 per cent higher than the labour cost transmission elasticity for the highest decile (0.174 per cent compared with 0.119 per cent0; for the import price index: the ratio of the difference being around 11 per cent (0.161 versus 0.145).

This difference in the import price elasticities is consistent with the inflation experience of the two deciles reported in Figure 10 above. It is evident from that figure that retail food inflation for the lowest income deciles is more variable than the highest decile. The relatively higher transmission elasticity is consistent with this as it implies that changing import prices have a greater impact on the lowest decile both when import prices are rising and when they are falling.

Table 9: Long-Run Elasticity Estimates over Different Income Deciles: (Lowest Income Decile and Highest Income Decile)

	Lowest Income Decile	Highest Income Decile
Elasticity of UK retail food prices (r_t) with respect to:		
Index of UK agricultural output prices (p_t)	0.329 (0.000)	0.392 (0.000)
Domestic labour costs (d_t)	0.174 (0.012)	0.119 (0.138)
UK manufacturing input costs (m_t)	0.119 (0.024)	0.113 (0.060)
Import price index for agricultural and manufactured products (i_t)	0.161 (0.013)	0.145 (0.070)
Elasticity of Index of UK agricultural output prices (p_t) with respect to:		
Import Price Index for agricultural and manufactured products (i_t)	1.308 (0.000)	1.300 (0.000)
Effective exchange rate for agricultural imports(a_t)	-0.725 (0.031)	-0.702 (0.000)

To re-cap, the main insight from the results presented in Table 9 is that the inflation transmission mechanism can vary between income deciles and that the effect of changes in the prices of food and agricultural imports is in addition to the impact associated with Engel's Law. However, these differences in the transmission elasticities do not translate into significant differences in the outcomes from impulse responses which imply that there are some offsetting factors that countervail the impact of import prices. This issue is worthy of further research (for example, by also accounting for the overall expenditure in food across income deciles).

8. Extension: Food Price Transmission and Entry of Discounters

We also extend the analysis to consider the potential impact of the entry of discounters into the UK retail food sector. Market shares of discounters have increased significantly since 2010 and may have affected the functioning of the incumbent main retailers. In the context of the current research, we address whether the entry of retailers would have had an impact on the estimated transmission elasticities. Before proceeding, we should note three caveats to avoid inappropriate interpretation of the results.

First, the model presented here is based on the time series properties of price series: it is not a structural model of competition that would be employed to formally test the impact of market entry on prices or the competitive behaviour of incumbent firms. Second, to the extent that the entry of discounters did have an effect on the functioning of food chains as a whole, all or some of the transmission elasticities could have changed. Moreover, attributing the observed changes to this cause ignores the effects of other factors that have changed over the period whose effect may weaken or strengthen any discounter effect. Third, to the extent that recent theoretical and empirical research addresses how price transmission and competition in specific markets, the outcome of this research has shown that the impact of increasing competition on price transmission is potentially ambiguous. In principle, while it may be expected that more competition increases price transmission (see, for example, McCorriston *et al*., 1998), more intense competition could reduce price transmission if the market was highly concentrated to begin with.

With these caveats in mind to caution against over-interpretation of the impact of increased competition in the UK food sector, we estimated an additional version of the econometric model that applies to the imports of processed and raw agricultural commodities. In this version of the model, the data end point was constrained to December 2011 when the discounters may have initially been making an impact; these results are compared with data covering the full sample period when the impact of discounters on the UK retail food sector would have been more fully materialised. The results from this comparison are presented in Table 10 below.

As can be seen from the results, transmission elasticities have changed from the earlier sample period (1996-2011) through to the later period (1996-2017). Elasticity estimates change in different directions: for domestic agricultural prices, the transmission elasticity increases from 0.062 per cent to 0.236 per cent. For imported agricultural and processed food products, the elasticity has decreased. These changes may reflect other factors, for example, changes in domestic sourcing over the two periods.

In terms of the impact of international factors on domestic agricultural prices in the second co-integrating relation, a comparison of the two sample periods also indicates a significant change in the transmission elasticities: the transmission elasticity with respect to import prices has decreased (1.170 compared with 1.453), while the elasticity with respect to the effective exchange rate has more than doubled (1.852 versus 0.715). These results would seem indicative of domestic agricultural prices being more exposed to international factors in the discounter-inclusive period, which would also translate into more variable food inflation given that the elasticity of retail food prices to domestic agricultural prices has also increased significantly in this time period.

In broad terms, the evidence base for the early period requires further enquiry so that the potential impact of discounters into the retail sector should be thoroughly investigated. For the 1996-2011 results reported in Table 10, they are generally in line with the previous discussion relating to Defra I above i.e. international factors were relatively more important in determining retail food prices than domestic factors as reflected in the relative sizes of the coefficients in relation to the import price index. However, as we have shown in relation to Defra I, there are other factors that would have been important in the earlier period that are not accounted for in estimating the current specification with the shorter data period including, most notably, the role for oil prices. This may account for the relatively lower impact of exchange rates and the sign on manufacturing input costs that record an impact opposite to what we would have expected and which has been confirmed to positively impact on retail food prices in the extended sample. In sum, this issue regarding the changing structure of the food supply chain warrants further investigation.

Table 10: Long-Run Elasticity Estimates over Different Sample Periods: 1996-2011 and 1996-2017

	Sample Period: 1996-2011	**Sample Period: 1996-2017**
Elasticity of UK retail food prices (r_t) with respect to:		
Index of UK agricultural output prices (p_t)	0.062 (0.308)	0.236 (0.001)
Domestic labour costs (d_t)	0.422 (0.000)	0.306 (0.000)
UK manufacturing input costs (m_t)	-0.071 (0.029)	0.135 (0.055)
Import price index for agricultural and manufactured products (i_t)	0.511 (0.000)	0.168 (0.009)
Elasticity of Index of UK agricultural output prices (p_t) with respect to:		
Import Price Index for agricultural and manufactured products (i_t)	1.453 (0.000)	1.170 (0.003)
Effective exchange rate for agricultural imports(a_t)	-0.715 (0.009)	-1.847 (0.000)

9. Summary

The research reported here highlights several innovations in modelling retail food inflation compared with the Defra I model. In particular, a key feature of the current project is to develop import price indices that more accurately reflect UK imports of agricultural and food imports both in terms of what and where imports are sourced from. This is essential to provide a basis for assessing the UK's trade profile and the corresponding trade measures that apply on specific product groups from EU and non-EU trading partners. As such, the new price indices can then be utilised to accommodate changes in aggregate price indices as the UK's trade arrangements change following the UK's departure from the European Union. The new price indices form a key input into the revised econometric model which quantifies the effects of the major determinants of retail food prices. There are two versions of this model: one which focuses on agricultural products; a second which covers agricultural products and processed food, the inclusion of the latter also being a key feature of the research. From this, we can derive the impacts of changes in the key determining variables of UK retail food inflation which can be reported via transmission elasticities and impulse response functions.

The key results from the econometric model confirm the important role played by domestic agricultural output prices, non-agricultural costs (such as labour and energy), import prices and exchange rates in UK retail food inflation. While international factors are important, retail food inflation is found to be more responsive to domestic agricultural prices than import prices once interactions between the variables is allowed for. Models involving 'agriculture-only' and 'agriculture and processed foods' import price indices and effective exchange rate weightings are similar in terms of the insights they produce.

A key output arising from the derivation of the new import price indices and the econometric models is the development of a user platform, *STEFI* (Scenario Tool Exeter Food Inflation) that can be readily employed by specialists and non-specialists at Defra to address alternative scenarios following the UK's exit from the EU and how the resulting changing patterns in the profile of trade measures and the geography of trade will impact on retail food prices. *STEFI* therefore requires detailed inputs on trade measures that will apply across the 20 commodity chapters and 8 regions. While *STEFI* uses the estimates from the econometric model, there is no requirement for users to have a detailed understanding of the econometric issues involved. Being Excel-based, *STEFI* is user-friendly and flexible. Of course, the estimates from the econometric model can be updated and there are potentially wider uses of the platform that could be considered in the future.

