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Impact of Animal Disease Outbreaks on the U.S. Meat Demand

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Impact of Animal Disease Outbreaks on The U.S. Meat Demand

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ABSTRACT

Since the early 2000s, the U.S. meat market has been affected by two main animal diseases: Bovine Spongiform Encephalopathy (BSE) and Highly Pathogenic Avian Influenza (HPAI)). This study examined the impact of BSE and HPAI outbreaks on the demand for beef, pork and broiler in the U.S from 1993 to 2019. Using the iterative SUR estimation of a Rotterdam model, we observed seasonal patterns in the demands for beef, broiler and broilers. Our findings showed that a BSE disease enhanced the pork demand, but this effect was short lived and reverted in the long run. An HPAI outbreak reduced broiler demand and boosted beef demand in the short run. Using graphs of variable elasticities, out study illustrated that the first BSE outbreak in 2003 had the largest impact on the U.S. meat markets.

KEYWORDS: Animal Diseases, Meat Demand, Bovine Spongiform Encephalopathy, Highly Pathogenic Avian Influenza

1. INTRODUCTION

U.S. meat demand is a complex and multi-faceted system, with numerous demand drivers that are changing and evolving over time (Tonsor et al., 2010). Data from the Food and Agriculture Organization (FAO) show that U.S. meat consumption increased from 88.66 kg per capita per year in 1961 to 124.10 kg per capita per year in 2017 (Hannah & Max, 2017). Changes in meat consumption by type, shown in Figure 1, reveal a rapid expansion of poultry consumption since 1960s at the expense of beef. In fact, beef and buffalo consumption fell from 46.49% in 1961 to 29.88% in 2017 as a percentage of total meat consumption. Over the same period, poultry's share of consumption has risen sharply from less than 20% of meat consumption in the early 1960s to more than 40% in 2017 (Hannah & Max, 2017). Lower retail prices of poultry relative to beef and pork, rapid development and marketing, as well as consumers' health-related concerns were likely the three main contributors to the rising demand for poultry (Bentley, 2019). Pig and hog consumption kept relatively steady at around 25% of meat consumption over this period.

[Figure 1 here]

Underpinned by health-related concerns, animal diseases have been demonstrated to be important determinants of meat demand (Ishida et al., 2010; Wang & de Beville, 2017). From a global perspective, animal diseases have caused serious problems for the economic market in the last few decades (OECD & FAO, 2018). Three animal diseases that have widely affected the world meat market include Bovine Spongiform Encephalopathy (BSE), avian influenza (AI) virus and African Swine Fever (ASF). The first case of BSE (also known as mad cow disease) was confirmed in the UK in 1986 (Smith & Bradley, 2003). Since then, BSE has spread around the world and disrupted global beef consumption. U.S. confirmed its first case of BSE in 2003 in Washington State in imports from Canada (CDC, 2018a). By the end of 2018, the United States has identified six BSE cases (CDC, 2018a).

AI, most commonly known as bird flu, was first reported in China in 1996 (Ku & Chan, 1999; Barral, Alvarez, Juste, Agirre, & Inchausti, 2008). The AI virus could infect both poultry and wild birds and had two components: highly pathogenic avian influenza (HPAI) and low pathogenicity avian influenza (LPAI). HPAI was a serious disease and required a rapid response (USDA, 2021a), while the infection of poultry with LPAI viruses were less dangerous (CDC, 2017). Before AI virus spread to the U.S., the AI virus used to be in the form of H5N1, which was a type of HPAI detected in Asia and Europe. But after it occurred in the U.S., the virus has mutated to other highly pathogenic forms such as H7N2 and H5 (Wang & de Beville, 2017; CDC, 2018b). U.S. reported H7N2 cases in Virginia in 2002, H5N2 cases in Texas in 2004 (Wang & de Beville, 2017), and three types of H5 (H5N1, H5N2, and H5N8) cases in 21 states from December 2014 to mid-June 2015 (Wang & de Beville, 2017; CDC, 2018b). USDA reports showed that from 2014 to 2015 Minnesota has confirmed 110 cases and Iowa confirmed 77 cases while the other states had at most 10 cases (USDA, 2021a). Avian influenza could also infect humans if enough bird flu gets into people's eyes, noses, or mouth (CDC, 2018b).

The impact of animal diseases on meat demand has attracted a lot of attention in previous studies. For instance, Wang & de Beville (2017) examined the media effects of animal diseases on the U.S. meat demand. Results showed that poultry demand was easily substituted by pork and beef given the news of bird flu virus. Several researchers investigated the animal diseases' effects in other countries. Park et al. (2008) conducted an error correction method and historical decomposition to examine the effect of domestic and overseas animal diseases on the Korean meat market from 1985 to 2006. Results showed that animal disease outbreaks resulted in a temporary price shock to the Korean meat market, and that the shock would be even more severe if the outbreak was overseas. Leeming & Turner (2004) used a series of simultaneous functions to estimate the effects of the BSE crisis on beef, lamb, and pork prices over the period 1985-2006 in the UK. They found a negative effect of BSE on beef price and a positive effect on lamb price. Mu et al. (2015) examined impacts of the BSE and AI on the U.S. meat demand and used media coverage to measure AI and dummy variables to measure BSE. They observed that beef was replaced by pork under BSE outbreaks. However, using media coverage to measure animal diseases may be inaccurate as it is difficult to disentangle positive versus negative news coverage and construct an objective measure of news information. Different from Mu et al. (2015), our study used indicator variables of AI and BSE outbreaks rather than media coverage to measure animal diseases. To the best of our knowledge, no previous studies have used indicator variables based on actual outbreak information to measure the impact of AI and BSE diseases on the U.S. meat market.

The goal of our study is to assess the impacts of domestic outbreaks of two animal diseases, i.e., HPAI and BSE on U. S. meat demand. With the meat dataset from USDA and disease data from World Organization for Animal Disease (OIE), USDA and CDC, we employed a two-stage procedure in this study. In the first stage, we estimated a linear Rotterdam demand system using the iterative seemingly unrelated regression (SUR). Next, we used the estimates of the SUR to derive both fixed and variable compensated elasticities. The plot of variable compensated elasticities was employed to examine changes in the effect of each animal disease outbreak on the dynamic meat demand. Our study revealed that a BSE disease outbreak boosted pork demand in the current period, but this effect was typically short lived. On the other hand, beef demand did not alter under a BSE outbreak, but would rise in the successive period. We also observed that an HPAI outbreak enhanced beef demand and reduced broiler demand during the same period. The patterns of the variable elasticities revealed that the first BSE outbreak had the largest impact on U.S. beef and pork consumption. Using indicator variables based on actual outbreak information, our study extends the previous literature by evaluating and comparing multiple disease outbreaks' impacts on meat demand.

