Market Impact of FMD Control Strategies: A UK Case Study

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Abstract Foot and Mouth Disease (FMD) poses a serious threat to the agricultural sector due to its highly contagious nature. Outbreaks of FMD can lead to substantial disruptions to livestock markets due to loss of production and access to international markets. In a previously FMD-free country, the use of vaccination to augment control of an FMD outbreak is increasingly being recognised as an alternative control strategy to direct slaughtering (Stamping-Out). Specific choice of eradication strategies depends on their costs and benefits. Economic impact assessments are often based on Benefit-Cost frameworks, which provide detailed information on the changes in profit for a farm or budget implications for a government (Rich *et al.*, 2005). However, this framework cannot capture price changes caused by the outbreak. Market equilibrium and hence prices are expected to change due to the outbreak as both production and demand (especially export) would be disrupted. The implications of a particular control strategy on the different market aspects can be positive or negative. Therefore, modelling systems able to capture the market impacts are needed for strategy evaluation.

This paper provides assessment of sectoral level impacts of the eradication choices of FMD outbreaks, which are typically not available from Benefit-Cost frameworks, in the context of the UK. The FAPRI-UK model, a partial equilibrium model of the agricultural sector, is utilised to investigate market outcomes of different control strategies (namely, Stamping-Out, and Vaccinate-to-Die) in the case of FMD outbreaks. The outputs from the simulations of the EXODIS epidemiological model (number of animals culled/vaccinated and

duration of outbreak) are used as inputs within the economic model to capture the overall price impact of the animal destruction and export ban.

Keywords:
Foot-and-Mouth Disease; economics; partial equilibrium model; disease control strategy; market impact

1. Introduction

Foot and Mouth Disease (FMD) poses a serious threat to the agricultural sector due to its highly contagious nature, which can lead to substantial disruptions to livestock markets. It is estimated that the outbreak in the UK in 2001 resulted in losses to agriculture and the food chain of approximately £3.1 billion, with further significant impacts on the wider economy (Thompson *et al.*, 2002). A *Stamping-Out* policy was implemented in 2001 to control the disease, whereby all infected stock and others exposed to infection (dangerous contact herds) were slaughtered. Subsequent legislation included provisions for emergency vaccination as a control strategy. Vaccination was considered as an alternative control strategy during the 2007 outbreak, but ultimately was not deployed due to advice on the degree of risk of the disease spreading (Anderson, 2008). There are two main vaccination strategies: *Vaccinate-to-Die* and *Vaccinate-to-Live*. The main difference between *Vaccinate-to-Die* and *Vaccinate-to-Live* is that vaccinated animals are culled in the former but not in the latter.

This paper focuses on the comparison of the *Stamping-Out* and the *Vaccinate-to-Die* strategies. For these two strategies, there are some similarities in the requirements with regard to regaining disease free status and lifting of export ban. Namely, the waiting period of applying for disease free status are 90 days for both and this waiting period starts after all infected and vaccinated (if vaccination is used) livestock are culled. This means that whether the *Vaccinate-to-Die* strategy would be preferred to the *Stamping-Out* strategy depends crucially on its impact on disease elimination. The obvious advantage of the *Vaccinate-to-Die* strategy is that it shortens the duration of the outbreak by slowing the spread of the disease. However, on the downside, this strategy entails the withdrawal of more livestock from the market. In addition, the logistics of undertaking vaccination and the culling of more animals may result in delays before the waiting period can start. Thus, in reality the duration of the outbreak may be longer under the Vaccinate-to-Die strategy.

This paper investigates the market impacts of the two strategies in FMD control (i.e. *Stamping Out* versus *Vaccinate-to-Die*) in the case of the UK using a partial equilibrium modelling framework. The results are based on linking the FAPRI-UK partial equilibrium model and the EXODIS epidemiological model. Outputs from the simulations of the EXODIS model (number of animals culled/vaccinated and duration of outbreak) are used as inputs within the FAPRI-UK model to capture the price impact of the destruction of animals and restrictions to internal trade. Furthermore, in view of the main advantage (shorter disease duration) and disadvantage (larger number of animal culling) of the *Vaccinate-to-Die* strategy in comparison to the *Stamping-Out* strategy, this paper assesses the potential delay that would make the advantages and disadvantages offset each other if initial results show advantage outweighs the disadvantage.

