Original Research Article

Global agricultural, food and energy price spikes: Impacts on low income households in the United Kingdom and policy options

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Governmental reports and academic papers argue that the recent agricultural, food and energy price rises in 2008 disproportionately affected the welfare of low income people in the United Kingdom(UK). Nevertheless, in food security research, greater attention has been given to developing countries than industrialized countries although the existence of food insecurity in high income countries including the UK is also well acknowledged. To ensure food security the Department for Environment, Food and Rural Affairs (Defra) highlights the importance of considering other countries and non-agricultural or non-food industries such as energy. We constructed a UK multi-household general equilibrium model to analyze the welfare impacts of agricultural, food and energy price hikes that occurred in 2008 on households of different incomes in the UK. It was found that agricultural, food and energy price spikes have the greatest impact on the lowest income group. Energy price impacts on households were significantly larger than food price impacts across all income groups. High cereal prices only had a marginal effect on livestock and raw milk and high energy prices only had a marginal effect on agricultural prices. Finally, direct income compensation policy was found to be more efficient than import liberalization policy on food and energy goods in terms of governmental finance, especially when the policy beneficiary is the lowest income households alone.

Key words: Agricultural price, agriculture in international trade, energy price, trade liberalization, United Kingdom.

INTRODUCTION

The recent global commodity price boom triggered social unrests in many developing countries, drove 44 million people into poverty (World Bank, 2011), and raised food security issue to a priority policy-driven agenda among national/international communities. This directed scientists to investigating the underlying causes behind the price hikes (e.g. Abbot et al., 2009; Piesse and Thirtle, 2009)

and to assessing the impacts on socioeconomic or health-related outcomes in developing countries (Arndt et al., 2008; Ivanic et al, 2012; Hadley et al., 2012; Yamauchi and Dewina, 2012; Yousif and Al-Kahtani, 2013; Zheng and Henneberry, 2012; Anriquez et al., 2013; Kumar and Quisumbing, 2013).

More attention was paid to the impact on developing

countries than to industrialized nations for this issue. Nevertheless, according to recent studies a substantial number of the UK population also might have faced a problem of ensuring food access/security. The Low Income Diet and Nutrition Survey (LIDNS) found that 29% of the low income population had experienced insufficient food access due to insufficient finance or other resources (e.g. storage facilities, transport), 39% reported that they had been concerned that food would run out before they obtained money to buy more, and 36% responded that they could not afford to consume a balanced diet[1] (Nelson et al., 2007). Dowler (2010) insists that unemployed benefit and the minimum wage affect the well-being of many households in the UK, comparing the cost family or single person needs to sustain their lives with the amount of money people unemployed or working on the minimum wage. The Joseph Rowntree Foundation (JRF) estimated that in 2014 there were 13 million people living in poverty in the UK with the median income in 2012/13 reduced by 9% in comparison with that in 2007/08 (JRF, 2014). Morris et al. (2000) evaluated the minimum cost of healthy living and concluded that the pay from the minimum wage was not enough to meet the minimum cost of healthy living without extra work hours even after consideration of statutory tax and social security deductions. In England the healthy living cost was 50% greater than the state pension and noticeably higher than official minimum income safety floor (Morris et al., 2007). The rise in minimum cost of living in 2011 was only slightly higher than general price inflation, but the recent social welfare cut disproportionately affected people on low income earnings (Hirsch, 2011). These studies suggest that in the UK the living standard of many people might not reach even the minimum cost for healthy living. Dowler and O'Connor (2012) made a detailed review on food poverty and insecurity for the UK and Ireland, and found the existence of serious food poverty in the jurisdictions.

The New Labour administration and the government made considerable effort for enhancing food security as a priority policy from 1997 to 2009 (Kneafsey et al., 2013). The Department for Environment, Food & Rural Affairs (Defra) (2006) stated that to attain food security "the real issues extend beyond the UK, beyond agriculture, beyond food", stressing the importance of taking into account the linkage with international markets and non-agricultural and non-food industries. This implies that food security in developing countries or other regions and energy security for the UK are significant elements to be considered to achieve the UK food security. Defra (2010) indicates how to secure food supply for the UK population, and also emphasizes that global food supply ultimately supports the

food availability and affordable prices for the UK, energy supply disruption and high energy price are crucial to food supply chain resilience, and UK food and energy import sources should be diverse. Further, it addresses the significance of affordability of healthy foods for people of low earnings.

To summarize, global agricultural productivity or production and availability in developing economies have been the focus for much of the research on food security, and relatively less attention has been paid to low income people in developed countries (Jarosz, 2011; Kneafsey et al., 2013). While dramatic increase in UK farmers' income is announced (Defra, 2013; Demby, 2014), low income households are likely to have disproportionately suffered from the commodity price inflation combined with the recent economic downturn. Within the context, it is important to evaluate to what extent the livelihood of low income households in the UK was affected by the price spikes of agricultural, food and energy commodities in comparison with other different income classes. We use a multi-household general equilibrium model to analyze the welfare impacts on low income households, the relation between food and energy prices, and the effectiveness of mitigation policies.

MATERIALS AND METHODS[2]

Computable general equilibrium (CGE) modelling that originates from Johansen (1960) and associated conceptual framework that underpins this methodology, has been widely used by academics and policy makers in national governments and international organizations. It can be used to describe agents' behaviour (i.e. households, producers, government, investment), and considers the interaction between various commodities and services markets and factors markets. This approach makes it possible to gauge responsive behaviour of producers and households to global agricultural and energy price hikes. In reality, households faced both domestic consumer price increases, influenced in turn by international prices, and income variations caused by changes in production prices. Partial equilibrium models that focus on a single or only a few markets struggle to capture the complexity of those effects. The input-output model is a linear programming model in which economic agents do not flexibly respond to relative price variations and is not a suitable approach for this subject either. We used a general equilibrium framework, which was considered as a more appropriate approach to these multi-faceted issues.

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[1] The "balance" was not defined in the interview, and it depended on the interpretation of each respondent (Nelson et al., 2007).

[2] The detailed model specifications are shown in Appendix.

Table 1. Aggregation of sectors and factors

Sector	Factor
Paddy rice*	Skilled labor
Wheat*	Unskilled labor
Oats*	Land
Barley*	Capital
Maize*	Natural resources
Other cereals*	
Vegetable and fruits†	
Oil seeds†	
Cane and beet†	
Plant fibers†	
Other crops†	
Cattle‡	
Other animal products‡	
Raw milk†	
Fishing†	
Processed rice*	
Cattle meat‡	
Other meat‡	
Vegetable oil†	
Milk (dairy products)†	
Sugar†	
Beverages and tobacco†	
Other food†	
Crude oil	
Coal	
Gas	
Petroleum and coke	
Transport	
Others	

Note: * and ‡ indicate grain and meat composite goods, respectively, and † signifies other food commodities in the structure of household consumption.