The rest of this paper is organized as follows. Section 2 reviews the previous studies. Section 3 describes our data. Section 4 introduces the econometric method. Section 5 shows the main results. Section 6 makes a summary and draws the conclusion.

2. LITERATURE REVIEW

It is widely assumed that perfectly informed consumers have stable preferences (Smallwood & Conlisk, 1979). However, consumer preferences would be altered if the information changes over time (Rieger et al., 2016). In the food industry, food safety has been a great source of concern for years. Food expected to be safe might be contaminated due to hazards in production, processing, storage, transport, or final preparation for consumption (FAO, 2021a). Animal food products are important parts of food consumption – they can improve human nutrition and heart and bone health. Meats, such as poultry, beef, and pork, provide nutrients- including protein, B vitamins (niacin, thiamin, riboflavin and B6), vitamin E, iron, zinc and magnesium (USDA, 2021b). Healthy animal food products could eliminate hunger, make people healthier, and contribute to sustainable food production (FAO, 2021b). Healthy animals hence become one of the keys to food safety. The biggest threat to the health of animals and animal food products mainly comes from animal diseases.

Several previous studies employed either an error correction model or simultaneous equations of meat prices to examine the impacts of animal disease crises on the domestic meat market (Leeming & Turner, 2004; Park et al., 2008). Using data for Korea from 1985 to 2006, Park et al. (2008) applied an error correction method and historical decomposition to show that animal disease outbreaks resulted in a temporary price shock to the Korean meat market, and the shock would be more severe if it were overseas. Historical decomposition is appropriate for the analysis of unanticipated exogenous shocks such as animal disease outbreaks (Park et al., 2008). Error correction models can directly measure the effects of lagged prices on current prices and estimate the price elasticity using the variables in logarithm forms. The main problem for the error correction models is that the error correction model estimations would not be valid if the variables are not cointegrated. Leeming & Turner (2004) used a series of simultaneous functions to estimate the effects of the BSE outbreaks on beef, lamb, and pork prices over the period 1985-2006 in the UK. They detected a negative effect on beef price and a positive effect on lamb price. However, both studies focused on the price reaction and neither assessed the consumption impacts of animal diseases.

Another set of studies considered the effects of animal disease on meat demand (Ishida et al., 2010; Wang & de Beville, 2017). Several researchers estimated the substitution relationships across different meat categories using the Inverse Almost Ideal Demand System (IAIDS) (Holt, & Balagtas, 2009; Holt, 2012; Wang & de Beville, 2017). For instance, Wang & de Beville (2017) examined the effects of bird flu news in media on consumers' consumption behavior in the U.S. from 2001 to 2009. They showed that poultry demand would be easily substituted by beef and pork given negative news of bird flus (Wang & de Beville, 2017). These studies widely relied on fixed elasticities by using the average budget share. Hence, they did not capture the effect of each disease outbreak on meat demand. A potential way to solve this problem is to plot the pattern of variable compensated elasticities and compare the elasticities in pre-disease periods and post-disease periods. However, we are not aware of any previous studies that have used this method to examine animal disease's effects on meat demand in the U.S. In this vein, we are the first to pursue such an approach.

Previous studies such as Wong et al. (2015), Tonsor et al. (2010), and Tonsor & Olynk (2011) have also used Rotterdam models, initially developed by Theil (1965), for meat demand analyses. Tonsor & Olynk (2011) showed how animal welfare information impacted beef, pork and poultry demand. Their findings indicated that pork and poultry demand decreased in the long run due to the rising media attention to animal welfare. However, to the best of our knowledge, no previous studies have used Rotterdam models to explicitly examine animal diseases' impacts on the meat market.

Many previous studies measured the animal disease impacts using media coverage that either discriminated between negative and positive reports (Verbeke & Ward, 2001; Wang & de Beville, 2017) or did not (Burton & Young, 1996; Piggott & Marsh, 2004; Attavanich et al., 2011). However, media information could have problems since it is likely to result in an unnecessary panic, and it is relatively untrustable among younger people and families with young children (McCluskey & Swinnen, 2004). An alternative method is to measure animal diseases using indicator variables of disease outbreaks (Leeming & Turner, 2004; Marsh et al., 2008; Ishida et al., 2010). The advantage of this method is that it can precisely measure the time of a disease outbreak.

In sum, while a lot of previous work has evaluated consumer demand, few studies used indicator variables to measure HPAI and BSE disease outbreaks' impact on meat demand. Little is known on the effect of these disease outbreaks on domestic meat demand using indicator variables of disease outbreaks. Our study aims to fill these gaps with this research.

3. DATA

The retail prices and consumption of beef, pork, and broilers over the periods 1993-2019 were obtained from USDA-Economic Research Service (USDA-ERS). Real retail meat prices were calculated using the consumer price index for all urban consumers from the U.S. Bureau of Labor Statistics. The CPI was rebased to 2012 instead of 1982-1984 to more closely reflect current process. Table 1 shows that, on average, beef had the highest consumption at 20.5 lb/capita, followed by broilers (18.8) and pork (13.5). On average, real retail prices of beef was the most expensive at $4.76/lb, followed by pork ($3.4/lb) and broilers ($1.99/lb).

[Table 1 here]

Figures 2 – 4 show patterns in meat consumption, prices and budget, respectively. Figure 2 shows that the U.S. broiler consumption increased from 1993 to 2019 while beef and pork consumption dropped in the same period. Figure 3 suggests that the broiler price had a downward trend from 1993 to 2019 whereas the price of beef increased over time. Figure 4 indicates that beef maintained the highest budget share of about 50% during the study period while pork and broiler had smaller budget shares of 25% and 20%, respectively.