We begin with a review of the literature in Section 2. This is followed by descriptions of the economic partial equilibrium model, the FAPRI-UK model and alternative scenarios in Section 3. The results are presented in Section 4 and conclusions are drawn in Section 5.

2. Literature review

Due to the potential loss caused by FMD outbreaks, control strategies are constantly reviewed and evaluated, among which economic assessments are important. Economic assessments mostly concern the costs of alternative control strategies and/or value of certain responses such as early detection, which help to reduce costs (e.g. Backer *et al*., 2009; Elbakidze *et al*., 2009). These analyses are often based on the Benefit-Cost framework, which provide detailed information on the changes in profit for a farm or budget implications for a government (Rich *et al.*, 2005). However, the Benefit-Cost framework cannot capture market price effects caused by changes in:

- Production due to culling of animals;
- Access to international markets; and
- Consumers' reaction.

These three impacts combine to affect equilibrium within commodity markets (Paarlberg *et al.*, 2002). Reduced production as a result of the destruction of animals exerts a positive impact on price. Counteracting this, if exports are banned in response to the outbreak, additional produce must be absorbed within the domestic market leading to an increase in supply. In addition, although FMD does not typically affect humans, there may be a negative consumption response to an outbreak due to consumer health concerns, even if these concerns are unfounded. Such concerns would lead to an inward shift in the demand curve and exert a downward impact on price. The ultimate impact on price depends on the weight of these individual effects and will vary across sectors depending on for example the importance of exports relative to domestic consumption. The partial equilibrium modelling framework, models both the supply side and the demand side of a market and solve for a market clearance price. Thus it is better suited to capture these effects. It enhances understanding of the market consequences for different commodities of different control strategies in response to an outbreak, complementing the Benefit-Cost analysis. There are assessments of FMD control strategies using partial equilibrium models for the United States (Paalberg *et al*. 2008; Hagerman *et al*. 2012), Australia (Buetre *et al*. 2013) and Canada (Tozer *et al.*, 2015).

The economic impacts of vaccination as a control strategy are explicitly examined by Hagerman *et al*. (2012), Buetre *et al*. (2013) and Tozer *et al.*, (2015), which reflect the rising recognition of this strategy in recent years. Both Hagerman *et al*. (2012) and Buetre *et al*. (2013) find that the desirability of vaccination depends on the scale of the outbreak. In addition, Buetre *et al.* (2013) factors in the delay in the start of waiting period for the vaccination strategy. It compares the *Vaccinate-to-Die* strategy with the *Stamping-Out* strategy and adds one month to the disease duration in the vaccination scenario assuming this is the extra time needed to finish all the culling. Since most of the potential outbreaks examined have an eradication time less than 180 days, this implies that for the Vaccination strategy to be preferred to Stamping-Out, it has to shorten the disease duration quite significantly. In both studies, the cost of vaccination strategy cannot be justified when the outbreak is small. Tozer *et al.*, (2015) is less informative in control strategy choices as it focuses on the dynamics of producer decisions using a discrete time optimal control model. The model assumes deterministic parameters that characterise the way in which FMD develops; in other words, there is no uncertainty with regards to the spread of the disease itself. To our knowledge, the market impacts of vaccination strategy for FMD control have not been examined in the UK. Following Hagerman *et al*. (2012) and Buetre *et al*. (2013), the control strategies will be assessed for potential outbreaks of different scales.

3. Model and scenarios

3.1 Model

The FAPRI-UK model is a partial equilibrium model of the agricultural sector (including the crop, livestock, dairy and biofuel sectors) of the UK. Production of agricultural commodities is modeled at the level of the four countries: England, Wales, Scotland and Northern Ireland. The FAPRI-UK modelling system produces Baseline projections over a ten year period of key variables in the beef, sheep, pig, poultry, dairy and crop sectors for each country in the UK under the assumption that current policies remain in place and specific macroeconomic assumptions hold. The Baseline provides a benchmark against which projections of the policy scenarios can be compared and interpreted (Moss *et al.* ,2010).[1] The Baseline used in this analysis was finalised in Spring 2016 and covers the projection period 2016 to 2025.