We constructed a UK multi-household general equilibrium model based on the single-country model developed by Devarajan et al. (1990), a standard CGE model, to analyze the impacts of food and energy commodity price booms in international markets on households and sectors in the UK. The data used to develop a UK social accounting matrix (SAM) were obtained from the Global Trade Analysis Project (GTAP) database (version 8: base year 2007).[3] For the purpose of this research, we set up 23 agricultural and food sectors, four energy sectors and five endowment factors; unskilled and skilled labor, capital, farmland and natural resources (Table 1). The household-related data in the SAM was disaggregated into five income cohorts, using the Living Costs and Food Survey data from the Office for

introduced these sectors into the original database by splitting "other cereals" (gro) sector based on the actual data from the FAOSTAT following the method established by Taheripour (2007).[4]

Each sector has a perfectly competitive profit maximizing firm with a Leontief production function to produce gross output, using the value added composite aggregated with the factors and intermediate inputs (Figure 1). To describe more specific land uses, we incorporate into the model 18 Agro Ecological Zones (AEZ) developed by the Food and Agriculture Organization (FAO) and International Institute for Applied Systems Analysis (IIASA).[5] Land is not mobile between different levels of the AEZs. The factors are assumed to be fully employed. The domestic outputs are allocated between domestic good supply and export by the constant elasticity of transformation (CET) technology. The Armington function is applied between import and domestic goods to create composite goods (Armington, 1969). We applied the Armington elasticity values from the GTAP database to both the CES and CET functions for international trade. The elasticity parameters for the value added composite was also cited from the GTAP database.

Representative quintile households maximize their utilities subject to their budget constraints. Each household has three tiers structure (Figure 2). First, households consider a trade-off among cereals ("Paddy rice", "Wheat", "Maize", "Oat", "Barley" and "Other cereals") and among meat products ("Cattle", "Other animal products", "Cattle meat", and "Other meat").[6] The consumption of meat and cereals is aggregated to make meat and grain composites using a CES function, whose elasticities of substitutions are assumed to be 0.951 and 0.567, respectively, based on work Tiffin and Tiffin (1999) that estimate the price elasticities of demand for foods in the Great Britain.[7] Second, the grain and meat composites and other food commodities[8] are aggregated to constitute a food composite with a CES function whose elasticity value is assumed to be 0.114 (Tiffin and Tiffin 1999). Finally, each household considers a trade-off among a food composite and other (non-food) goods under a Cobb-Douglas function. We assume heterogeneous households on food consumption behaviour, applying elasticity with changes by -20%, -10%, 0%, +10%

not explicitly hold the sectors of maize, oats, and barley, we

[3] For more details about the GTAP database, see the official website of the GTAP at https://www.gtap.agecon.purdue.edu/databases/v8/.

[4] Taheripour (2007) presents a method to create bioethanol and biodiesel sectors using the Splitcom developed by Mark Horridge. We applied it to the disaggregation of grain sectors, which are, however, operated on the General Algebraic Modeling System (GAMS).

[5] See Lee (2005) for further information.

[6] "Other animal products" include swine, poultry and other live animals. "Other meat" contains pig meat and offal. See the GTAP website for the detailed sector list: https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp.

[7] The price elasticity of demand can be approximated to the elasticity of substitution. See Shoven and Whalley (1992).

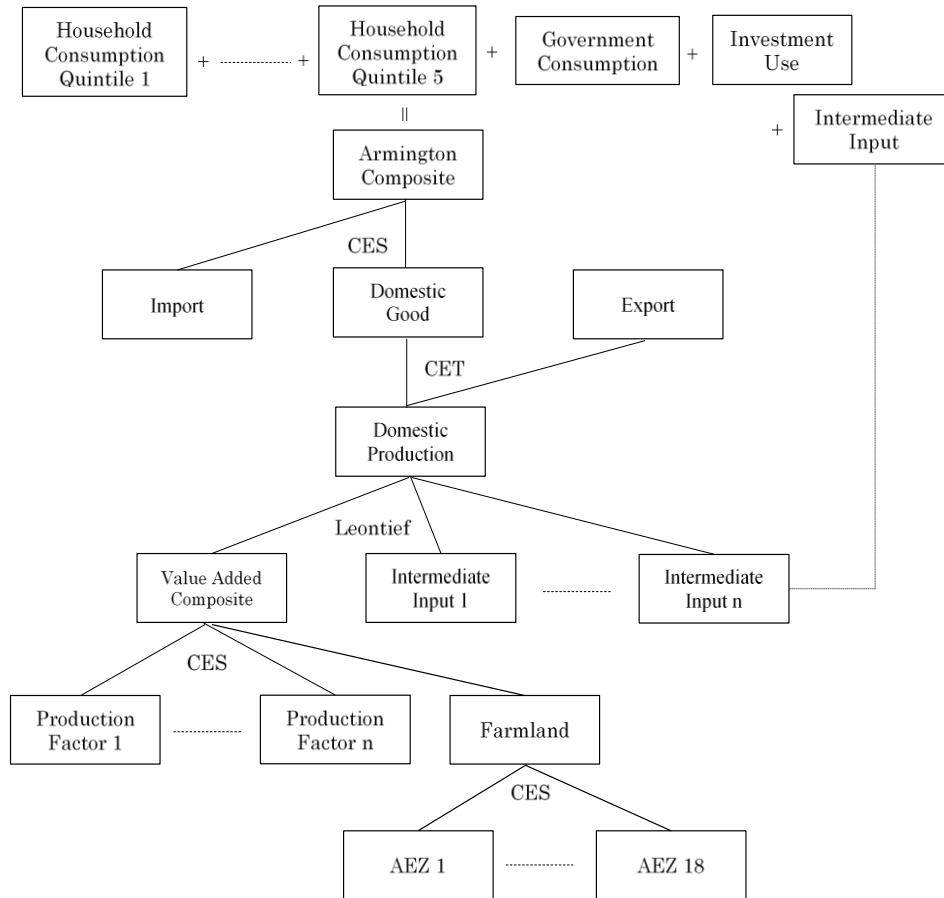[8] See Table 1 for the aggregation of sectors in household consumption.