There are two issues that could improve the insights arising from the research reported here. One issue that requires further development in the employment of this assessment tool is to accommodate non-tariff measures that apply to agricultural and food imports by trading partner. The *ad valorem* tariff equivalents of non-tariff measures are often higher than *ad valorem* tariffs and the incidence and coverage of non-tariff measures are greater on food and agricultural products compared with other traded products (see Berden *et al*., 2013, and Egger *et al*., 2015). Of course, non-tariff measures in the food sector are complex and it can be the case that some non-tariff measures are potentially trade enhancing (i.e. food standards reassure consumers about food safety issues and therefore can increase trade). Nevertheless, accounting for non-tariff measures would therefore provide more accuracy on how food and agricultural imports will be affected in the post-Brexit trading environment.

Second, further investigation of the impact on different household types may be warranted. The initial exploration of this issue in Section 8 suggests that important differences in food inflation across income deciles exist, and therefore that the UK's departure from the EU may impact differentially across income deciles. This analysis can be extended to address alternative characterisations of household types (e.g. retired households) that will give more policy-relevant insight into the impact that changes in the geography of UK trade and the corresponding changes in the profile of trade barriers may affect different groups.

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Appendices

Appendix 1: Table 1 List of All Variables Considered in Model Specifications and Data Sources

Variable	Definition
FCPI	Consumer retail price index of food.
Domestic Input Prices and Costs	
DAOPI	Domestic agricultural output prices. Index of farm gate prices in UK.
DLC	Domestic labour costs. Index of average earnings in the UK.
UKMIC	UK manufacturing input costs. Index of input costs in UK manufacturing including energy and raw materials (excluding wages and salaries of labour).
UKFMIC	UK food manufacturing input costs. Index of input costs in UK manufacturing including energy and raw materials (excluding wages and salaries of labour).
UKMOPI	UK manufacturing output prices. Price index of goods sold in the UK made by UK manufacturers.
UKFMOPI	Food manufacturing output prices. Price index of goods sold in the UK market by the UK food manufacturers.
Demand	
UR	Rate of unemployment in UK
UN	Numbers in unemployment
JVR	Job vacancy rate
Import Prices	
IPA	Import price index of agricultural products entering UK.
IPM	Import price index of processed/manufactured food products entering UK.
IPAM	Import price index of agricultural and processed/manufactured food products entering UK.
Effective Exchange Rates	
EERA	Effective exchange rate of agricultural imports into the UK.
EERM	Effective exchange rate of manufactured food imports into the UK
EERAM	Effective exchange rate of agricultural and processed/manufactured food imports into the UK

Appendix1: Table 2 - Variables Used in Final Specifications and Data Sources

Variables	Definition	Source	Series Code	Sample	Notes
FCPI	UK Consumer Retail Food Price Index.	Office for National Statistics (ONS) https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/d7bu/mm23?referrer=search&searchTerm=d7bu	D7BU	1988(1)–2018(7) 2005(M1)=100	Food and non-alcoholic beverages at retail
DAOPI	Index of UK agricultural output prices at the farm-gate.	DEFRA			Index 2005=100
DLC	Index of domestic Labour costs defined as average Earnings index for the UK (seasonally adjusted).	Office for National Statistics (ONS).	KAB9		Denoted LMNQ previously. 2000=100. Re-based to 2005(M1)=100.
UKMOPI	Price index of goods sold by UK manufacturers i.e. the price of goods output (produced) by the UK manufacturer and sold within the UK market (Output PPI).	Office for National Statistics (ONS)	JVZ7		Index 2010=100. See https://www.ons.gov.uk/economy/inflationandpriceindices/bulletins/producerpriceinflation/july2018 for details
UKFMOPI	Price index of goods sold by UK food manufacturers i.e. the price of goods output (produced) by the UK food manufacturer and	Office for National Statistics (ONS)	K37L	1996(1)-2017(12) Index 2010=100	See above for details

	sold within the UK market. (Output PPI)				
UKMIC	UK manufacturing input costs including fuel and materials	Office for National Statistics (ONS)	K646	1996(1)-2018-(7)	See above for details
UKFMIC	UK food manufacturing input costs including fuel and materials	Office for National Statistics (ONS)	MC35	1996(1)-2018(7)	See above for details
EERAM	Effective Exchange Rate for agricultural and manufactured food imports into the UK.	Authors' calculations.		Index 2002-2004=100	Based on HMRC chapters covering agricultural commodity and food products (01-15, 1701,1801)
EERA	Effective Exchange Rate for agricultural imports into the UK	Authors' calculations.		Index 2002-2004=100	Agricultural commodities only (HMRC Chapters 01-15, 1701,1801)
EERM	Effective Exchange Rate for manufactured food into the UK	Authors' calculations.		Index 2002-2004=100	Processed food products only (16, 1702,1802,19-22)
IPAM	Import Price Index for agricultural and manufactured food imports into the UK.	Authors' calculations.		Index 2002-2004=100	Based on HMRC chapters covering agricultural commodity and food products (01-16, 1701,1801)
IPA	Import Price Index for agricultural products into the UK	Authors' calculations.		Index 2002-2004=100	Processed food products only (16, 1702,1802,19-22)
IPM	Import Price Index for manufactured food products into the UK	Authors' calculations.		Index 2002-2004=100	

POIL	Oil Price on world market; UK Brent, light blend 38 API, fob U.K.	http://www.imf.org/external/np/res/commod/index.asp	POILBRE	US$ per barrel. 1996 (7) =100

Appendix 2: Creation of the Data

Price Indices –Some technical background

In general, the expenditure on a group of $i = 1, \ldots n$ products at a point t is $\sum_{i=1}^{n}(p_{i,t} \times q_{i,t})$ where $p_{i,t}$ and $q_{i,t}$ are the prices and quantities of each product in the group. If, across two periods (say 0 and *t*), the same quantities of each product were sold so that $q_{i,0} = q_{i,t} = q_i$, but under different prices, then a simple price index would take the form:

$$\frac{\sum_{i=1}^{n}(p_{i,t}q_i)}{\sum_{i=1}^{n}(p_{i,0}q_i)} \tag{A1}$$

However, since quantities are likely to be different at the two points in time, we needed to account for the changing relative importance of each product in the price index. This was achieved by weighting each price by the quantity. However, if we did this simply by using:

$$\frac{\sum_{i=1}^{n}(p_{i,t}q_{i,t})}{\sum_{i=1}^{n}(p_{i,0}q_{i,0})} \tag{A2}$$

this new index would not distinguish changes in quantities from changes in prices and as a result the index is as much a quantity index as a price index (doubling prices keeping quantities constant would double the index but so would doubling the quantity keeping the price constant). In order to gain a pure price index, we needed to control for changes in quantities and the most common way to do this is by using a weighting scheme that is fixed to some point in the sample so that the index measures price changes alone relative to the level in some base (Laspeyres) or current (Paasche) period.