[Figure 2 here]
[Figure 3 here]
[Figure 4 here]

Since the data on individual cases of Low Pathogenic Avian Influenza (LPAI) were not available and Highly Pathogenic Avian Influenza (HPAI) was a more serious illness and had to be reported, our study focused only on the HPAI cases for bird flu. We used the outbreaks of the identified BSE and HPAI in the U.S to measure the animal diseases. If BSE and HPAI cases were identified, the disease index for each disease was equal to 1 and 0 otherwise. The HPAI data were collected from OIE and Animal and Plant Health Inspection Service at USDA. The BSE data were obtained from the CDC website (CDC, 2018a). Table 2 shows the specific dates of HPAI and BSE outbreaks in the U.S. from 1993 to 2019. During this period, the U.S. had eight HPAI outbreaks and six BSE outbreaks.

[Table 2 here]

4. METHODOLOGY

Following Wong et al., (2015) and Tonsor & Olynk (2011), we specified a Rotterdam demand model as

$$w_{it}\Delta \ln q_{it} = \phi_{i,0} + \sum_{s=1}^{3} \psi_{i,s} S_s + \theta_i \Delta Q_t + \sum_{j=1}^{3} \pi_{ij} \Delta \ln p_{jt} + \sum_{l=0}^{1} \delta_{il} HPAI_{i,t-l} + \sum_{l=0}^{1} \gamma_{il} BSE_{i,t-l} + v_{it}, \qquad \forall i \in \{1,2,3\} \tag{1}$$

where i = 1, 2 and 3 referred to beef, pork, and broilers, respectively; w_{it} was the i-th good income share at time t; q_i was the meat i consumption per capita; π_{ij} was the Slutsky coefficient indicating the total substitution effect of the change in the price of good j on the demand for good i; $\Delta Q_t = \sum_{i=1}^{n} w_{it} \Delta \ln q_{it}$ was the finite change versions of the Divisia quantity index; p_j denoted the price for commodity j. $HPAI_{i,t-l}$ and $BSE_{i,t-l}$ were the indicators for animal disease outbreaks of HPAI and BSE, respectively; S_s denoted the quarterly dummies; v_{it} was the error term; $\phi_{i,0}$ was a time trend variable; and θ_i, π_{ij}, $\psi_{i,s}$, δ_{il} and γ_{il} were the estimated coefficients.

Based on economic theory, general demand restrictions were imposed using parameter constraints (Marsh et al., 2004). The adding-up condition was imposed as

(Adding-up)
$$\sum_{i=1}^{3} \theta_i = 1, \sum_{i=1}^{3} \pi_{ij} = 0, \sum_{i=1}^{3} \phi_{i,0} = 0\,, \sum_{i=1}^{3} \psi_{i,s} = 0, \sum_{i=1}^{3} \delta_{il} = 0, \sum_{i=1}^{3} \gamma_{il} = 0, \quad \forall j,k,s,l \tag{2}$$

which required that the marginal budget shares on each good summed to unity ($\sum_{i=1}^{3} \theta_i = 1$) and that the net effect of a price change on the budget equaled zero ($\sum_{i=1}^{3} \pi_{ij} = 0$) (Deaton & Muellbauer, 1980). The rest of the adding-up conditions required that the net effect of a preference change on the budget summed to zero. The homogeneity and symmetry restrictions were specified as

(Homogeneity)
$$\sum_{j=1}^{3} \pi_{ij} = 0, \quad \forall i \tag{3}$$

(Symmetry)
$$\pi_{ij} = \pi_{ji}, \qquad \forall i,j \tag{4}$$

Following Marsh et al. (2004), the fixed compensated price elasticities (ε_{ij}) and expenditure elasticities (η_i) from the Rotterdam model were

$$\varepsilon_{ij} = \frac{\pi_{ij}}{\bar{w}_i}, \eta_i = \frac{\theta_i}{\bar{w}_i} \quad (5)$$

where $\bar{w}_i$ denoted the average budget share of meat i. An alternative method to measure elasticities was to use a variable budget share (w_{it}) such that

$$\varepsilon_{ijt} = \frac{\pi_{ij}}{w_{it}}, \eta_{it} = \frac{\theta_i}{w_{it}} \quad (6)$$

where ε_{ijt} and η_{it} represented the variable price and expenditure elasticities, respectively.

Following Tonsor et al., (2010) and Tonsor & Olynk (2011), we estimated the model in two ways. First, assuming the prices and expenditure were predetermined, we used an iterative seemingly unrelated regression (SUR) in estimations. Second, we assumed endogenous prices and expenditure and used iterative three-stage least squares (IS3SLS) in estimation. Following the approach of Eales and Unnevehr (1993), Kinnucan et al. (1997) and Tonsor & Olynk (2011), our instruments included lagged prices and quantities, lagged total per capita expenditure, a price index for energy, corn prices received by producers, US population, 90-day treasury bill yields, real per capita consumer income and a time trend. We conducted Hausman specification tests to determine the exogeneity of prices and quantities. If we failed to reject the null hypothesis of exogeneity in the Hausman tests, we employed iterative SUR estimations, otherwise we would use IS3SLS. Either iterative SUR or IS3SLS would drop one equation of commodity i and build a system of two equations under the adding-up constraint. The coefficients and the variances of the dropped equation were recovered using a series of nonlinear combination calculations (nlcom function in Stata) (Valdez-Lafarga et al., 2019).

5. RESULTS

We failed to reject the null hypothesis of exogeneity in the Hausman test in all evaluations, indicating that the prices and quantities were exogeneous. We hence used the estimates from the iterative SUR in the following estimations. The estimation dropped the equation of pork and used the equations of beef and broiler. The coefficients for pork were derived from equation (2) – (4). Table 3 shows the coefficient estimates of the Rotterdam model. Seasonal estimates indicate that beef and broilers had the lowest consumption in the last quarter whereas pork consumption reached a peak in that period. Results also show that beef and broiler demand were the highest in the second and first quarters, respectively.