Figure 1: The overview of the model structure
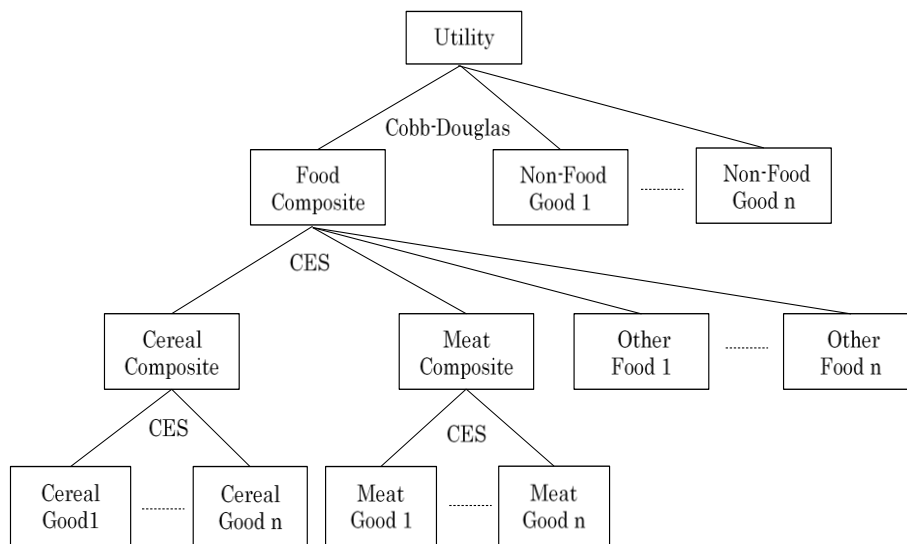
Figure 2: The structure of household consumption

Table 2. Scenario design

Scenario	Shock Factor					
	Grain	Meat & fish	Other foods	Energy	Factor mobility	Liberalization
REFERENCE						
GRAIN	*					
MEATFISH		*				
FOOD	*	*	*			
ENERGY				*		
COMBINED	*	*	*	*		
GRAINLONG	*				*	
MEATFISHLONG		*			*	
FOODLONG	*	*	*		*	
ENERGYLONG				*	*	
COMBINEDLONG	*	*	*	*	*	
FOODLIB	*	*	*			*
ENERGYLIB				*		*

and +20% to Quintiles 1, 2, 3, 4, and 5[9] under the assumption that responsiveness to price variations would not be identical between different income quintiles.

In this model, we assume the saving-driven for saving-investment closure, foreign saving is exogenous, and the current account is balanced by the adjustment of exchange rate. We adopted the small-country assumption, and assumed that global prices were exogenous. The numéraire in this model is the capital price of the sector "Others" for Quintile 5.

An important feature of the model we have used is that households of different income quintiles are included. This allows for the differences in spending behaviour between such households. The average behaviour of households in each quintile is represented, although we realize that demographic and lifestyle variation within households in the same quintile will affect the elasticities of consumption behaviour. Consumption of energy and transport for example will be more constrained in some households than others.

Experimental design

To quantify the impacts of the global food and energy price spikes that occurred between 2007 and 2008, we conducted comparative static analyses using the following six shock factors (see Tables 2 and 3): (1) increase in world "Grain" price, (2) global "Meat and fish" price rises, (3) international "Other food" price hikes, (4) global "Energy" price spikes, (5) flexible factor mobility to evaluate long-term impacts, and (6) trade liberalization of food and energy to mitigate adverse shocks of the price surges. With

the above six factors, we established 13 scenarios to determine which income group would experience net benefit/detriment as a result of the price inflations, with/without the governmental policies.

Shock Factors 1, 2, 3 and 4: Global Price rises in 2008

Table 3 depicts the magnitude of exogenous shocks used in our simulations. The exogenous shocks of all the commodities except "Oats", "Sugar cane and beet", "Milk" and "Other meat" were estimated using historical monthly price data from the IMF Commodity Prices between July 2007 and July 2008. We estimated international price changes for the above four commodities, which did not appear in the IMF Primary Commodity Prices by dividing the world total export value by global export quantity from the FAOSTAT. The sector/commodity "Other meat" in the GTAP database includes various types of meat (swine, poultry, turkey, rabbit and duck), but since pork and chicken are more commonly consumed than the other types of meat among the UK population, we used the weight of only pork and chicken imports to estimate the weighted average of the price changes with the IMF Primary Commodity Prices and the FAOSTAT.

Shock Factor 5: Production factor mobility

We simulated both short- and long-term effects of international price shocks by modulating factor mobility assumptions: unskilled labor is mobile across sectors in the short-term evaluations with skilled labor and AEZ farmlands also being assumed to be mobile between sectors under the long-term simulations though the AEZ farmlands do not move beyond their own AEZ level.

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[9] Quintiles 1 and 5 are defined as the lowest and highest income quintiles, respectively in this research.

Table 3. Shocks of global prices

Commodity	Shock [%]
Grain	
Paddy rice	140
Wheat	38
Maize	81
Oats	23
Barley	40
Processed rice	140
Meat & fish	
Fishing	29
Cattle meat	13
Other meat	8
Other foods	
Oil seeds	85
Cane and beet	33
Raw milk and dairy	9
Vegetable oil	237
Energy	
Crude oil	73
Coal	167
Gas	84
Petroleum	73

Data source: The IMF Primary Commodity Prices

Shock Factor 6: Trade liberalization of food and energy goods

The abolition of unilateral import tariff and non-tariff barriers of food and energy commodities was assumed as the countermeasure against price volatilities to alleviate shocks in the domestic markets. The import barriers for food and energy goods between the UK and other regions reported by the GTAP database range between 20.4% and 0% and between 12% and 1.9%, respectively. The border barriers in the database are tariff equivalent and include actual import tax and international price difference.

The GRAIN, MEATFISH, FOOD and ENERGY scenarios gauge the short-term impacts of each shock factor by reproducing the 2008 price surges (see Table 3). The COMBINED scenario simulates the synthesized price variations of food and energy in the short-term. The GRAINLONG, MEATFISHLONG, FOODLONG, ENERGYLONG, and COMBINEDLONG scenarios are the ones to evaluate the long-term impacts assuming more flexible endowment factors' mobility. To assess the efficacy of trade liberalization, the import taxes on food and/or energy goods were abolished with the short-term assumption that allowed only unskilled labor mobility across sectors to simulate emergent responses by the government in scenarios FOODLIB and ENERGYLIB. Finally, for the optimal liberalization, the tax rates for foods are reduced by 10% using the FOODLIB scenario.

RESULTS AND DISCUSSION

Impacts of price spikes on households

In this subsection, we concentrate on the share of welfare effect in household income (i.e. equivalent variation (EV) divided by income) to measure 'real impacts' of the price hikes since EV in absolute value tends to indicate larger values for wealthier households on the ground that higher income households tend to expend more for general commodities/services. In our study, Quintiles 1 and 5 signify the lowest and highest income groups, respectively.

The results for short-term welfare impacts (EV divided by income) are summarized in Table 4. It is found that lower income groups tend to have more negative effects from the price shocks in the food-related scenarios (i.e. Scenarios GRAIN, MEATFISH and FOOD), and Quintile 1 receives the most adverse impact in each scenario. On the other hand, Quintile 5 is only slightly affected or benefited since the increased demand for factors leads to higher factor prices that cancels out, in part or completely, the negative effect from the high food prices. The ENERGY scenario shows the same trend as the food-related scenarios across income groups, but the negative impacts of energy price spikes are greater than for food price spikes. Quintile 1 undergoes an adverse impact of -6.14%, which is equivalent to 4.6 times greater than that of the FOOD scenario. In the COMBINED scenario where food and energy price shocks are given together, the lowest income household, Quintile 1, is most affected with -7.42% that is almost twice as high as the impact in Quintile 2, whilst Quintile 5 experiences a negligible effect of -0.46%.