A simple Laspeyres price index is computed as:

$$P_t = \frac{\sum_{i=1}^{n}(p_{i,t}q_{i,0})}{\sum_{i=1}^{n}(p_{i,0}q_{i,0})} \tag{A3}$$

where P_t is the index of the price levels for the group of *n* products at point *t* relative to their values at $t = 0$, the base period (usually the first year). Note that we can rewrite the Laspeyres Price index using expenditure weights rather than quantities. Defining $E_{i,0}$ as the expenditure in the base period then $E_{i,0} = p_{i,0}q_{i,0}$ and therefore $q_{i,0} = \frac{E_{i,0}}{p_{i,0}}$. Substituting these into the Laspeyres price index above gives:

$$P_t = \frac{\sum_{i=1}^{n}(p_{i,t}q_{i,0})}{\sum_{i=1}^{n}(p_{i,0}q_{i,0})} = \frac{\sum_{i=1}^{n}\left[p_{i,t}\frac{E_{i,0}}{p_{i,0}}\right]}{\sum_{i=1}^{n}E_{i,0}} = \frac{\sum_{i=1}^{n}\left[\frac{p_{i,t}}{p_{i,0}}E_{i,0}\right]}{\sum_{i=1}^{n}E_{i,0}} = \sum_{i=1}^{n} s_{i,0}\left(\frac{p_{i,t}}{p_{i,0}}\right) \tag{A4}$$

from which we can see that the price index is the sum of the relative prices multiplied by the share of the prices in the base period.

There are a wide range of price indices that can be used each with their own advantages and disadvantages. While the most commonly used is the Laspeyres index which uses weights that are fixed to a specific time or time span, a chain-linked Laspeyres index updates weights every period and as a result overcomes the problem of outdated weights. This is advantageous when the weights are changing systematically over time. We use the Laspayeres index approach in the derivation of the import price indices to facilitate a comparison between the new import price indices for UK food and agricultural imports and other commodity price indices widely available such as the FAO Food Price Index.

Import Prices (Unit Values)

For each of our 20 commodity groups, we created unit value series for each of the 8 geographical regions. These are then weighted by the value share of the region to produce an overall unit value for each commodity group. All the unit value series are expressed in £/unit of net mass (typically kg).

In what follows, superscripts denote the commodity groups (01, 02 . . . 22) and subscripts denoting the i^{th} region and t^{th} time period, so that, for example, a unit value index for HS01 (live animals) denoted UV_t^{01} based on imports from the eight regions is given by:

$$UV_t^{01} = \sum_{i=1}^{8} s_{i,t}^{01} \; UV_{i,t}^{01} \qquad \text{(A6)}$$

UV_t^{01} : the weighted average unit value (£/kg) of live animals at time *t* from all overseas (EU and Non-EU) sources;

$UV_{i,t}^{01}$: the unit value (£/kg) of live animals imported from the i^{th} region at time *t* ;

s_{it}^{01} : the value share of live animal imports coming from the i^{th} supplier at time *t* (i.e. the proportion of the value of live animals coming from the i^{th} region).

Being unit values, they are derived from the value and quantity of imports and are hence expressed in £/kg. As a result, they were useful for addressing issues relating to changing the geography of UK trade associated with relative prices. Unlike the price indices that were subsequently created and which were normalised to a specific base year, the unit values are in absolute (rather than relative terms) and hence explicitly allow us to acknowledge different price levels from different sources. This is pertinent for addressing post-Brexit issues further down the line. As a result, these unit values formed the basic data for subsequent manipulation and from which the price indices were created.

The Laspeyres weighting scheme used by the FAO

The Laspeyres (historical base period) weighting scheme measures changes in prices relative to the prices of a composition of products imported in a base period, which in its simplest form is a single period at the start of the sample. Other choices of base period could have been used. Given the volatility of commodity prices, it is typical to use an average value over a relatively long period to lessen the effect of this period-on-period variation in composition. Looking at the construction of other commodity price indices (e.g. the UN FAO Food Price Index), we worked with the Laspayeres index with the base period for constructing shares and the base period as the 3 year average for the middle years in our time series (i.e. 2002-2004). In a recent note (FAO, 2014), the FAO show that it would not seem to matter, at least with working with world prices, whether the base year is different (say, due to the commodity crises in 2007-08 and 2011) or whether an alternative price index is used (e.g. Paasche or other alternatives). As a result, we used a Laspeyres index where the base period is an average of the data in 2002-2004. This is consistent with the FAO commodity series and thus facilitated a direct comparison with their overall commodity price index as well as the sub-component (e.g. meat or sugar) of the main index.

Price indices for each commodity group by region

In this section, we detail the creation of Laspeyres price indices by region for each of the 20 commodity groups using FAO (2002-2004) weighting (Step III). These regional price indices were then combined to form a price index at the commodity group level (Step IV). As before, we will illustrate the methods using the nomenclature introduced previously, so that:

$$PILF_t^{01} = \sum_{i=1}^{8} s_{i,0}^{01}\left(\frac{UV_{i,t}^{01}}{UV_{i,0}^{01}}\right) \tag{A7}$$

is the Lasepyres price for index live animals at time *t* from all sources using FAO (2002-04) expenditure weights with:

$\left(\frac{UV_{i,t}^{01}}{UV_{i,0}^{01}}\right) = PILF_{i,t}^{01}$ being the price index of live animals from region $i = 1,...,8$ at time *t* relative to the base period (average of 2002-2004) and $s_{i,0}^{01}$ is the value share live animals imports coming from region $i = 1,...,8$ at time *t* relative to the base period (average of 2002-2004).

This price index was then weighted by the value share of live animals in total imports to form the aggregate import price series (see below). For each of these commodity group level indices, the regional weights differ, being specific to each commodity group.

Aggregate Price Indices

The aggregate import price index using Laspeyres weighting at time *t* is given by:

$$PILF_t = \sum_{c=1}^{20} w_{c,t} PILF_t^c \tag{A8}$$

where $PILF_t$ is the import price index aggregated across all sub-commodity price indices at time *t*, $PILF_t^c$, and $w_{c,t}$ is the weight of each commodity group in total agricultural and food imports with the weights based on the share of the import value of the chapter in the total value of imports at time *t*. As a complement to this overall import price index, we also created indices for agricultural commodity imports based on 13 unprocessed commodity groups (HS2 groups 01, 02, 03, 04, 07, 08, 09, 10, 11, 12, 15, 1701 and 1801) and another series for processed products based on 7 food and beverage groups covering processed and manufactured products (HS2 groups 16, 1702, 1802, 19, 20, 21 and 22). The weights $w_{c,t}$ change reflecting the importance of each commodity group level in the aggregate in which it belongs.

Effective Exchange rates

The effective exchange rates (continuing the example presented in outlining the construction of the import price indices above) for live animals at time *t* is given by:

$$EER_t^{01} = s_{1,0}^{01} ER_t^{eu} + \sum_{i=2}^{8} s_{i,0}^{01} ER_t^{usd} \tag{8}$$

$s_{1,0}^{01}$ is the import share of live animals imports from Euro countries; $s_{i,0}^{01}$ is the share from region $i = 2,...,8$ at time *t*; ER_t^{eu} and $ER_t^{usd}$are the exchange rate Euro to £ Sterling and US$ into £ Sterling at time *t*.

Effective Exchange Rate for Agricultural Products

The aggregate agricultural effective exchange rate at time *t* is given by:

$$EER_t^{agri} = \sum_{c=1}^{13} w_{c,t}^{agri} EER_t^c \qquad (9)$$

where EER_t^{agri} is the aggregate agricultural effective exchange rate at time t, $w_{c,t}^{agri}$ is the weight of the chapter *c* in total agricultural import value at time *t*, and the EER_t^c is the effective exchange rates for chapter *c* at time *t*. It is worth noting that the aggregate agricultural effective exchange rate will involve the HS2 groups 01, 02, 03, 04, 07, 08, 09, 10, 11, 12, 15, 1701 and 1801.

Effective Exchange Rate for Processed Products

The aggregate processed effective exchange rate at time *t* is given by:

$$EER_t^{pro} = \sum_{c=1}^{7} w_{c,t}^{pro} EER_t^c \qquad (10)$$

where EER_t^{pro} is the aggregate processed effective exchange rate at time *t*, $w_{c,t}^{pro}$ and EER_t^c are the weight of the chapter in the total processed import value and the corresponding effective exchange rate. The calculation is based on the processed products (HS2 groups 16, 1702, 1802, 19, 20, 21 and 22).