Animal diseases' estimates in Table 3 suggest that the meat demand impacts of animal disease outbreaks differed in the short run and the long run. In the short run, the BSE outbreak enhanced pork demand by 0.007 lbs. The HPAI outbreaks have reduced broiler demand by 0.007 lbs per capita and stimulated beef demand by 0.008 lbs. The HPAI's beneficial effects on nonbird meat were consistent with findings of Wang et al. (2017). Our results indicate that these effects were relatively short lived, with a reduction in pork demand (-0.007 lbs) and a rebound in beef demand (0.010 lbs) in the long run. Our results also found insignificant long-run HPAI effects on meat demand.

The coefficient estimates of expenditure and meat prices in Table 3 were used to derive elasticities following Tonsor et al. (2010). Table 4 presents the compensated elasticities based on equation (5). Expenditure elasticities were estimated to be 0.815, 1.055 and 1.415 for beef, pork and broiler, respectively, suggesting that broilers are the most expenditure sensitive meat with a one percent rise in the meat budget increasing broiler consumption by 1.415 percent. Consistent with economic theory, we observed negative own-price elasticities for all meats, albeit statistically significant only for beef (-0.223). Table 3 also suggested that pork and beef are substitutes. In fact, a one percent increase in the price of pork would increase the demand for beef by 0.142 percent. Our estimates are consistent with Tonsor & Olynk (2011) in terms of the signs. The difference of the magnitude is likely due to the data collected from the different periods.

Figure 6 plots variable compensated elasticities derived from equations (6). An advantage of variable compensated elasticities is that they capture the dynamics of elasticities before and after each disease outbreak. Panel A shows that income elasticities rose sharply for pork and decreased rapidly for beef after the first BSE outbreak in 2003. This meant that given the growth in the meat budget, consumers would notably buy more pork products and less beef after the first BSE outbreak in the U.S. The rest of the animal disease outbreaks did not alter the consumer's meat consumption as much as the first BSE outbreak. A similar evaluation could be found in Panel B. Panel B indicates that the beef equation had a reduction in own-price elasticity while the pork equation had a rise in own-price elasticity, suggesting that the first BSE outbreak led consumers to buy more pork products and fewer beef products. Panel C shows a distinctive pattern of how meats were substituted over time. Cross-price elasticities for beef in Panel C show that beef would be more easily substituted by pork since U.S.'s first BSE outbreak. The curve of cross-price elasticity for pork with respect to beef also suggested a consistent result, in which the pork substituted more beef after the BSE outbreak in 2003. Figure 6 also indicate that the broiler demand did not vary as much as pork and beef demands after each animal disease outbreak. But since broiler had the highest income and own-price elasticities, the broiler demand may be hampered most if the general meat demand dropped.

6. SUMMARY AND CONCLUSIONS

This study focused on U.S. meat consumption during the period from 1993 to 2019. Using a Rotterdam model, our research estimated the impacts of two domestic animal diseases (BSE and HPAI) on the consumption of three types of meat (beef, pork and broilers). Our study used the outbreaks of animal diseases as the disease indicators. Using the iterative SUR estimation of a Rotterdam model, we observed seasonal patterns in the demands for beef, broiler and broilers. Beef and broiler demands were the lowest in the fourth quarter whereas at the same time, the pork demand was the highest.

Our findings suggest that broilers were the most expenditure sensitive meat with a one percent rise in the meat budget increasing broiler consumption by 1.415 percent. This finding would also suggest a largest decrease in broiler consumption (relative to other meats) due to a reduction in meat expenditure for reasons such as Covid-19 pandemic. Our estimates of fixed compensated elasticities showed that beef was a normal good and that pork and beef were substitute goods.

Our estimation showed that a BSE disease enhanced the pork demand, but this effect was short lived and reverted in the long run. An HPAI outbreak reduced broiler demand and boosted beef demand in the short run. Using graphs of variable elasticities, out study illustrated that the first BSE outbreak in 2003 had the largest impact on the U.S. meat markets. After 2003 U.S. beef was more easily substituted by pork. Our plots also illustrated that the other animal disease outbreaks did not alter the consumer's meat consumption as much as the first BSE outbreak.

Since beef, pork, and broiler markets are the main types of meat in the U.S., the implications from our study are informative for U.S. retail markets. Our research showed that animal diseases tend to alter meat demand in the short run with substitutions across beef and pork and broilers and beef. These findings suggest that retailers should adjust their inventories to increase the substitutes of a met affected by a disease outbreak. For instance, if a BSE case was identified, grocery stores should immediately add more pork products to their inventories, but not for an extended period.

While our study analyzed the effects of BSE and HPAI outbreaks on U.S. meat consumption, we did not examine the impact of African swine fever (ASF) on U.S. markets. ASF was confined to Africa until the mid-20th century when it spread to Europe, and further to South America (Costard et al., 2013). ASF heavily hit China's hog and pork industry starting in August 2018 throughout 2019. As China was the largest pork market in the world, ASF in China can indirectly influence the global pork market as well (Carriquiry et al., 2020). Our study did not include ASF as the U.S. has not had any cases of ASF so far (USDA, 2020). However, based on the substitutability between pork and beef revealed in our findings, it is likely that that if such outbreak had occurred, consumers would be more likely to switch from pork to beef than to poultry.

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Table 1. Summary statistics of quarterly data used in model estimation

Variables	Observation	Mean	Median	S.D.	Maximum	Minimum
Beef Consumption (lb/capita)	108	20.527	21.213	2.010	23.802	16.89
Pork Consumption (lb/capita)	108	13.539	13.516	1.989	17.718	9.725
Broiler Consumption (lb/capita)	108	18.846	18.628	1.948	23.418	14.659
Real Retail Beef Prices ($/lb)*	108	4.757	4.634	0.602	6.207	3.874
Real Retail Pork Prices ($/lb)*	108	3.400	3.402	0.195	4.042	3.004
Real Retail Broiler Prices ($/lb)*	108	1.976	1.954	0.171	2.306	1.672
Identified HPAI outbreaks in US (%)	108	5.505				
Identified BSE outbreaks in US (%)	108	7.339				

Note: * Inflation-adjusted dollars (deflated by Consumer Price Index base year = 2012).