As markets of the Member States within the EU are deeply integrated, under most analyses the model is run in conjunction with the EU-GOLD model so that the results represent market equilibrium of the whole EU.[2] However, this no longer applies in the case of an FMD outbreak. When an FMD outbreak occurs, export of animal products from the outbreak country will be banned until the disease is eradicated and a specified waiting period has passed. The time taken to eradicating the disease obviously depends on the success of the control strategy used, while the waiting period also depends on the control strategy as specified in existing regulations. Details of the waiting period for each of the control strategies examined within this paper will be provided in the next section. The export ban implies that trade flows between the outbreak country and its trading partners become uni-directional (*i.e.* imports are still possible while exports cease). In the case of the UK, if commodities redirected from export outweigh the reduction in production following an FMD outbreak, this results in excess supply, which exerts a downward impact on price in the domestic market. Price falls may deepen, depending on whether the outbreak causes a food scare in consumption. The last route through which equilibrium is restored is a reduction in imports in response to the absorption of exports on the domestic market. Therefore, domestic UK prices may be lower than EU prices for certain periods of time. Conversely, domestic prices would rarely be higher than EU prices during the year of outbreak as imports are always possible. Significant modifications are carried out in the model for this analysis to allow for the temporary deviation in UK prices from their counterparts in the EU. Essentially, there are two sets of market clearing prices in the livestock sectors during the outbreak period (including the waiting period), one for the UK and one for rest of the EU.

For the markets to reach equilibrium following an FMD outbreak, the price elasticity of import is a particularly crucial parameter; that is, the extent of import change relative to price change. It is important to acknowledge that there is considerable uncertainty regarding the extent to which imports are likely to be displaced by the rechanneling of exports to the domestic market. More specifically, it is the rate of displacement rather than the quantity as a

[1] Project information on the AFBI website: https://www.afbini.gov.uk/articles/sector-modelling-fapri-uk-project

[2] The EU-GOLD model is a partial equilibrium model of the agricultural sector at the EU level. It is developed and maintained by the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri.

whole, which is of concern as the export ban implies a sudden substantial increase in supply to the domestic market from the rechanneled exports. This has important implications on the price impact of an FMD outbreak. Imports may be slow to readjust due to contractual reasons and demand requirements, e.g. imports from the southern hemisphere may fulfil demand requirements during specific periods of the season. It is also possible that imports adjust quickly in response to the rechanneling of exports. As a result, sensitivity analyses regarding import adjustments are carried out in which changes in imports are exogenously imposed. Two extreme cases are examined: no displacement and substantial displacement. In the case of no displacement, it is assumed that imports remain unchanged compared to Baseline projections. This reflects the assumption that imports are slow to adjust and cannot be readily cancelled. In the case of substantial displacement, it is assumed that imports are reduced by 90% of exports that are diverted to the domestic market due to the export ban, implying that imports adjust instantaneously in response to the imposition of an export ban. The sensitivity analysis provides a means to quantify the price impact of an FMD outbreak under different trade assumptions.

3.2 Scenarios

Two FMD control strategies are examined in this paper:

i. Stamping-Out

Under this scenario, numbers of animals culled from simulations of the epidemiological model are incorporated within the economic model, resulting in reductions in livestock numbers and animals available for slaughter. In addition to the number of culled animals, the epidemiological model provides data on the duration of the outbreak. Under the 'Stamping-out' scenario, the waiting period for applying for Disease Free Status and resuming export is 90 days after the last case of FMD.

ii. Vaccinate-to-Die

Similar to Scenario (i), numbers of culled animals from the epidemiological model are entered as supply shocks in the economic model and exports resume 90 days after the last infected and vaccinated animals are killed.

The analysis undertaken in this paper is based on stochastic simulations of the EXODIS epidemiological model undertaken by the Animal and Plant Health Agency (APHA) as an extension of Exercise Rowan.[3] The epidemiological model simulations are based on an outbreak equivalent to the characteristics of the virus in the UK in 2001, but take into account up-to-date UK contingency plans. The stochastic output from the epidemiological model yielded 200 outcomes, which reflect alternative developments of the same FMD virus. In order to identify the market impact of these different outcomes, the median outputs from the epidemiological model are used as inputs within the economic model (Table 1). See Feng *et al.* (2017) for additional analysis on the tails of the distribution from the epidemiological model outcomes.

[3] The initial phase of Exercise Rowan was undertaken in the latter part of 2015. During the exercise, the EXODIS model was used to test FMD response capability in the UK. See Roche *et al.* (2015) for further information on the EXODIS model.