Effective Exchange Rate for All (agricultural and processed) Products

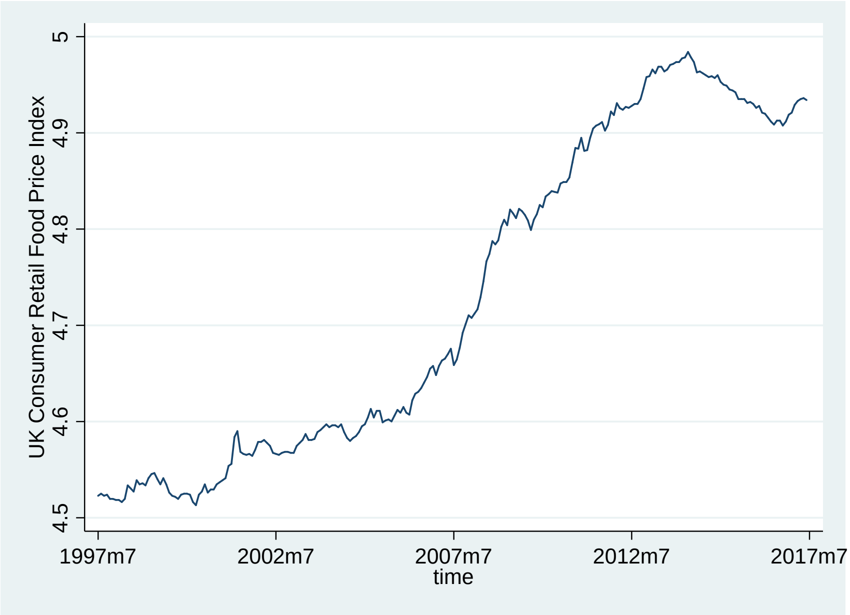
The aggregate effective exchange rate at time *t* is given by:

$$EER_t = \sum_{c=1}^{20} w_{c,t} EER_t^c \qquad (11)$$

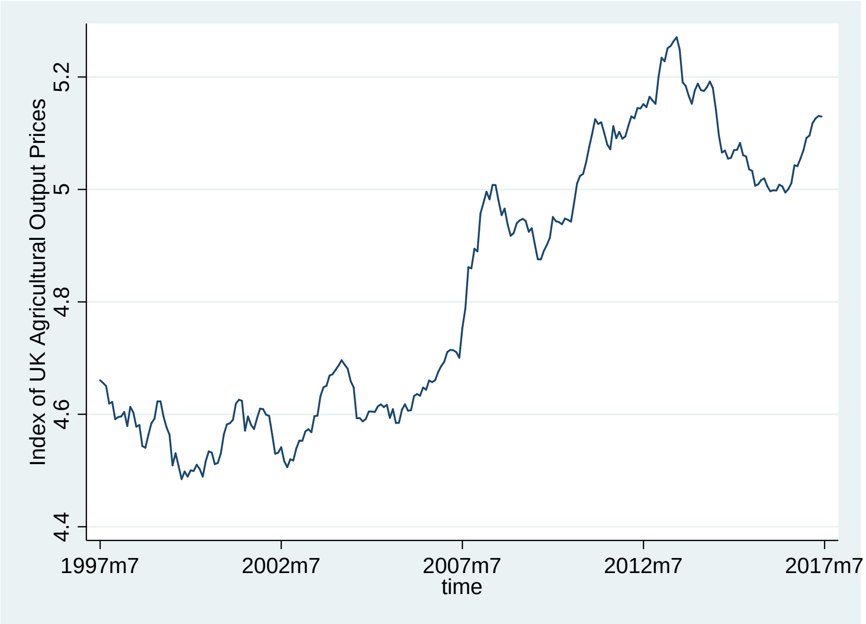
where the EER_t is computed for the whole 20 chapters, $w_{c,t}$ represents the import share of the chapter in the total import value at time *t*, its corresponding effective exchange rate is denoted as EER_t^c.

Appendix 3: Descriptive Data Analysis

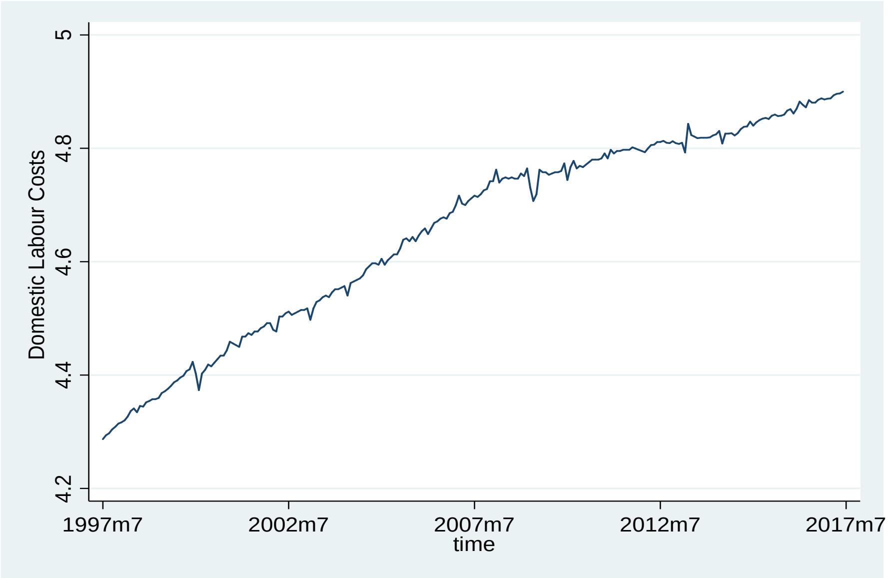
Appendix Figure 1: Retail Food Price Index (natural logs)



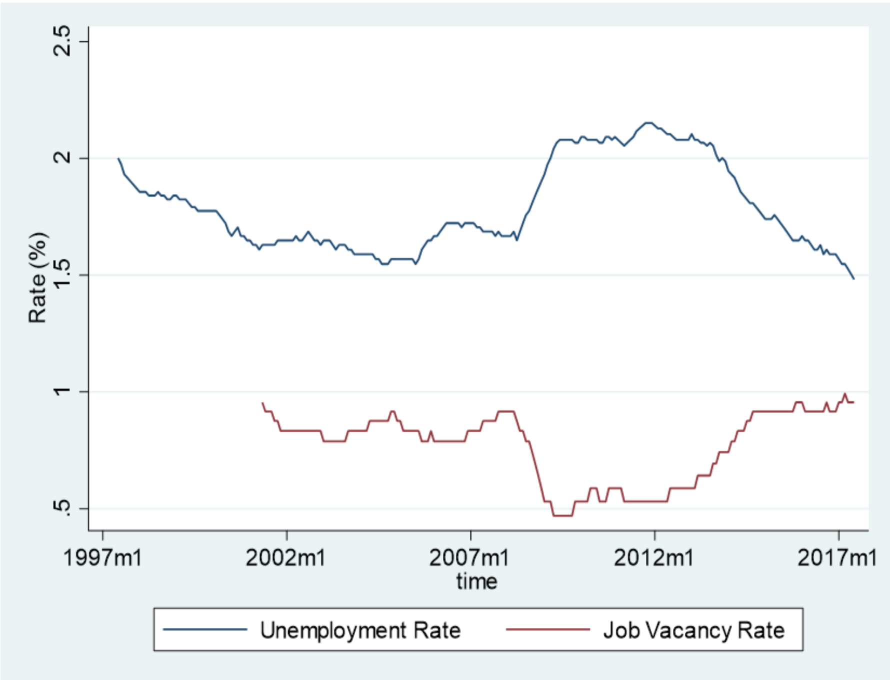
Appendix Figure 2: Index of UK Agricultural Output Prices (natural logs)