Table 2. Animal Disease Outbreaks in the U.S. from 1993 to 2019

Diseases	Year	Quarter	State
HPAI	2004	1	TX
	2014	4	OR, WA
	2015	1	AR, CA, ID, KS, MO, OR, WA
	2015	2	IA, IN, MN, MO, MT, ND, NE, SD, WI
	2016	1	IN
	2016	3	AK
	2016	4	MT
	2017	1	TN
BSE	2003	4	WA
	2005	2	TX
	2006	1	AL
	2012	2	CA
	2017	3	AL
	2018	3	FL

Table 3. Estimated coefficients in Rotterdam Model

	(1) Beef	(2) Pork	(3) Broiler
Expenditures	0.439***	0.270***	0.291***
	(0.045)	(0.037)	(0.033)
Beef Price	-0.120***	0.076**	0.044
	(0.041)	(0.032)	(0.028)
Pork Price	0.076**	-0.047	-0.029
	(0.032)	(0.038)	(0.027)
Broiler Price	0.044	-0.029	-0.015
	(0.028)	(0.027)	(0.031)
BSE.US	-0.003	0.007**	-0.005
	(0.004)	(0.003)	(0.003)
HPAI.US	0.008**	-0.001	-0.007**
	(0.004)	(0.004)	(0.003)
Lag1.BSE.US	0.010**	-0.007**	-0.003
	(0.004)	(0.003)	(0.003)
Lag1.HPAI.US	-0.003	-0.002	0.005
	(0.004)	(0.002)	(0.003)
Quarter 1	0.024***	-0.046***	0.022***
	(0.002)	(0.002)	(0.002)
Quarter 2	0.032***	-0.041***	0.009***
	(0.003)	(0.002)	(0.002)
Quarter 3	0.008***	-0.015***	0.007***
	(0.003)	(0.002)	(0.002)
Constant	-0.017***	0.025***	-0.008***
	(0.002)	(0.002)	(0.001)

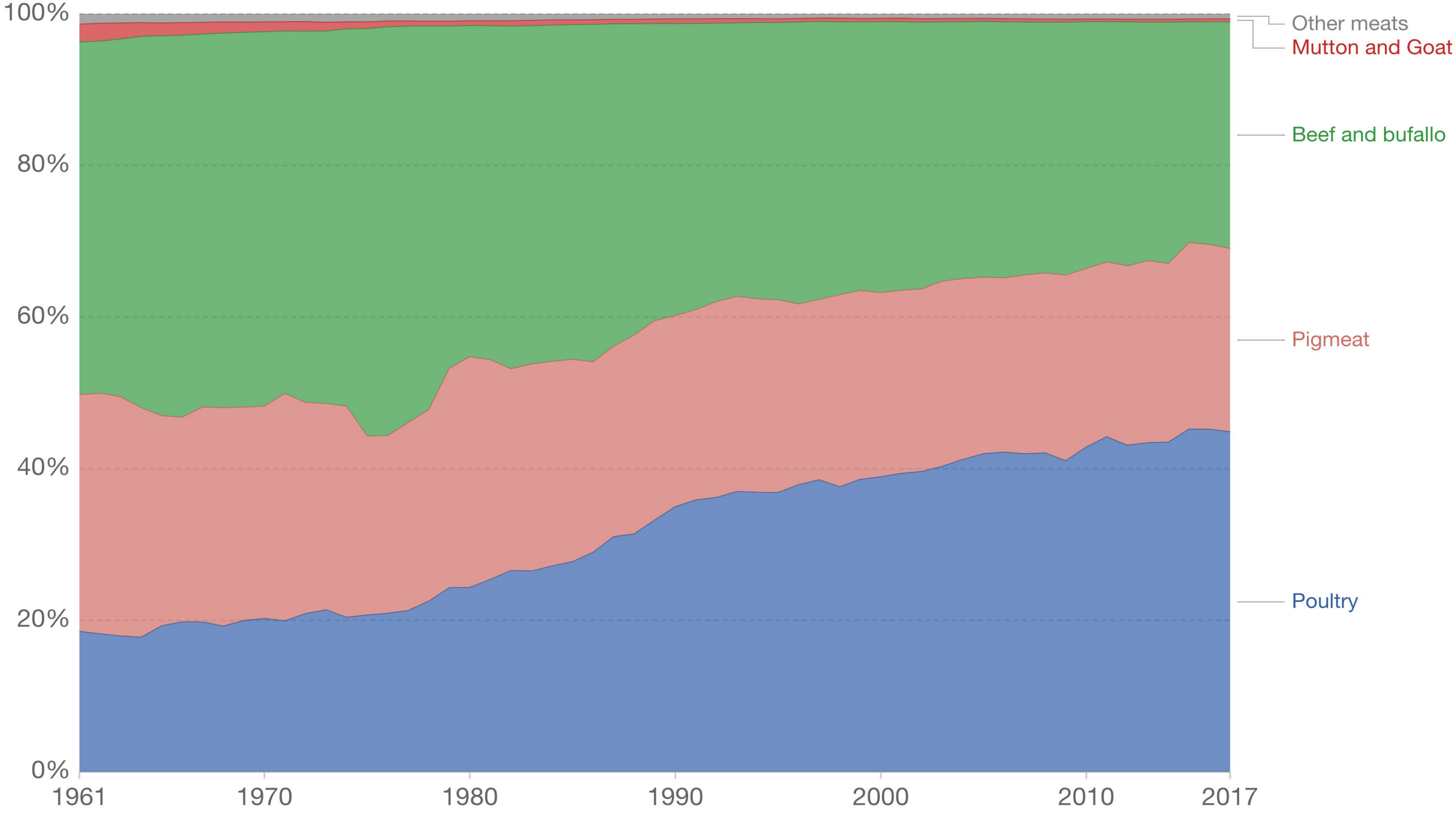
Notes: We use the observation of fourth quarter in 1992 to derive the differenced term in the first quarter of 1993. The number of observations (n) is hence 108. Our iterative SUR estimation applied a small sample adjustment, in which an alternative divisor (n-k, where k is the number of parameters in each equation) was used to compute the covariance matrix for the equation residuals. Standard errors are in the parenthesis. Log likelihood is 776.24. Estimations in Column (2) were estimated based on equation (2) - (4). ***: $p<0.01$, **: $p<0.05$, *: $p<0.1$.