Table 5 shows the results of welfare impacts (EV divided by income) by household income under the long-term assumption. Though there are some exceptions, it is generally observed that negative effects are mitigated in the long-term simulations for both food and energy price rises compared with those in the short term simulations with factors responding more flexibly to the price shocks. However, the difference in the degree of the impacts for all the scenarios between the short and long terms is not be very large. Similarly to the short-term results, the welfare of lower income households tends to deteriorate more significantly with an exception in the FOODLONG simulation.

Inter-sectoral analysis

We considered the price linkage between sectors using the

Table 4. Short-run welfare impacts (EV's share of income) on households

	EV [% of income]				
	GRAIN scenario	**MEATFISH scenario**	**FOOD scenario**	**ENERGY scenario**	**COMBINED scenario**
Quintile 1	-0.19	-0.54	-1.33	-6.14	-7.42
Quintile 2	-0.07	-0.21	-0.38	-3.64	-3.99
Quintile 3	-0.03	-0.07	-0.12	-1.95	-2.06
Quintile 4	-0.02	-0.04	-0.04	-1.42	-1.45
Quintile 5	-0.01	0.00	0.02	-0.48	-0.46
Total	-0.02	-0.04	-0.07	-1.23	-1.29

Table 5. Long-run welfare impacts (EV's share of income) on households

	EV [% of income]				
	GRAINLONG scenario	**MEATFISHLONG scenario**	**FOODLONG scenario**	**ENERGYLONG scenario**	**COMBINEDLONG scenario**
Quintile 1	-0.20	-0.53	-0.57	-6.02	-6.52
Quintile 2	-0.06	-0.19	0.11	-3.57	-3.42
Quintile 3	-0.03	-0.07	0.03	-2.00	-1.95
Quintile 4	-0.01	-0.04	0.08	-1.45	-1.36
Quintile 5	-0.01	0.00	0.10	-0.49	-0.39
Total	-0.02	-0.04	0.07	-1.24	-1.16

Table 6. Inter-sectoral effects of grain and energy prices in nominal term

	Nominal Price Change [%]			Nominal Price Change [%]	
	GRAIN	**GRAINLONG**		**ENERGY**	**ENERGYLONG**
Sector	**scenario**	**scenario**	**Sector**	**scenario**	**scenario**
Cattle	0.04	1.57	Paddy rice	1.75	1.83
Other animal products	2.84	2.05	Wheat	1.48	1.34
Raw milk	1.38	3.28	Oat	1.55	1.53
Cattle meat	-0.02	0.37	Barley	0.74	0.79
Other animal meat	0.27	0.34	Maize	1.75	1.83
Milk	0.13	0.49	Other cereal	1.55	1.55
CPI (base=1.00)	1.001	1.001	CPI (base=1.00)	1.042	1.047

GRAIN and ENERGY scenarios. The livestock sectors (i.e. "Cattle meat", "Other meat", and "Milk" sectors) where large amount of cereals is used as feed stock are considered to be sensitive to grain prices. However, Table 6 indicates that the inter-sectoral impacts both between grain and meat prices and between energy and agricultural prices are limited in the short- and long-term with the prices being elevated only by 2-3%. This is because of the proportional shares of cereals in the production cost structure of the "Cattle," "Other animal products" (e.g. pigs and fowl) and "Raw milk" sectors accounting only for 3%, 20% and 9%, respectively.[10]

Modern farming is often considered to be energy intensive in comparison to labor intensive farming in developing countries. However, the share of energy intermediate inputs in the total production costs of most agricultural sectors in the UK constitutes less than 1%.[11] Therefore, the energy impact on agricultural prices are also not as significant as expected despite the greater magnitude of the energy price shocks.

Policy responses

First, we compare the effectiveness of unilateral import tariff liberalization of food and/or energy with that of direct

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[10] With no consideration of general equilibrium effects, if grain prices rose by 50%, the price of "Other animal products" increases by 10% (=50×0.2).

[11] The figures are estimated from the GTAP database version 8.

Table 7. Effectiveness of import tariff abolition on food and energy commodities

|	EV [mil. USD]					
	FOOD scenario (1)	FOODLIB scenario (2)	Effect (2)-(1)	ENERGY scenario (3)	ENERGYLIB scenario (4)	Effect (4)-(3)
Quintile 1	-595.8	-214.6	381.2	-2746.5	-2452.5	294.0
Quintile 2	-423.1	11.0	434.2	-4062.0	-3617.1	444.9
Quintile 3	-387.6	53.9	441.5	-6384.9	-5761.4	623.5
Quintile 4	-215.3	266.2	481.4	-7885.1	-7095.0	790.1
Quintile 5	182.4	726.8	544.3	-5398.7	-4446.5	952.2
Total	-1439.4	843.3	2282.7	-26477.2	-23372.5	3104.7
Tax revenue	782159.8	781638.6	-521.2	777033.7	775880.5	-1153.2
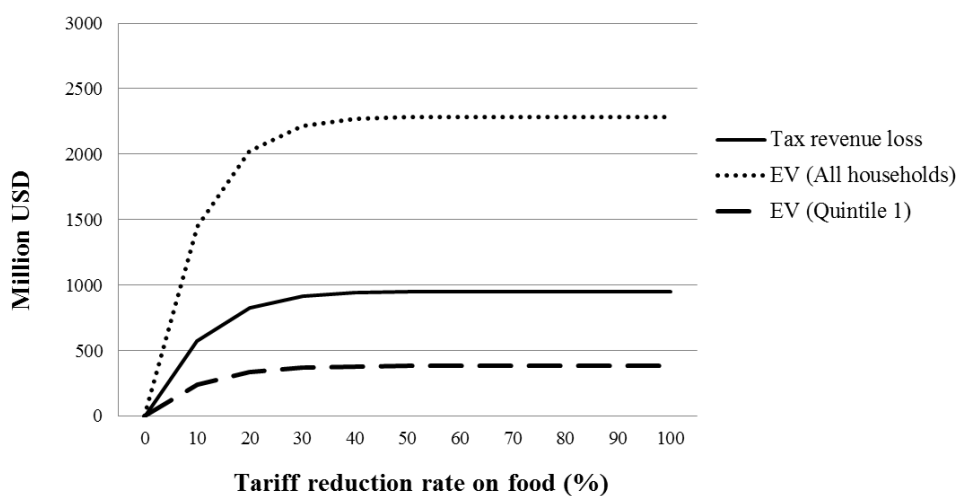
Figure 3: Policy response: Food liberalization with different rates of reduction

income transfer (e.g. welfare benefit) to Quintile 1 (the lowest income group) under the FOOD, FOODLIB, ENERGY and ENERGYLIB scenarios. Second, we identify the optimal food import tax rate for households' welfare (optimum defined as EV minus tax revenue reduced). To discuss emergent policy responses against fluctuated prices, the short-term factor mobility is assumed (i.e. unskilled labor alone is mobile across sectors). We focus on EV in absolute value to be able to directly compare between the efficacy of the policies and potential tax loss.