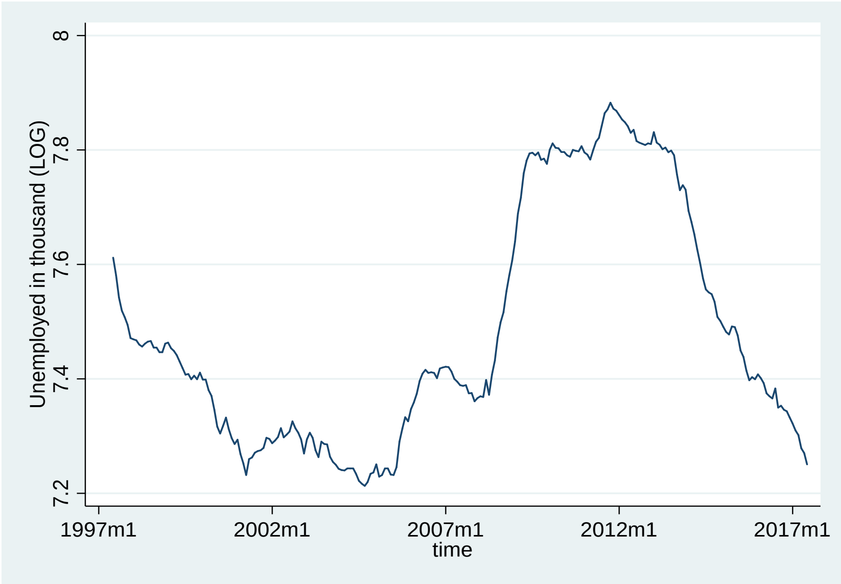
Appendix Figure 3: UK Domestic Labour Costs (natural logs)



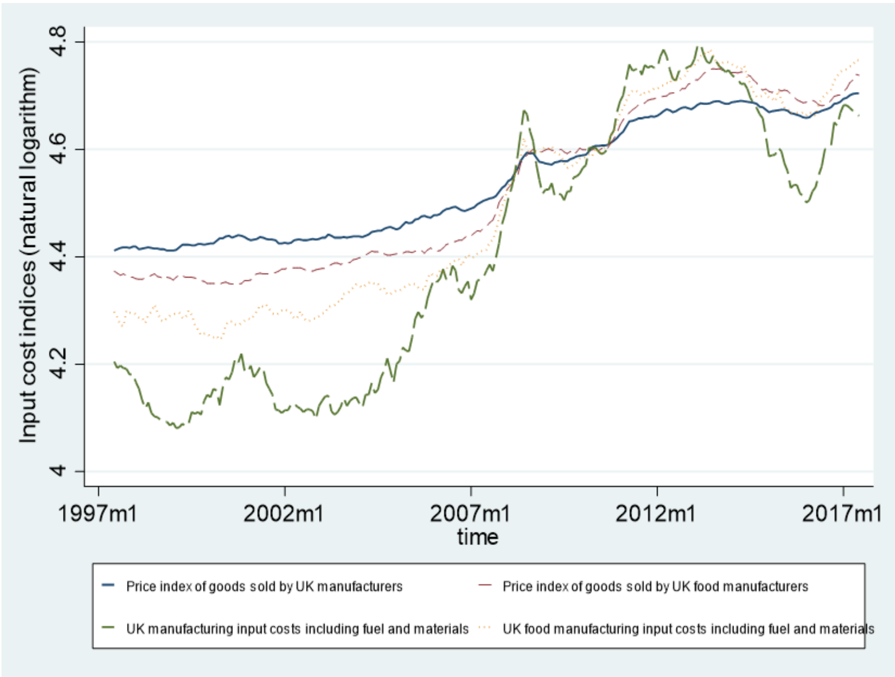
Appendix Figure 4: Unemployment and Job Vacancy Rate



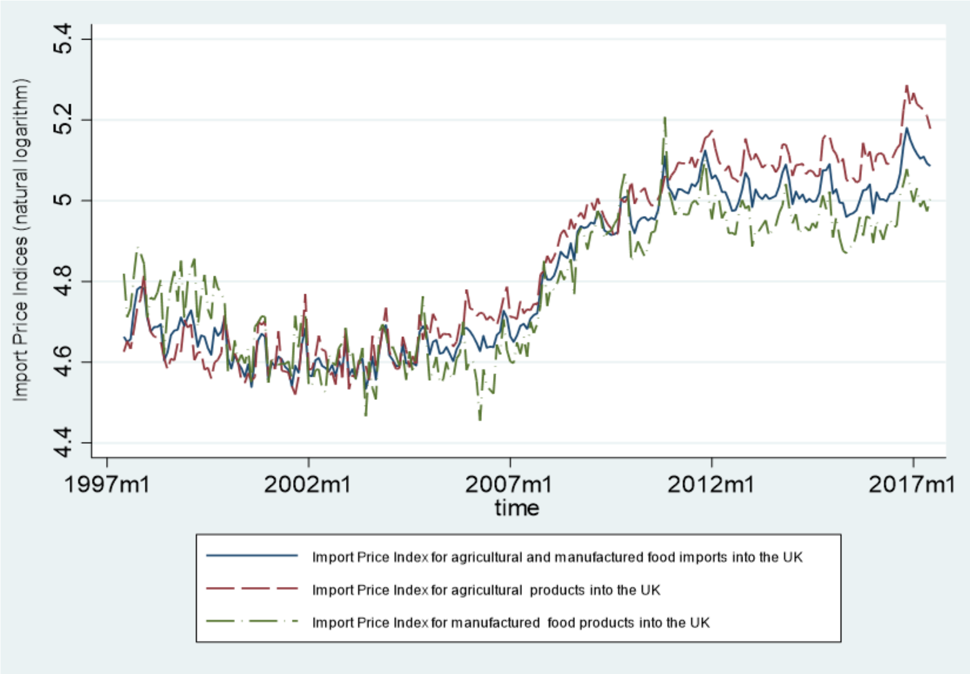
Appendix Figure 5: Number of Unemployed (000s)



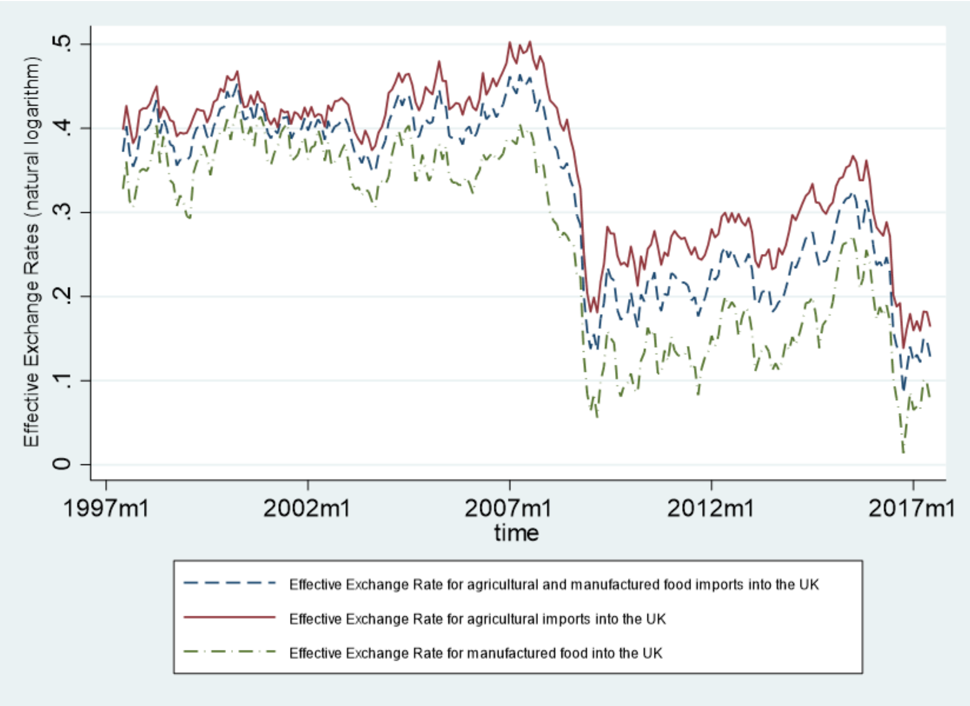
Appendix Figure 6: Indices for Input Costs Series (natural logs)