Table 1: Median Outputs from the EXODIS Epidemiology Model

	Stamping Out	Vaccinate to Die
Infected Premises	230	120
Period to apply for Disease Free Status (days)	171	141
Total Culled Animals	342,558	1,020,682
Total Vaccinated Animals	-	837,518

Underlying the *Stamping-Out* and *Vaccinate-to-Die* scenarios it is assumed that all exports of beef, sheep and pig meat are halted for the duration of the outbreak plus three months after the detection of the last case, in line with World Animal Health Guidelines. Thus, it is assumed that there is no regionalisation, *i.e.* exports from the whole country are banned. The reduction in exports as a result of the export ban is computed as a proportion of the length of the export ban:

Export Reduction = Export under the Baseline * (Days of Export Ban/365)

The length of the export ban is defined as the period of the last reported case plus the waiting period before it is possible to apply for Disease Free Status. This definition may be interpreted as the most optimistic estimation of the duration of the export ban as it implies no delay in approval.

In addition to simulating the model based on this most optimistic case, following Buetre *et al. (2013)*, this paper also investigates the implications of possible delays in the waiting period due to the logistics of vaccinating and culling a large number of animals under the Vaccinate-to-Die strategy. In particular we examine the length of time that would make the Vaccination strategy less advantageous over the Stamping-Out strategy if initial results show the vaccination strategy is preferred. Instead of imposing a fixed period of delay as in Buetre *et al. (2013)*, a "break-even" delay is investigated. That is, a delay that would make the advantage (shorter disease duration) and disadvantage (larger number of animal culling) of the *Vaccinate-to-Die* strategy offset each other. The indicator we used is sectoral output value (the multiplication of price and production).

4. Results

4.1 No delays in the waiting period prior to applying for disease free status

Table 2 reports the impacts of the Stamping Out and Vaccinate-to-Die strategies assuming that there are no delays to the waiting period before applying for disease free status; i.e. it is assumed that the waiting period for the two strategies is the same.

Starting with the *'Stamping-Out'* scenario, UK prices fall by 7.9, 24.7 and 17.3 per cent respectively in the beef, sheep and pig sectors in 2017 for an outbreak of median scale. The negative price impact is attributable to the additional produce absorbed onto the domestic market due to the export ban, which leads to an increase in domestic supply. In contrast to the 2001 FMD outbreak, the decline in production due to the culling of animals is relatively small, reflecting the improved contingency measures that have been introduced. The limited decline in production is insufficient to offset the rechanneling of exports and hence, commodity prices decline. The sheepmeat sector experiences the greatest price decline due to the high level of self-sufficiency. The projected value of output in the sheepmeat sector falls by 25.1 per cent and primarily reflects the drop in price.

Table 2: FMD Control Strategy Results – Comparison between Baseline projections and Scenario in Year of Outbreak (2017)

	Basline	Stamping-Out	Vaccinate-to-Die
Beef Sector			
Production (1000 tonnes)	906	903	898
Consumption (1000 tonnes)	1107	1143	1133
Net Exports (1000 tonnes)	-201	-240	-235
Price (£/100kg dw)	318	293	300
Output (£ million)	2,881	2645	2691
Changes in per cent			
Production		-0.3%	-0.9%
Consumption		3.2%	2.3%
Price		-7.9%	-5.8%
Output		-8.2%	-6.6%
Sheep Sector			
Production (1000 tonnes)	319	318	313
Consumption (1000 tonnes)	313	341	333
Net Exports (1000 tonnes)	7	-23	-19
Price (£/100kg dw)	375	283	306
Output (£ million)	1,199	898	957
Changes in per cent			
Production		-0.6%	-1.9%
Consumption		8.8%	6.3%
Price		-24.7%	-18.6%
Output		-25.1%	-20.2%
Pig Sector			
Production (1000 tonnes)	916	910	905
Consumption (1000 tonnes)	1429	1510	1491
Net Exports (1000 tonnes)	-513	-600	-586
Price (£/100kg dw)	132	109	114
Output (£ million)	1,211	995	1035
Changes in per cent			
Production		-0.7%	-1.2%
Consumption		5.7%	4.3%
Price		-17.3%	-13.5%
Output		-17.9%	-14.6%

Compared to *'Stamping-Out'*, *'Vaccinate-to-Die'* leads to the culling of more animals and hence, lower production. In addition, the *'Vaccinate-to-Die'* control strategy also significantly curtails the time-span of the outbreak and as a consequence, the duration of the export ban. As a result, fewer exports are absorbed onto the domestic market. As a consequence of both these effects, the price impacts are less marked under the *'Vaccinate-to-Die'* scenarios compared to *'Stamping-Out'*. For example, the sheep meat price falls by 18.6% under the median '*Vaccinate-to-Die*' scenario, compared to 24.7% under the equivalent '*Stamping-Out*' scenario. The projected value of output falls by a greater amount than price in percentage terms (20.2% versus 18.6%) due to the fall in production.