Table 4. Fixed compensated elasticities of Rotterdam Model

	(1) Beef	(2) Pork	(3) Broiler
Expenditures	0.815***	1.055***	1.415***
Beef Price	-0.223***	0.298**	0.213
Pork Price	0.142**	-0.184	-0.142
Broiler Price	0.081	-0.114	-0.071

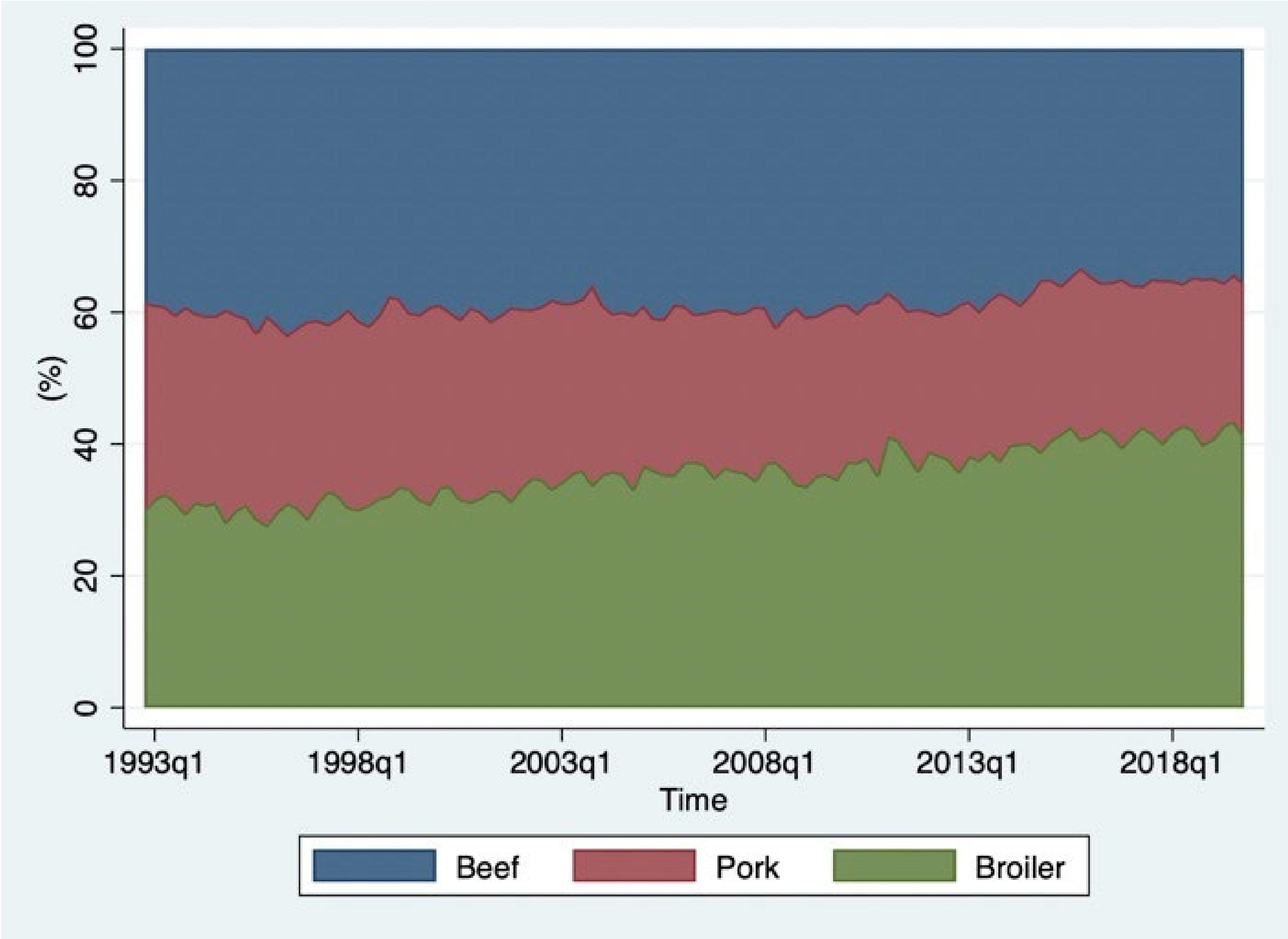
Notes: The compensated elasticities are calculated based on equation (5). The means of the budget shares were 53.837%, 25.566% and 20.597% for of beef, pork and broiler, respectively. ***: p<0.01, **: p<0.05, *: p<0.1.

Figure 1. Per capita meat consumption by type in United States, 1961 to 2017



Source: Ritchie & Roser (2017) and the UN Food and Agricultural Organization (FAO).
Notes: Average per capita meat consumption broken down by specific meat types, measured in kilograms per person per year. Data is based on per capita food supply at the consumer level, but does not account for food waste at the consumer level.

Figure 2. Quarterly U.S. Meat Consumption Per Capita



Notes: Different from Figure 1, Figure 2 is refereeing to our sample period.