Appendix Figure 7: Import Price Indices (natural logs)



Appendix Figure 8: Effective Exchange Rates (natural logs)



Appendix Table 3: Summary Statistics for the Main Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
FCPI	241	4.7280	0.1695	4.5131	4.9841
DAOPI	241	4.8218	0.2419	4.4847	5.2707
DLC	241	4.6528	0.1781	4.2799	4.9000
UKMOPI	241	4.5410	0.1072	4.4116	4.7041
UKFMOPI	241	4.5235	0.1496	4.3490	4.7501
UKMIC	241	4.4096	0.2454	4.0809	4.7950
UKFMIC	241	4.4915	0.1882	4.2456	4.7867
UR	241	1.7931	0.1884	1.4816	2.1518
UN	241	7.4822	0.2062	7.2130	7.8827
JVR	194	0.7665	0.1501	0.4700	0.9933
EERAM	241	0.3212	0.1004	0.0849	0.4641
EERA	241	0.3581	0.0911	0.1388	0.5032
EERM	241	0.2648	0.1143	0.0139	0.4274
IPAM	241	4.8138	0.1910	4.5340	5.1802
IPA	241	4.8492	0.2224	4.5200	5.2862
IPM	241	4.7937	0.1679	4.4552	5.2073

Appendix Table 4: Non-Stationarity Tests

Panel A: Augmented Dickey–Fuller unit-root test with level data (Null: a variable follows a unit-root process)		
Variables	Constant	Constant and Trend
FCPI	-0.217	-1.108
DAOPI	-0.107	-2.195
DLC	-1.939	-2.240
UKMOPI	0.741	-1.537
UKFMOPI	0.948	-1.956
UKMIC	-0.340	-1.403
UKFMIC	0.360	-1.758
UR	-0.004	0.220
UN	-0.161	0.249
JVR	-1.033	-0.858
EERAM	-0.747	-2.251
EERA	-0.676	-2.083
EERM	-1.042	-2.604
IPAM	-1.160	-3.133*
IPA	-1.333	-4.043***
IPM	-2.803*	-4.453***

Panel B: Augmented Dickey–Fuller unit-root test with differenced data (Null: a variable follows a unit-root process)		
Variables	Constant	Constant and Trend
FCPI	-13.693***	-13.664***
DAOPI	-12.787***	-12.801***
DLC	-20.361***	-20.589***
UKMOPI	-8.504***	-8.517***
UKFMOPI	-8.753***	-8.809***
UKMIC	-11.438***	-11.420***
UKFMIC	-12.251***	-12.265***
UR	-11.206***	-11.214***
UN	-9.690***	-9.694***
JVR	-12.859***	-13.055***
EERAM	-14.020***	-14.041***
EERA	-14.320***	-14.358***
EERM	-14.644***	-14.646***
IPAM	-17.063***	-17.056***
IPA	-20.542***	-20.527***
IPM	-21.194***	-21.166***

Panel C: Phillips–Perron unit-root test with level data (Null: a variable follows a unit-root process)		
Variables	Constant	Constant and Trend
FCPI	-0.358	-1.149
DAOPI	-0.408	-2.421
DLC	-2.910**	-1.650
UKMOPI	0.287	-1.725
UKFMOPI	0.382	-2.001
UKMIC	-0.551	-1.781
UKFMIC	0.064	-1.875
UR	-0.552	-0.413
UN	-0.654	-0.455
JVR	-1.266	-1.083
EERAM	-0.944	-2.538
EERA	-0.924	-2.406
EERM	-1.042	-2.749
IPAM	-0.691	-3.037
IPA	-0.732	-3.863**
IPM	-2.067	-3.793**

Panel D: Phillips–Perron unit-root test with differenced data (Null: a variable follows a unit-root process)		
Variables	Constant	Constant and Trend
FCPI	-13.779***	-13.752***
DAOPI	-13.101***	-13.114***
DLC	-23.117***	-24.365***
UKMOPI	-8.532***	-8.545***
UKFMOPI	-8.998***	-9.074***
UKMIC	-11.629***	-11.612***
UKFMIC	-12.459***	-12.470***
UR	-11.721***	-11.730***
UN	-9.991***	-9.995***
JVR	-13.065***	-13.229***
EERAM	-14.049***	-14.065***
EERA	-14.390***	-14.421***
EERM	-14.619***	-14.621***
IPAM	-17.783***	-17.796***
IPA	-21.616***	-21.633***
IPM	-23.352***	-23.352***

Appendix 4: Econometric Methods

In this appendix, we extend the discussion of the econometric methodology as reported in Section 5 of the report.

To estimate the parameters of the model we adopt a Co-integrated Vector Auto-Regression (C-VAR). Technical details are given in Davidson *et al.* (2016) so the following merely provides a sketch of the econometric methods. In general terms, the C-VAR is given by standard vector auto-regression, namely:

$$\mathbf{x}_t = \mathbf{\Phi}_1 \mathbf{x}_{t-1} + \mathbf{\Phi}_2 \mathbf{x}_{t-2} + \ldots + \mathbf{\Phi}_p \mathbf{x}_{t-p} + \mathbf{\Psi D}_t + \boldsymbol{\varepsilon}_t \quad (1)$$

in which coefficient restrictions are incorporated that correspond to the long-run economic equilibria that are posited to exist among the variables in $\mathbf{x}_t$. Statistical tests are employed to ascertain the congruence of the long-run relations with the data. As discussed in the report, this gives rise to two equilibrium relationships, one relating to domestic price transmission and the other relating to trade. These two economic equilibria are given by:

Price Transmission Equilibrium

$$\log(FCPI)_t = \beta_{11}\log(\mathrm{DAOPI})_t + \beta_{12}\log(\mathrm{DLC})_t + \beta_{13}\log(\mathrm{UKMIC})_t + \beta_{14}\log(\mathrm{IPAM})_t \quad (2a)$$

Trade Equilibrium

$$\log(DAOPI)_t = \beta_{21}\log(\mathrm{EERAM})_t + \beta_{22}\log(IPAM)_t \quad (2b)$$

Returning to (1), note that deterministic terms (constants and trends) populate $\mathbf{D}_t$; $\boldsymbol{\varepsilon}_t$is a vector of disturbances, each element of which is assumed to be serially independent with zero mean and finite covariance matrix, $\mathbf{\Sigma}$. While (1) captures the dynamic correlations between the variables succinctly, the C-VAR is difficult to interpret economically, as it represents merely a statistical description of the relationships between the current values of variables dated at t and their previous values in $t-1$ to $t-p$. Where the variables form long-run (or more technically, co-integrated) relationships, then these allow (1) to be more conveniently expressed in its vector error correction (VECM) form:

$$\Delta\mathbf{x}_t = \boldsymbol{\alpha}\boldsymbol{\beta}'\mathbf{x}_{t-1} + \sum_{i=1}^{p-1}\mathbf{\Gamma}_i \Delta\mathbf{x}_{t-i} + \mathbf{\Psi D}_t + \boldsymbol{\varepsilon}_t \quad (3)$$

Noting that $\Delta\mathbf{x}_t = (\mathbf{x}_t - \mathbf{x}_{t-1})$ and that the equilibrium relationships are parameterised by the matrix $\boldsymbol{\beta}$, it is possible to see that the error correction representation describes how the variables in $\mathbf{x}_t$ change over time. Importantly, equation (3) defines a matrix of error correction coefficients $\boldsymbol{\alpha}$, elements of which load deviations from each of the long-run relations (contained in the long run matrix $\boldsymbol{\beta}'\mathbf{x}_t$) into $\Delta\mathbf{x}_t$ for 'correction' (hence the name). Given that $\Delta\mathbf{x}_t$ describes how each of the variables change over time, error correction coefficients measure the average rate at which each variable adjusts to maintain equilibrium following a shock and indicate the proportion of the long-run adjustment that occurs in each period: the higher the value, the faster is the process of adjustment.