Table 7 presents a summary of the simulation results for import tax liberalization on food or energy goods. The effect of tax abolition for food on Quintile 1 is equivalent to $381.2 million while the lost tax revenue by the policy implementation is estimated at $521.2 million, which suggests that direct transfer of income is more fiscally efficient. In the same way, the policy performance for energy goods for Quintile 1 is assessed at $294.0 million

while the reduced tax revenue is $1153.2 million that is clearly greater than the efficacy. Accordingly, direct income support by the government is more effective than the tax barrier removal. It is notable that free trade policies for both goods exacerbate the income distribution with higher income households benefiting from these policies.

Here we discuss on the effect of optimal tariff reduction rate on food commodity for the EV (Figure 3). Assuming the policy beneficiary to be Quintile 1 only, the decline in tax revenue exceeds welfare gain at any point of tariff reduction rate, and hence the optimal rate is 0%. However, it ranges between 80% and 100% under the assumption that the beneficiary is all the quintiles. It is noticeable that with only 20% or 30% tax cut the net economic benefit (EV minus lost tax revenue) rises dramatically to attain 89% or 97% of those in the cases of the complete tariff abolition, respectively. Moreover, it is found that food liberalization brings about substantial effects on domestic food prices,

decreasing by 4.6% on average compared with those in the FOOD scenario.

Robustness tests for uncertain parameters

The results reported above depend on assumed parameter values in the model. The Armington elasticities, which determine the substitutability between international trade and domestic supply are crucial for the analyses. We employ the Monte-Carlo method to conduct the systematic sensitivity analyses (SSA) using the standard deviations estimated by Hertel et al. (2003). The minimum value of the elasticities is set at 0.2 to avoid computational difficulty. We estimated 95% confidence intervals and the coefficient variations (CV)[12] running 1000 times iterative calculations for each scenario. If $|CV| < 50$, it is statistically robust under the assumption that variables follow the normal distribution (Keeney and Hertel 2009).

    The sensitivity results are reported in Tables A1-A5. We found that most of our results with respect to the parameters are robust except Quintile 5 for Scenarios MEATFISH and FOOD in Table A1, Quintile 5 for the scenario MEATFISH and Quintiles 1-4 for Scenario FOOD in Table A2 and "Cattle," "Cattle meat," and "Milk" for Scenario GRAIN in Table A3.

Conclusion

In this analysis, we assessed the welfare impacts of the global food and energy price hikes in 2008 on low income households using a UK multi-household general equilibrium model, and discussed the policy implications for food and energy import tariff liberalization as an emergent counter-policy against volatile prices. Our main findings are as follows: in the short-term, the agricultural, food and energy price spikes disproportionately impact the lowest income group, the energy price negative effects are far greater than food price rises for disadvantaged people, and in the long term the negative impacts are generally but marginally alleviated. High cereal prices only had marginal impact on the prices in the livestock and raw milk sectors. Energy price spikes also do not alter agricultural prices to a significant extent. Further, we found that unilateral free trade policies on agricultural or energy goods were inefficient in terms of the governmental budget in comparison with income transfer policy, assuming that the policy beneficiary was the lowest income households alone. On top of that, trade liberalization worsen the income distribution.

    Based on our simulations, UK policy makers should concentrate more on counter policies against energy price

surges compared to agricultural and food price hikes to mitigate adverse impacts on households. The social welfare effects (total effects of all the quintiles) of free trade policies on both food and energy commodities exceed the tax losses in monetary value. Hence, trade liberalization is more effective than social benefit policy (direct income compensation) if policy makers are interested in alleviating the negative impacts on all the households and do not focus on income distribution. Moreover, the UK government did not have to be concerned about the adverse spillover effects of energy price on agricultural and food prices at least in the 2008 commodity price rises.

    Although it should not be simply compared with other literature that investigated for developing countries, our main result is consistent with the existing research that focuses on developing countries with respect to that poor households seem to have been affected disproportionately. As far as we know, the present article is the first one that focuses on measuring the welfare impacts of agricultural or food price spikes on low income households in high income countries using a quantitative and mathematical modeling approach. However, our primary outcome is consistent with the past descriptive studies and governmental reports.

    It is worth noting a limitation of our approach, which is the inability to identify hotspots with micro-household data with geographical location information. In our model, households were aggregated into five income groups that did not allow us to explore different areas within the UK. It would be useful information for policy makers to plan more effective counter-measures against price rises, but is beyond the scope of the present analysis. The identification will be an issue for future research.

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[12] The CV is defined as the standard deviation divided by the mean×100.

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APPENDIX

A.   **Sensitivity Analyses**

Table A1. Sensitivity analysis for short-run welfare impacts on households

Scenario	Income Quintile	95% confidence interval of EV [mil. USD]			CV
		Upper	Mean	Lower	
GRAIN	Quintile 1	-88.5	-85.2	-80.4	-2.3
	Quintile 2	-91.3	-77.7	-69.6	-6.3
	Quintile 3	-110.9	-89.3	-77.8	-9.4
	Quintile 4	-128.1	-96.3	-79.0	-12.5
	Quintile 5	-161.0	-98.5	-66.5	-24.0
MEATFISH	Quintile 1	-252.3	-237.7	-214.5	-3.2
	Quintile 2	-235.1	-226.6	-212.0	-2.1
	Quintile 3	-232.8	-227.2	-211.3	-1.5
	Quintile 4	-228.6	-216.1	-199.4	-2.2
	Quintile 5	-41.7	-11.9	9.2	-86.0
FOOD	Quintile 1	-818.2	-610.0	-461.1	-11.6
	Quintile 2	-715.0	-448.8	-239.7	-21.1
	Quintile 3	-692.4	-417.4	-200.3	-23.2
	Quintile 4	-575.7	-254.3	12.1	-46.3
	Quintile 5	-298.0	117.4	481.4	133.8
ENERGY	Quintile 1	-2776.5	-2705.0	-2434.7	-2.3
	Quintile 2	-4107.1	-4001.6	-3606.4	-2.3
	Quintile 3	-6458.6	-6288.9	-5637.4	-2.4
	Quintile 4	-7976.2	-7766.5	-6963.5	-2.4
	Quintile 5	-5559.2	-5355.4	-4842.3	-2.1
COMBINED	Quintile 1	-3538.3	-3291.5	-3003.8	-3.0
	Quintile 2	-4736.0	-4420.9	-3985.1	-3.1
	Quintile 3	-7032.7	-6668.0	-5978.8	-2.7
	Quintile 4	-8423.9	-7975.9	-7138.4	-2.8
	Quintile 5	-5687.0	-5210.0	-4634.8	-4.0

Notes: "CV" indicates the coefficient variation (standard deviation divided by the mean*100). "Quintile 1" and "Quintile 5" denote the lowest and highest income households, respectively.