Figure 3. Real Retail Meat Prices ($/lb), Base Year 2012

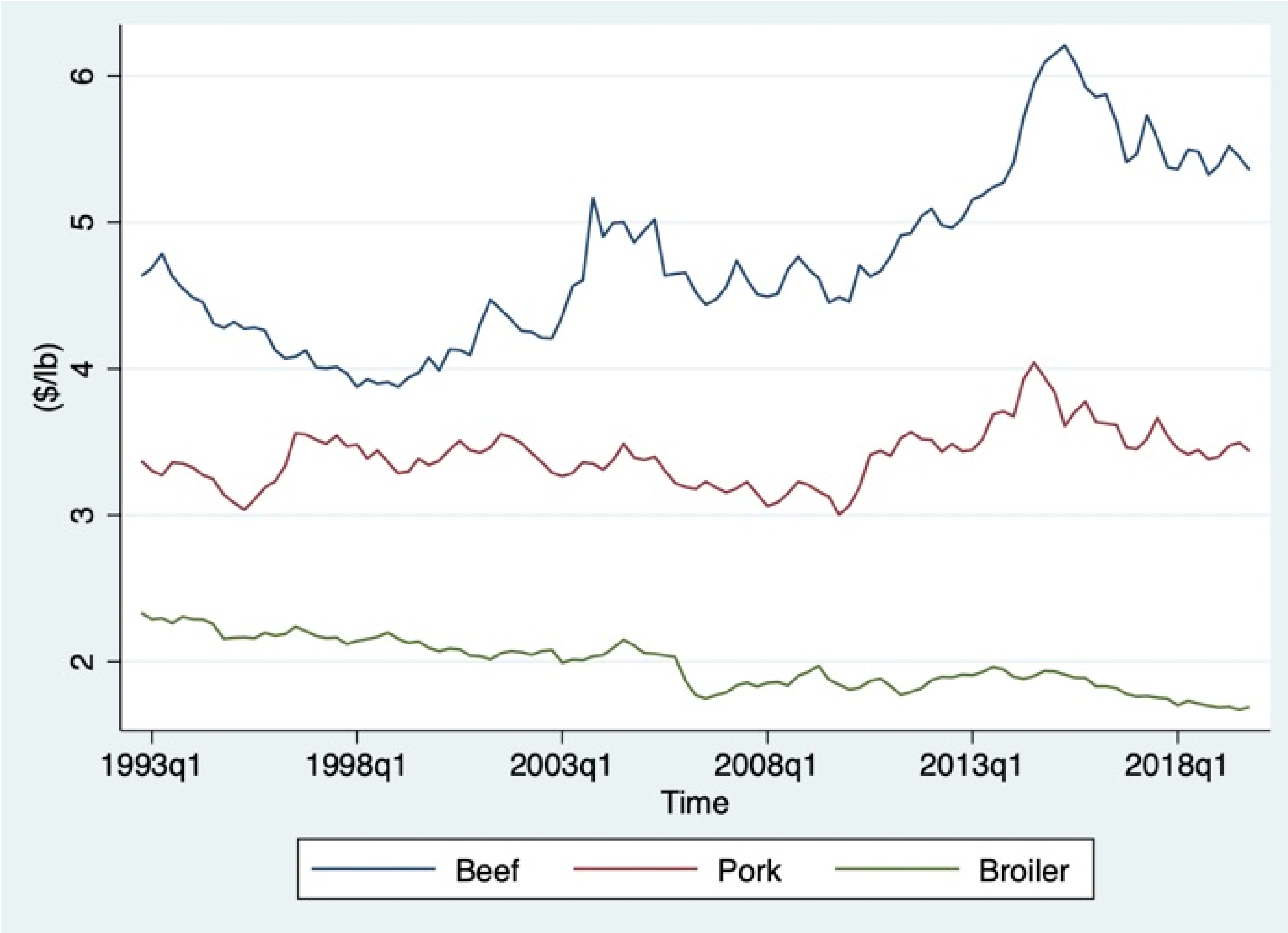


Figure 4. Quarterly Meat Budget Shares Per Capita (%)

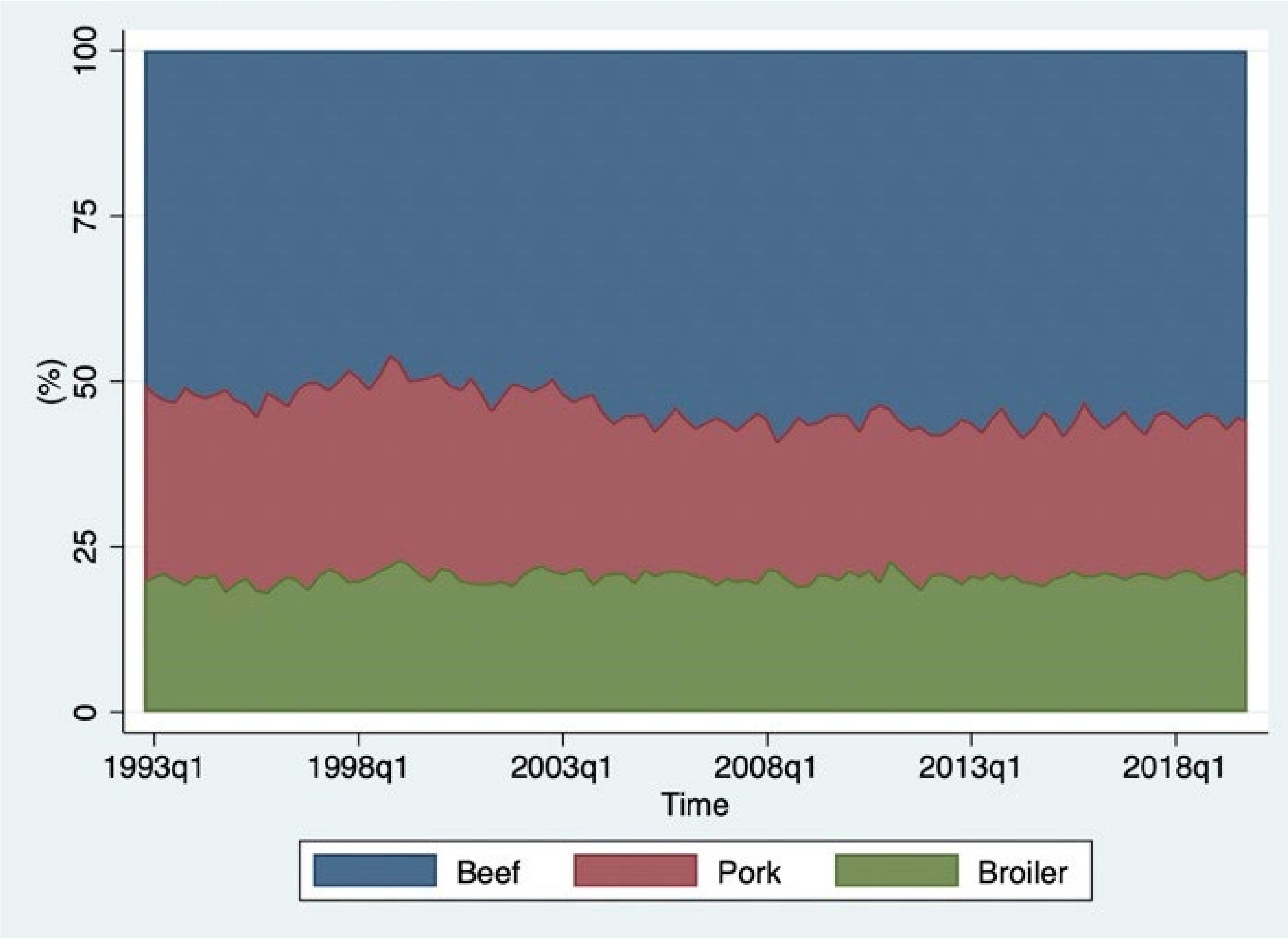
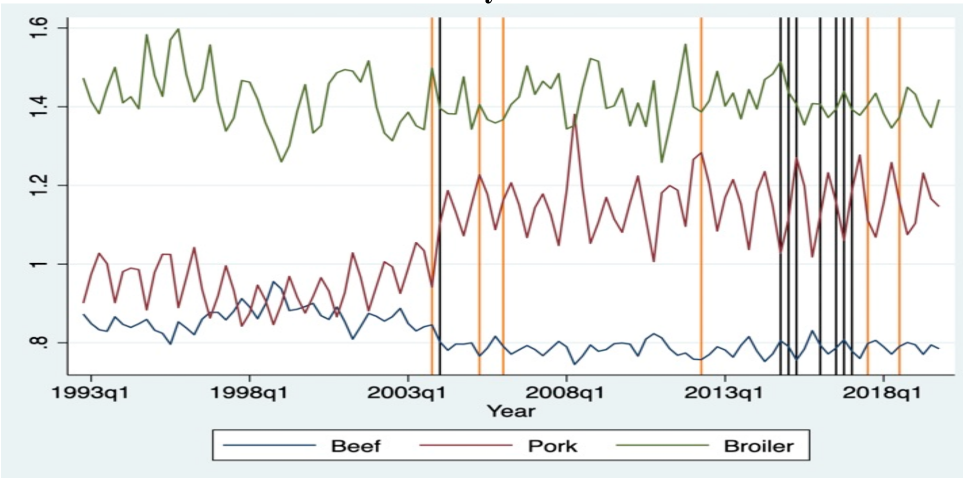
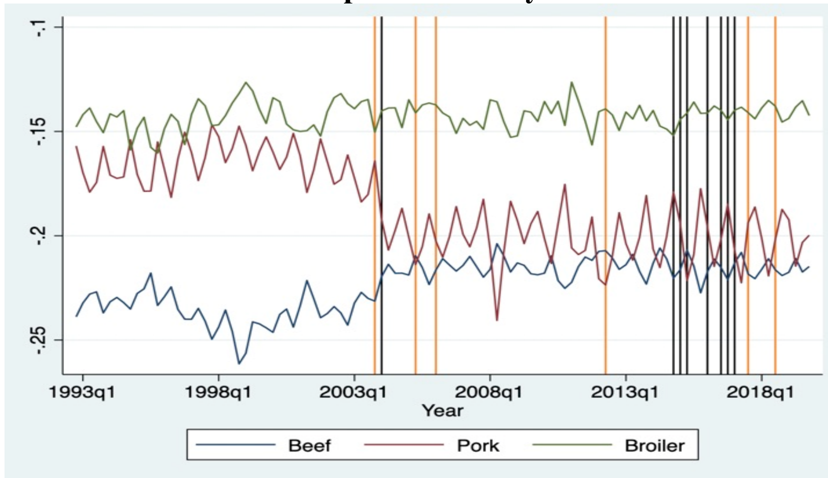