4.2 Delays to the waiting period under Vaccination-to-Die

It has been shown that under the Vaccinate-to-Die strategy, the negative impact of the FMD outbreak on the sectoral value is smaller compared to the Stamping-Out strategy due to a shorter disease period and larger reduction in production (in other words, more livestock are culled). In the analysis so far, it is assumed that these livestock can be culled in a timely manner, i.e. the waiting period for regaining the disease free status starts immediately after the disease is eliminated. However, as argued in Buetre *et al.* (2013), with the use of vaccination, the number of livestock to be culled is much larger compared to the Stamping Out strategy, which presents challenges to resources available for the culling task. In our case, based on the output of the EXODIS model, the total number of culled animals in the Vaccinate-to-Die scenario is three times that in the Stamping-Out case for outbreaks of median scale. It is very likely that the culling task takes a longer time with the use of vaccination than without.

Here, rather than presuming the length of delay caused by more culling in the Vacciante-to-Die scenario, we search for the "break-even" delay, that is a delay that would result in all the sector obtaining output values at least as much as the stamping out case. The break-even length of delay is found to be 33 days in the median outbreak (more detailed results in Table 3). This means, in an outbreak of median scale, if delays associated with the culling of more animals under the vaccination strategy is shorter than 33 days, all the sectors still have larger (albeit marginally for some) output values under the Vaccinate-to-Die strategy than under the Stamping-Out strategy.

Table 3: Output, prices and production under different scenarios

		Baseline	Stamping Out	Vaccinate to Die without culling delay	Vaccinate to Die with culling delay
Length of delay					33 days
Output					
Cattle	£ Million	2881	2645	2691	2647
Pig	£ Million	1211	995	1035	996
Sheep	£ Million	1189	890	949	894
Price					
Cattle	£/100 kg	318	293	300	295
Pig	£/100 kg	132	109	114	110
Sheep	£/100 kg	375	283	306	288
Production					
Cattle	1,000 tonne	906	903	898	898
Pig	1,000 tonne	916	910	905	905
Sheep	1,000 tonne	319	318	313	313

5. Summary and Discussion

By combining epidemiology and partial equilibrium modelling frameworks the analysis undertaken in this study demonstrates the potential market consequences of alternative FMD control strategies. It is projected that an FMD outbreak has a negative impact on market prices and value of output, regardless of the control strategy. Although the analysis is based on a virus similar to the characteristics of the 2001 outbreak, unlike this previous outbreak, the number of animals culled and hence the production impact is relatively modest. This reflects the evolvement of contingency plans, with co-ordination measures helping to reduce the spread of disease. While the projected decline in production under both the *Stamping-Out* and *Vaccinate-to-Die* scenarios results in lower value of output, the largest impact on value of output stems from the drop in price due to the closure of export markets. Similarly, studies in other geographical areas have shown that the export ban exerts the larger impact on farm revenue compared with production changes (e.g. Paarlberg *et al.*, 2002 and Paarlberg *et al.*, 2008).

It is important to acknowledge that underlying this analysis it is assumed that exports are halted for the full duration of the outbreak plus 90 days after the last case or the last vaccinated animal is culled. The price and value of output impact would be diminished if export markets were to reopen sooner. Potentially governments could pursue regionalisation, whereby trade is allowed to resume from non-infected regions, providing it is possible to demonstrate the disease is contained (Paarlberg *et. al*, 2002).

The results of this analysis indicate that the price and value of output impacts are lower under *Vaccinate-to-Die* compared to *Stamping-Out*. This primarily reflects the effectiveness of *Vaccinate-to-Die* in slowing the spread of the disease and hence curtailing the duration of the export ban. This comparison is based on the assumption that there are no delays in gaining the approval of reopening export markets. In reality, this may be more difficult with regards to vaccination due to logistical reasons. It was demonstrated that, under a median outbreak, the market impact is greater under Vaccinate-to-Die compared to Stamping-Out if the delay is less than 33 days. Our results illustrate the potential desirability of vaccination and also some conditions that the desirability can be realised. In reality, when planning for FMD control, decision makers need to assess resource available in the event of an outbreak and also the costs of allocating additional resource in weighing up the different strategies.

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