Table A2. Sensitivity analysis for long-run welfare impacts on households

Scenario	Income Quintile	95% confidence interval of EV [mil. USD]			CV
		Upper	Mean	Lower	
GRAINLONG	Quintile 1	-83.2	-87.2	-91.5	-1.8
	Quintile 2	-50.5	-69.2	-97.0	-17.3
	Quintile 3	-71.8	-90.1	-118.0	-13.9
	Quintile 4	-55.9	-86.9	-134.0	-24.0
	Quintile 5	-24.8	-81.7	-170.2	-48.1
MEATFISHLONG	Quintile 1	-214.9	-234.1	-246.5	-2.7
	Quintile 2	-198.1	-215.1	-220.3	-1.5
	Quintile 3	-209.4	-227.9	-232.6	-1.5
	Quintile 4	-196.1	-213.6	-229.7	-2.8
	Quintile 5	16.7	-8.6	-43.4	-142.7
FOODLONG	Quintile 1	256.5	-267.9	-683.7	-71.2
	Quintile 2	824.5	99.8	-451.6	261.6
	Quintile 3	854.0	80.8	-503.4	342.9
	Quintile 4	1368.0	405.7	-301.3	83.5
	Quintile 5	2311.8	1043.8	103.6	43.2
ENERGYLONG	Quintile 1	-2355.3	-2645.6	-2727.2	-2.5
	Quintile 2	-3481.6	-3911.3	-4030.4	-2.5
	Quintile 3	-5689.1	-6414.2	-6614.1	-2.6
	Quintile 4	-7037.4	-7938.1	-8186.4	-2.6
	Quintile 5	-4850.9	-5423.0	-5695.6	-2.4
COMBINEDLONG	Quintile 1	-2309.3	-2881.3	-3335.0	-7.5
	Quintile 2	-2942.0	-3770.8	-4391.4	-7.9
	Quintile 3	-5247.5	-6276.0	-6982.4	-5.7
	Quintile 4	-6182.1	-7463.5	-8325.8	-5.9
	Quintile 5	-2955.1	-4335.8	-5342.6	-11.5

Notes: CV indicates the coefficient variation (standard deviation divided by the mean*100). "Quintile 1" and "Quintile 5" denote the lowest and highest income households, respectively.

Table A3. Sensitivity analysis for inter-sectoral impacts (cereal to dairy)

Sector	95% confidence interval for nominal price change [%]							
	GRAIN scenario				GRAINLONG scenario			
	Upper	Mean	Lower	CV	Upper	Mean	Lower	CV
Cattle	0.10	0.03	-0.02	94.1	2.15	1.37	0.26	34.0
Other animal products	3.49	2.46	0.66	34.9	2.92	1.77	0.20	42.8
Raw milk	1.69	1.17	0.21	38.5	4.31	2.81	0.42	37.1
Cattle meat	0.00	-0.02	-0.05	-52.6	0.59	0.33	0.04	37.8
Other animal meat	0.37	0.23	0.05	38.3	0.50	0.30	0.03	41.4
Milk	0.18	0.10	-0.02	55.4	0.69	0.42	0.04	39.8
CPI (base=1.00)	1.001	1.001	1.000	0.01	1.001	1.001	1.000	0.01

Notes: CV indicates the coefficient variation (standard deviation divided by the mean*100).

Table A4. Sensitivity analysis for inter-sectoral impacts (energy to agriculture)

	95% confidence interval for nominal price change [%]							
	ENERGY scenario				ENERGYLONG scenario			
Sector	Upper	Mean	Lower	CV	Upper	Mean	Lower	CV
Paddy rice	1.84	1.72	1.52	4.6	1.92	1.79	1.56	3.8
Wheat	1.66	1.33	0.80	20.3	1.58	1.25	0.86	14.7
Oat	1.67	1.47	1.19	9.8	1.67	1.48	1.26	6.3
Barley	0.99	0.72	0.48	20.8	0.91	0.77	0.63	7.9
Maize	1.84	1.72	1.52	4.6	1.92	1.79	1.56	3.8
Other cereal	1.68	1.48	1.21	9.2	1.68	1.50	1.28	5.8
CPI (base=1.00)	1.001	1.001	1.000	0.01	1.044	1.042	1.037	0.12

Notes: CV indicates the coefficient variation (standard deviation divided by the mean*100).

Table A5. Sensitivity analysis for the effects of trade liberalization

	95% confidence interval for liberalization effects [mil. USD]							
	FOODLIB scenario				ENERGYLIB scenario			
	Upper	Mean	Lower	CV	Upper	Mean	Lower	CV
Quintile 1	408.3	372.3	318.7	6.1	300.4	288.3	259.8	3.9
Quintile 2	475.5	423.7	349.7	7.6	454.4	436.5	394.4	3.8
Quintile 3	480.2	431.6	357.4	7.2	637.4	610.0	540.1	4.4
Quintile 4	532.3	470.6	377.0	8.3	807.7	773.3	686.1	4.3
Quintile 5	619.8	533.3	407.5	10.0	982.9	947.5	885.8	2.5
Total	2515.0	2231.5	1809.1	7.9	3192.6	3061.9	2785.3	3.6
Tax revenue	-390.1	-550.1	-780.2	-18.5	-936.3	-1232.3	-1560.5	-13.5

Notes: CV indicates the coefficient variation (standard deviation divided by the mean*100).

B. Algebraic Model Summary

Sets

i, j	Sector/commodity
h	Factor of production
hh	Household
aez	Agro-ecological zone (AEZ)
gr	Grain
me	Meat
$naez$	Non-AEZ factor
fd	Food good
nfd	Non-food good

Coefficients

β_j^{yland}	Share parameter of AEZ composite for sector j
$\beta_{hh,h,j}$	Share parameter of value added input h for sector j owned by household hh
b_j	Scale parameter of value added function for sector j
$\beta_{hh,aez,j}^{land}$	Share parameter of land input in the AEZ for sector j
b_j^{land}	Scale parameter of land input for sector j
$ax_{i,j}$	Share parameter of intermediate input i for sector j
$ay_{i,j}$	Share parameter of value added composite for sector j
ξ_j^e	Share of allocation for export for sector j
ξ_j^d	Share of allocation for domestic supply for sector j
θ_j	Scale parameter in transformation function for sector j
δ_j^d	Share parameter of domestic supply for sector j
δ_j^m	Share parameter of import for sector j
$\alpha_{hh,i}$	Share parameter of household consumption of commodity/service i
γ_{hh}^f	Scale parameter of non-meat-grain good for household hh
$\delta_{hh,ngm}^f$	Share parameter of non-meat-grain good ngm
γ_{hh}^{cm}	Scale parameter of meat composite for household hh
δ_{hh}^{cm}	Share parameter of meat composite for household hh
γ_{hh}^{cg}	Scale parameter of grain composite for household hh
δ_{hh}^{cg}	Share parameter of grain composite for household hh
μ_i	Share parameter of government consumption of good i
ss^g	Average propensity to save of government
ss_{hh}^p	Average propensity to save of household hh
τ_j^z	Production tax rate for sector j