Figure 6. Variable compensated elasticities of Rotterdam model

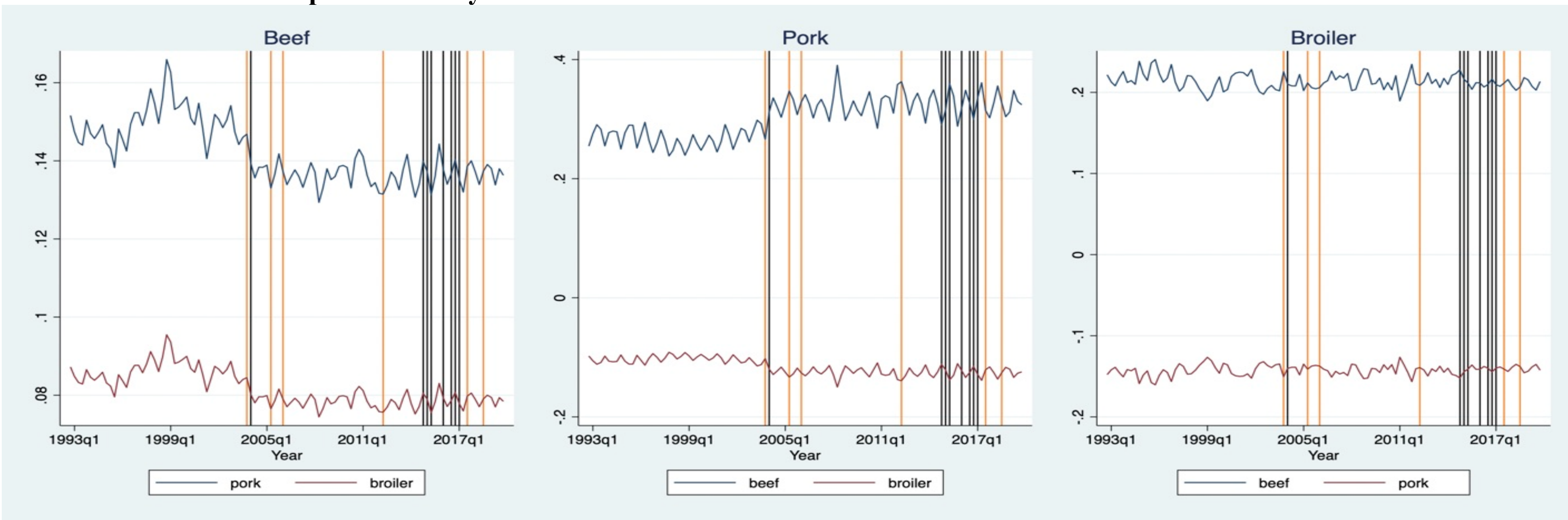
Panel A: Estimated income elasticity



Panel B: Estimated own-price elasticity



Panel C: Estimated cross-price elasticity



Note: The compensated elasticities are calculated based on equation (6). Orange vertical lines denote BSE disease outbreaks and black vertical lines denote HPAI disease outbreaks.