Given the relatively long lags that are likely to characterise the dynamic adjustment as shocks pass through the food chain, the error correction coefficients represent an efficient description of the adjustment process over the longer term. Note that in (3), the process of dynamic adjustment is further augmented in the short term by the matrices of coefficients $\mathbf{\Gamma}_i$ for $i = 1, \ldots, p - 1$ which capture any differences between the actual response and that implied by the error correction process and so allow the short and long-run responses to differ. In sum, the VECM approach presents a convenient way of modelling both the short and long-run adjustment process among the variables in an economically meaningful way (for details see Davidson *et al.*, 2016).

Appendix 5: Final Model Specification and Output

For the project we estimated two models of retail food prices. The first, 'Model A' is based on raw agricultural products. This reflects the specification of the current work that was developed in the 2011 DEFRA project which used the world price of a basket of internationally-traded agricultural commodities as the principal driver in price transmission.

To reflect the growing importance of trade in processed and manufactured food products, an alternative specification, 'Model B', was estimated, which accounts for trade in both agricultural raw materials and processed/manufactured food products.

Model A: Retail Prices based on Raw Agricultural Output Prices

Variables: FCPI, DAOPI, DLC, UKMIC, IPA, EERA

```
                       Johansen tests for co-integration
Trend: constant                                         Number of obs =     241
Sample:  1997m6 - 2017m6                                         Lags =       3
-------------------------------------------------------------------------------
                                                         5%
maximum                                      trace    critical
  rank    parms       LL       eigenvalue  statistic    value
    0      78      4084.6277           .    113.5915    94.15
    1      89      4104.4495     0.15168     73.9478    68.52
    2      98      4119.8347     0.11986     43.1774*   47.21
    3      105     4128.2796     0.06768     26.2876    29.68
    4      110      4134.575     0.05090     13.6967    15.41
    5      113     4138.5448     0.03241      5.7572     3.76
    6      114     4141.4234     0.02361
```

Results above suggest a co-integrating rank of two. To identify these as the price transmission relation and import demand relation respectively we impose the following restrictions:

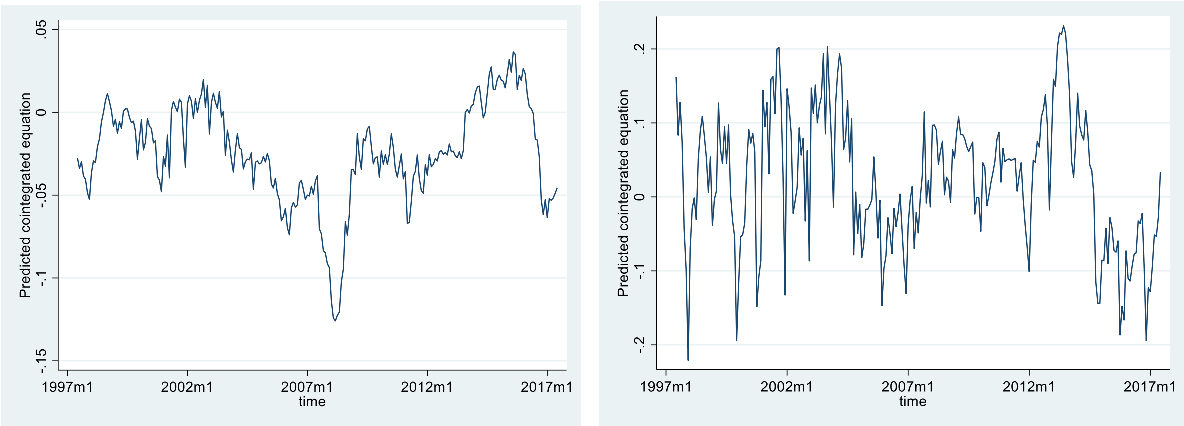
```
 ( 1)   [_ce1]fcpi = 1
 ( 2)   [_ce1]eera = 0
 ( 3)   [_ce2]daopi = 1
 ( 4)   [_ce2]fcpi = 0
 ( 5)   [_ce2]ukmic = 0
 ( 6)   [_ce2]dlc = 0

------------------------------------------------------------------------------
        beta |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
_ce1         |
        fcpi |          1          .        .       .            .           .
       daopi |  -.2423065   .0726758    -3.33   0.001    -.3847484   -.0998646
         dlc |  -.2555704   .0504217    -5.07   0.000    -.3543951   -.1567456
       ukmic |  -.1430524   .0729581    -1.96   0.050    -.2860476   -.0000571
        eera |          0  (omitted)
         ipa |   -.162336   .0648346    -2.50   0.012    -.2894095   -.0352625
       _cons |  -.9768253          .        .       .            .           .
-------------+----------------------------------------------------------------
_ce2         |
        fcpi |          0  (omitted)
       daopi |          1          .        .       .            .           .
         dlc |          0  (omitted)
       ukmic |          0  (omitted)
        eera |  -.9069209    .327614    -2.77   0.006    -1.549033   -.2648093
         ipa |  -1.440486   .1335002   -10.79   0.000    -1.702142   -1.178831
       _cons |   2.512206          .        .       .            .           .
------------------------------------------------------------------------------
LR test of identifying restrictions: chi2(2) = 3.834       Prob > chi2 = 0.14
```

Long-Run Elasticities [P-values]

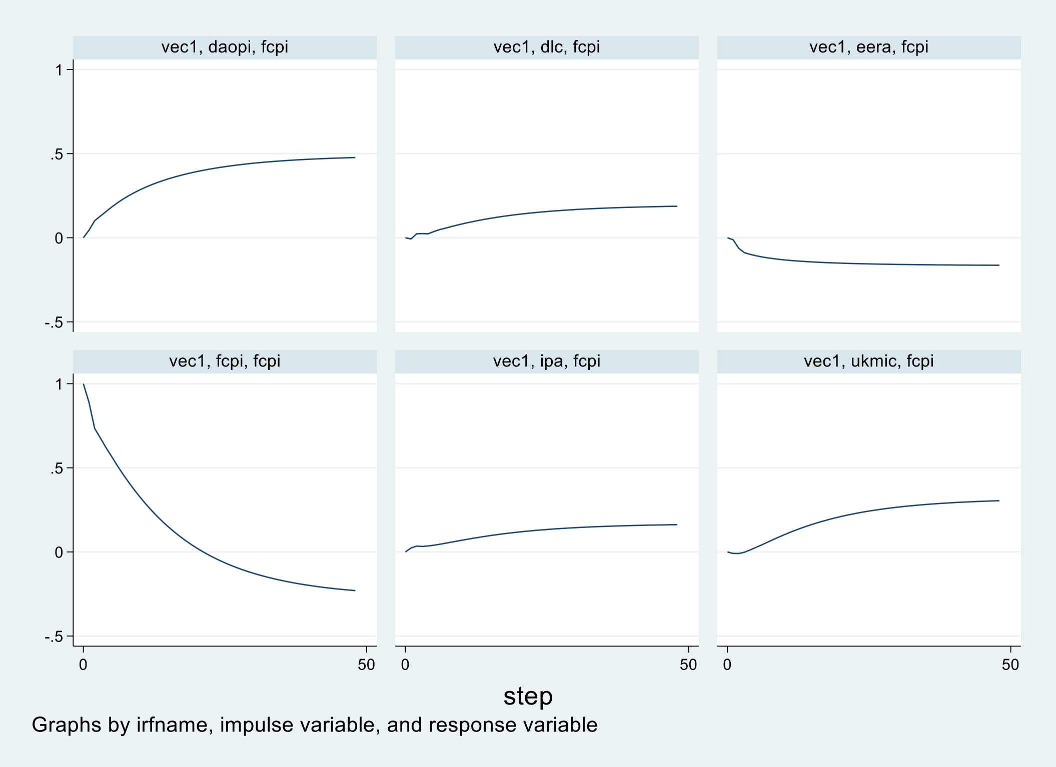
Price Transmission Equilibrium Relation	
Elasticity of UK retail food prices with respect to:	
Index of UK Agricultural output prices	0.242
	[0.001]
Domestic Labour costs	0.256
	[0.000]
UK manufacturing input costs	0.143
	[0.050]
Import Price Index for agricultural products	0.162
	[0.012]
Import Demand Price Equilibrium Relation	
Elasticity of Index of UK Agricultural output prices (p_t) with respect to:	
Import Price Index for agricultural products (i_t)	1.440
	[0.000]
Effective Exchange Rate for agricultural imports	0.906
	[0.006]