τ_{hh}^{d}	Direct tax rate for household hh
τ_{j}^{m}	Import tariff rate for sector j
λ_{i}	Share parameter of investment of good i

Price Variables

p_{j}^{land}	Price of AEZ composite for sector j
$p_{h,j}^{f}$	Price of production factor h for sector j
p_{j}^{y}	Price of value added composite for sector j
p_{j}^{z}	Price of production for sector j
p_{j}^{e}	Price of export for sector j
p_{j}^{d}	Price of domestic supply for sector j
p_{j}^{m}	Price of import for sector j
p_{i}^{q}	Price of Armington composite for good i
p_{hh}^{cf}	Price of food composite for household hh
p_{hh}^{cm}	Price of meat composite for household hh
p_{hh}^{cg}	Price of grain composite for household hh

Activity variables

$LAND_{j}$	AEZ composite for sector j
$F_{h,j}$	Factor input h for sector j
Y_{j}	Value added composite for sector j
Z_{j}	Domestic production for sector j
$X_{i,j}$	Intermediate input of good i for sector j
E_{i}	Export of commodity/service i
D_{i}	Domestic good i
M_{i}	Import of commodity/service i
Q_{i}	Armington composite of good/service i
X_{i}^{p}	Household consumption of good/service i
X_{i}^{g}	Government consumption of good/service i
X_{i}^{v}	Investment uses of good/service i
S_{hh}^{p}	Household saving for household hh
S^{g}	Government saving
T_{j}^{z}	Production tax revenue
T_{i}^{m}	Import tariff revenue
T_{hh}^{d}	Direct tax revenue from household hh
ε	Exchange rate

CF_{hh} — Food composite for household hh

CM_{hh} — Meat composite for household hh

CG_{hh} — Grain composite for household hh

σ_j^{land}	Substitution between AEZ land in the production of good j
σ_j^{fa}	Substitution between endowments in the production of good j
σ_i^{tr}	Transformation between export and domestic supply of good/service i
σ_i^{arm}	Substitution between import and domestic good/service to make Armington composite i
$\sigma_{hh,i}^{fd}$	Substitution between meat and grain composites and other food goods to make food composite good i for household hh
$\sigma_{hh,j}^{me}$	Substitution between meat goods to make meat composite for household hh
$\sigma_{hh,j}^{gr}$	Substitution between grain goods to make grain composite for household hh

Other exogenous variables

p_i^{We}	World export price for good/service i
p_i^{Wm}	World export price for good/service i
$FF_{h,j}$	Endowment h for sector j
S^f	Foreign saving

AEZ aggregate

$$F_{hh,aez,j} = \left(\frac{b_j^{land}{}^{\frac{(\sigma_j^{land}-1)}{\sigma_j^{land}}} \beta_{hh,aez,j}^{land} p_j^{land}}{p_{hh,aez,j}^f} \right)^{\sigma_j^{land}} LAND_j \qquad \forall hh, aez, j \quad (1)$$

$$LAND_j = b_j^{land} \left(\sum_{hh,aez} \beta_{hh,aez,j}^{land} F_{hh,aez,j}^{\frac{(\sigma_j^{land}-1)}{\sigma_j^{land}}} \right)^{\frac{\sigma_j^{land}}{\sigma_j^{land}-1}} \qquad \forall j \quad (2)$$

Value added aggregate

$$Y_j = b_j \left(\sum_{hh,naez} \beta_{hh,naez,j} F_{hh,naez,j}^{\frac{(\sigma_j^{fa}-1)}{\sigma_j^{fa}}} + \beta_j^{yland} LAND_j^{\frac{(\sigma_j^{fa}-1)}{\sigma_j^{fa}}} \right)^{\frac{\sigma_j^{fa}}{\sigma_j^{fa}-1}} \qquad \forall j \quad (3)$$

$$F_{hh,naez,j} = \left(\frac{b_j{}^{\frac{(\sigma_j^{fa}-1)}{\sigma_j^{fa}}} \beta_{hh,naez,j} p_j^y}{p_{hh,naez,j}^f} \right)^{\sigma_j^{fa}} Y_j \qquad \forall hh, naez, j \quad (4)$$

$$LAND_j = \left(\frac{b_j^{\frac{(\sigma_j^{fa}-1)}{\sigma_j^{fa}}} \beta_j^{yland} p_j^y}{p_j^{land}} \right)^{\sigma_j^{fa}} Y_j \qquad \forall j \qquad (5)$$

-Gross output producing firm

$$\text{Production function: } Z_j = \min\left(\frac{X_{i,j}}{ax_{i,j}}, \frac{Y_j}{ay_j} \right) \qquad \forall j \qquad (6)$$

Demand function for intermediates

$$X_{i,j} = ax_{i,j} Z_j \qquad \forall i, j \qquad (7)$$

Demand function for value added

$$Y_j = ay_j Z_j \qquad \forall j \qquad (8)$$

Unit price function

$$p_{j,r}^z = ay_j p_j^y + \sum_i ax_{i,j} p_i^q \qquad \forall j \qquad (9)$$

CET transformation for export and domestic good

$$Z_i = \theta_i \left(\xi_i^e E_i^{\frac{\sigma_i^{tr}+1}{\sigma_i^{tr}}} + \xi_i^d D_i^{\frac{\sigma_i^{tr}+1}{\sigma_i^{tr}}} \right)^{\frac{\sigma_i^{tr}}{\sigma_i^{tr}+1}} \qquad \forall i \qquad (10)$$

$$E_i = \left(\frac{\theta_i^{\frac{\sigma_i^{tr}+1}{\sigma_i^{tr}}} \xi_i^e \left(1+\tau_i^z\right) p_i^z}{p_i^e} \right)^{-\sigma_i^{tr}} Z_i \qquad \forall i \qquad (11)$$

$$D_i = \left(\frac{\theta_i^{\frac{\sigma_i^{tr}+1}{\sigma_i^{tr}}} \xi_i^d \left(1+\tau_i^z\right) p_i^z}{p_i^d} \right)^{-\sigma_i^{tr}} Z_i \qquad \forall i \qquad (12)$$

Armington aggregate

$$Q_i = \gamma_i \left(\delta_i^m M_i^{\frac{(\sigma_i^{arm}-1)}{\sigma_i^{arm}}} + \delta_i^d D_i^{\frac{(\sigma_i^{arm}-1)}{\sigma_i^{arm}}} \right)^{\frac{\sigma_i^{arm}}{\sigma_i^{arm}-1}} \qquad \forall i \qquad (13)$$

$$M_i = \left(\frac{\gamma_i^{\frac{(\sigma_i^{arm}-1)}{\sigma_i^{arm}}} \delta_i^m p_i^q}{(1+\tau_i^m) p_i^m} \right)^{\sigma_i^{arm}} Q_i \qquad \forall i \qquad (14)$$

$$D_i = \left(\frac{\gamma_i^{\frac{(\sigma_i^{arm}-1)}{\sigma_i^{arm}}} \delta_i^d p_i^q}{p_i^d} \right)^{\sigma_i^{arm}} Q_i \qquad \forall i \quad (15)$$

Balance of payments and export and import price

$$\sum_i p_i^{We} E_i + S^f = \sum_i p_i^{Wm} M_i \qquad (16)$$

$$p_i^e = \varepsilon p_i^{We} \qquad \forall i \quad (17)$$

$$p_i^m = \varepsilon p_i^{Wm} \qquad \forall i \quad (18)$$

-Household Utility function:

$$UU_{hh} = \prod_{nz} X_{hh,nz}^{p}{}^{\alpha_{hh,nz}} CF_{hh}^{\sum \alpha_{hh,zz}} \qquad \forall hh \quad (19)$$

Demand functions for household

$$X_{hh,nfd}^{p} = \frac{\alpha_{hh,nfd}}{p_{nfd}^q} \left(\sum_{h,j} p_{hh,h,j}^f FF_{hh,h,j} - T_{hh}^d - S_{hh}^p \right) \qquad \forall hh, nfd \quad (20)$$

$$CF_{hh} = \frac{\sum_{fd} \alpha_{hh,fd}}{p_{hh}^{cf}} \left(\sum_{h,j} p_{hh,h,j}^f FF_{hh,h,j} - T_{hh}^d - S_{hh}^p \right) \qquad \forall hh \quad (21)$$

Food composite for household

$$CF_{hh} = \gamma_{hh}^f \left\{ \sum_{ngm} \left[\delta_{hh,ngm}^f X_{hh,ngm}^{p}{}^{\frac{\sigma^f-1}{\sigma^f}} \right] + \delta_{hh}^{fcg} CG_{hh}^{\frac{\sigma^f-1}{\sigma^f}} + \delta_{hh}^{fcm} CM_{hh}^{\frac{\sigma^f-1}{\sigma^f}} \right\}^{\frac{\sigma^f}{\sigma^f-1}} \qquad \forall hh \quad (22)$$

$$X_{hh,ngm}^{p} = \left(\frac{\gamma_{hh}^{f}{}^{\frac{\sigma^f-1}{\sigma^f}} \delta_{hh,ngm}^f p_{hh}^{cf}}{p_{ngm}^q} \right)^{\sigma^f} CF_{hh} \qquad \forall hh, ngm \quad (23)$$

$$CM_{hh} = \left(\frac{\gamma_{hh}^{f}{}^{\frac{\sigma^f-1}{\sigma^f}} \delta_{hh}^{fcm} p_{hh}^{cf}}{p_{hh}^{cm}} \right)^{\sigma^f} CF_{hh} \qquad \forall hh \quad (24)$$

$$CG_{hh} = \left(\frac{\gamma_{hh}^{f}{}^{\frac{\sigma^f-1}{\sigma^f}} \delta_{hh}^{fcg} p_{hh}^{cf}}{p_{hh}^{cg}} \right)^{\sigma^f} CF_{hh} \qquad \forall hh \quad (25)$$

Grain composite for household

$$CG_{hh} = \gamma_{hh}^{cg} \left\{ \sum_{gr} \left[\delta_{hh,gr}^{cg} X_{hh,gr}^{p}{}^{\frac{\sigma^{cg}-1}{\sigma^{cg}}} \right] \right\}^{\frac{\sigma^{cg}}{\sigma^{cg}-1}} \qquad \forall hh \quad (26)$$

$$X_{hh,gr}^{p} = \left(\frac{\gamma_{hh}^{cg\frac{\sigma^{cg}-1}{\sigma^{cg}}} \delta_{hh,gr}^{cg} p_{hh}^{cg}}{p_{gr}^{q}} \right)^{\sigma^{cg}} CG_{hh} \qquad \forall hh, gr \quad (27)$$

Meat composite for household

$$CM_{hh} = \gamma_{hh}^{cm} \left\{ \sum_{me} \left[\delta_{hh,me}^{cm} X_{hh,me}^{p \frac{\sigma^{cm}-1}{\sigma^{cm}}} \right] \right\}^{\frac{\sigma^{cm}}{\sigma^{cm}-1}} \qquad \forall hh \quad (28)$$

$$X_{hh,me}^{p} = \left(\frac{\gamma_{hh}^{cm\frac{\sigma^{cm}-1}{\sigma^{cm}}} \delta_{hh,me}^{cm} p_{hh}^{cm}}{p_{me}^{q}} \right)^{\sigma^{cm}} CM_{hh} \qquad \forall hh, me \quad (29)$$

Government consumption

$$X_{i}^{g} = \frac{\mu_{i}}{p_{i}^{q}} \left(\sum_{hh} T_{hh}^{d} + \sum_{j} T_{j}^{z} + \sum_{j} T_{j}^{m} - S^{g} \right) \qquad \forall i \quad (30)$$

Direct tax revenue

$$T_{hh}^{d} = \tau_{hh}^{d} \sum_{h,j} p_{hh,h,j}^{f} FF_{hh,h,j} \qquad \forall hh \quad (31)$$

Production tax revenue

$$T_{j}^{z} = \tau_{j}^{z} p_{j}^{z} Z_{j} \qquad \forall j \quad (32)$$

Import tariff revenue

$$T_{j}^{m} = \tau_{j}^{m} p_{j}^{m} M_{j} \qquad \forall j \quad (33)$$

Investment

$$X_{i}^{v} = \frac{\lambda_{i}}{p_{i}^{q}} \left(\sum_{hh} S_{hh}^{p} + S^{g} + \varepsilon \, S^{f} \right) \qquad \forall i \quad (34)$$

Household saving

$$S_{hh}^{p} = ss_{hh}^{p} \sum_{h,j} p_{hh,h,j}^{f} FF_{hh,h,j} \qquad \forall hh \quad (35)$$

Government saving

$$S_{g} = ss^{g} \left(\sum_{hh} T_{hh}^{d} + \sum_{j} T_{j}^{z} + \sum_{j} T_{j}^{m} \right) \qquad (36)$$

Market-clearing conditions Commodity/service market

$$Q_{i} = \sum_{hh} X_{hh,i}^{p} + X_{i}^{g} + X_{i}^{v} + \sum_{j} X_{i,j} \qquad \forall i \quad (37)$$

Factor market

$$\sum_{j} FF_{hh,h,j} = \sum_{j} F_{hh,h,j} \qquad \forall h, hh \quad (38)$$