All estimated coefficients are theory-congruent and statistically significant at the 5% level. All transmission elasticities are inelastic. Retail prices are relatively more responsive to domestic prices than import prices. Exchange rate pass-through is less than one. The LR test indicates the validity of the identifying restrictions (p-value = 0.147). Co-integrating residuals appear stationary confirming the co-integrating rank of two.

Residuals from the Co-integrated equations 1 and 2



Impulse response functions of the retail price index (FCPI) to 1% shocks in all the variables are as follows.



Results suggest that adjustment is slow, with half-life being between 6 and 12 months. Long-run effects are similar to those implied by the long-run elasticities with the exception of domestic agricultural prices, where the long-run IRF is twice as big as the *ceteris paribus* effect, consistent with the idea that domestic prices have an important indirect effect through import prices.

Model B: Retail Prices based on the Price of Raw Agricultural and Processed Food Prices
(The output below relates to the results of the model reported in the text)

```
Variables: FCPI, DAOPI, DLC, UKMIC, IPAM, EERAM,

                         Johansen tests for co-integration
Trend: constant                                        Number of obs =     241
Sample:  1997m6 - 2017m6                                        Lags =       3
-------------------------------------------------------------------------------
                                                            5%
maximum                                      trace    critical
  rank    parms       LL       eigenvalue  statistic    value
    0      78      4131.4272           .    114.2259    94.15
    1      89      4151.7425     0.15515     73.5953    68.52
    2      98      4166.1981     0.11305     44.6840*   47.21
    3      105     4174.3106     0.06511     28.4591    29.68
    4      110     4180.4321     0.04953     16.2160    15.41
    5      113     4184.6438     0.03435      7.7926     3.76
    6      114     4188.5401     0.03182
-------------------------------------------------------------------------------
```

Results above suggest a co-integrating rank of two. To identify these as the price transmission relation and import demand relation respectively we impose the following restrictions:

```
 ( 1)  [_ce1]fcpi = 1
 ( 2)  [_ce1]eeram = 0
 ( 3)  [_ce2]daopi = 1
 ( 4)  [_ce2]fcpi = 0
 ( 5)  [_ce2]ukmic = 0
 ( 6)  [_ce2]dlc = 0
------------------------------------------------------------------------------
        beta |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
_ce1         |
        fcpi |          1          .        .       .            .           .
       daopi |  -.2356785   .0716616    -3.29   0.001    -.3761326   -.0952243
         dlc |  -.3061989   .0480485    -6.37   0.000    -.4003723   -.2120256
       ukmic |  -.1354441   .0707161    -1.92   0.055    -.2740451    .0031568
       eeram |          0  (omitted)
        ipam |  -.1682568    .064434    -2.61   0.009    -.2945452   -.0419684
       _cons |  -.7820363          .        .       .            .           .
-------------+----------------------------------------------------------------
_ce2         |
        fcpi |          0  (omitted)
       daopi |          1          .        .       .            .           .
         dlc |          0  (omitted)
       ukmic |          0  (omitted)
       eeram |  -1.170081   .3877544    -3.02   0.003    -1.930066   -.4100965
        ipam |  -1.847091   .2021832    -9.14   0.000    -2.243363   -1.450819
       _cons |   4.466729          .        .       .            .           .
------------------------------------------------------------------------------
LR test of identifying restrictions: chi2(2) = 1.725        Prob > chi2 = 0.422
```

```
The LR test indicates the validity of the identifying restrictions (p-value =
0.422).
```

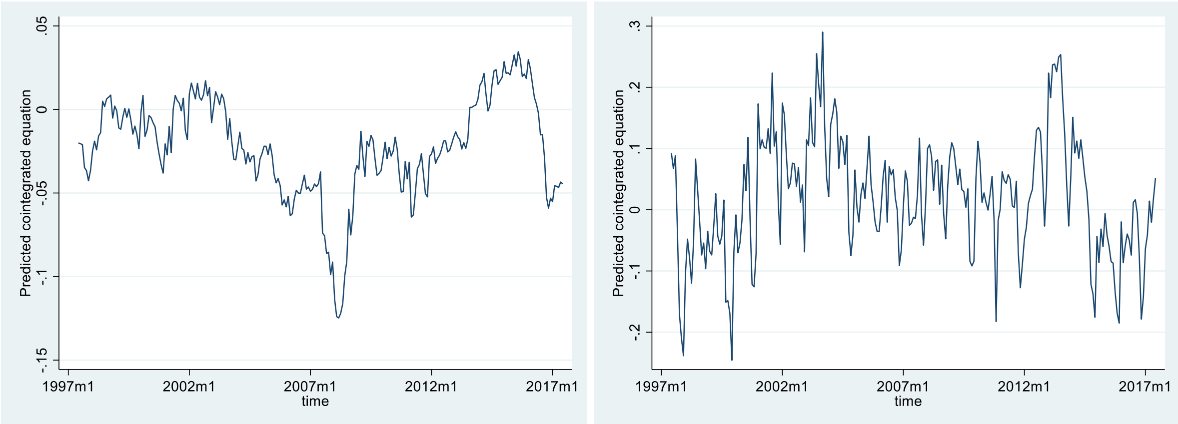
Long-Run Elasticities [P-values]

Price Transmission Equilibrium Relation	
Elasticity of UK retail food prices with respect to:	
Index of UK Agricultural output prices	0.236
	[0.001]
Domestic Labour costs	0.306
	[0.000]
UK manufacturing input costs	0.135
	[0.055]
Import Price Index for agricultural and manufactured food	0.168
	[0.009]
Import Demand Price Equilibrium Relation	
Elasticity of Index of UK Agricultural output prices (p_t) with respect to:	
Import Price Index for agricultural and manufactured food (i_t)	1.847
	[0.000]
Effective Exchange Rate for agricultural and manufactured food (a_t)	1.170
	[0.003]

As with Model A, all estimated coefficients are theory-congruent and statistically significant at the 5% level. All transmission elasticities in the vertical price transmission relation are inelastic. Retail prices are relatively more responsive to domestic prices than import prices. Exchange rate pass-through is slightly greater than one. There is a striking similarity with the coefficients estimated from Model A, the only difference being the relations between domestic and import prices. As expected, UK farm-gate prices are estimated to have to a smaller impact on import prices that include processed and manufactured foods.

Co-integrating residuals appear stationary confirming the co-integrating rank of two.

Residuals from the Co-integrated equations 1 and 2



Impulse response functions of the retail price index (FCPI) to 1% shocks in all the variables are as follows. Results are similar to those for Model A.