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**The Importance of Biosecurity:  
How Diseases Can Affect International Beef Trade**

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## **Abstract**

We quantify effects of disease outbreaks on agricultural trade with a gravity model of impacts of foot and mouth disease (FMD) and bovine spongiform encephalopathy (BSE) on beef trade. We account for official FMD status and for the impact of recent disease outbreaks. During and after a FMD outbreak, exporting countries substitute away from markets recognized as FMD-free toward lower value markets not recognized as FMD-free. Similarly, a country that has experienced BSE will export less to markets that have not experienced BSE and more to markets that have. Regaining official recognition of FMD-free status may aid recovery but does not negate the effects of a recent FMD outbreak. Models of FMD impacts should incorporate these medium-run effects, otherwise costs of an outbreak may be greatly understated. For countries not free of FMD, if the disease were to be eradicated an exporter should eventually be able to substitute towards higher value FMD-free markets. The value of this change in export market profile should be counted when considering the benefits of FMD eradication programs.

## **Keywords**

beef  
biosecurity  
BSE  
FMD  
food safety  
gravity model  
international trade

## **JEL Codes**

F14; Q17

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## 1. Introduction

Animal disease outbreaks, particularly foot and mouth disease (FMD) and bovine spongiform encephalopathy (BSE), may have severe economic consequences for international beef trade.<sup>1</sup> With global exports valued at US\$40 billion in 2015, beef is a large contributor to world agriculture trade and so understanding the effects of diseases on beef trade is an important food policy concern. The salience of this issue for exporting countries is increased by the fact that the effects of a disease outbreak on market access may persist long after the outbreak has ended. For example, the full United States ban on Canadian beef imports after a 2003 BSE outbreak in Alberta lasted only four months, but the border opened only partially thereafter and it took four more years to end all restrictions on Canadian beef imports. Thus, as noted by Jones and Davidson (2014), the policy concern with animal disease outbreaks may quickly shift from issues of food safety to issues of market access.

These market access issues may not be well understood in the literature. Trade barriers that importers erect in response to a disease outbreak may force exporters to switch to lower value markets, such as those not FMD-free, so costs of the outbreak may exceed what is shown by studies that focus just on the immediate trade impact. If exports by other countries rise to fill the gaps left by a traditional exporter whose market access is affected by a disease outbreak, it may take several years for the disease-affected exporter to regain market share in higher value markets after the outbreak is over. It may take even longer for a country to be officially recognized as disease-free and this lack of recognition may further hinder market access.

These multiple and time-varying effects on market access may confound studies of how animal disease outbreaks affect international food trade. For example, Yang, Reed and Saghaian (2013) use a gravity model to show that a FMD outbreak reduces exports during the period of the outbreak, with the impact possibly varying with whether a vaccination or slaughter policy is in place. This research does not, however, consider differences in response when the importer has FMD, whether there are persistent effects of the outbreak on trade, or whether official recognition of disease-free status reduces the trade impacts. A similar possible understatement of long run effects on market access may be present in the analysis by Tozer and Marsh (2012) of a hypothetical FMD outbreak in Australia (the second largest beef exporter in the world). This study suggested that after implementation of FMD mitigation measures, it would take just one year for the Australian beef price to return to base scenario levels. This relatively quick recovery differs from what we find in the current study, which is that disease outbreaks affect trade for several years after they are contained.

In this paper we use a gravity model of international beef trade, for 195 countries from 1996 to 2013, to study the trade impacts of FMD and BSE. Our approach is novel in taking

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<sup>1</sup> See, for example, Lloyd *et al.* (2006) and Wieck and Holland (2010) on BSE and Knight-Jones and Rushton (2013) and Kompas, Nguyen and Ha (2015) for useful surveys on FMD. Estimates of the value of trade are based on UN Comtrade data used throughout this article.

into account both a country's official disease status and the impact of recent disease outbreaks. By accounting for these factors separately we can address important food policy issues such as whether a disease outbreak has persistent trade effects even after it is eradicated and whether official recognition of disease-free status can facilitate trade after disease eradication. The value of distinguishing between recent disease outbreaks and official disease status is shown by our finding that, in the case of FMD, the substitution by exporters away from markets that are recognized as FMD-free towards lower value markets that are not recognized as FMD-free occurs both during *and* after a disease outbreak. Similarly, a country that has experienced BSE tends to subsequently export less to markets that have not experienced BSE and more to markets that have. This substitution to lower value markets can create persistent impacts, so that the costs of a disease outbreak may be rather higher than what is shown by models that just consider the immediate impacts on trade. The distinction between disease outbreaks and being officially recognized as disease-free is also an important one for policy makers since there are often costly compliance activities required in order to gain disease-free recognition and some exporters may question the value of gaining this status.

Our approach can be applied to any commodity affected by pests or diseases, although meaningful results are more likely for commodities with a small number of significant diseases subject to periodic outbreaks, such as FMD and BSE. The growing literature using the gravity model to estimate the impact of food safety standards on trade flows, which we review in Section 2, might be informed by our approach. A disease outbreak typically means that a country no longer meets the requirements of importing markets, so exporters switch to markets that impose less stringent standards – this is analogous to the case of the food standards literature; however, we explicitly consider conditions in the exporting country in a way that the food standards literature does not.

The remainder of the paper is structured as follows: Section 2 summarizes prior studies; Section 3 describes our data and the gravity model methodology; Section 4 covers the empirical results; and, Section 5 discusses the implications and concludes the paper.

## **2. Previous Literature**

Simulated impacts of animal disease outbreaks in several countries are reported in recently commissioned studies. For example, the Australian Bureau of Agricultural and Resource Economics and Sciences and the New Zealand Ministry of Primary Industries have combined Computable General Equilibrium (CGE) and epidemiology models to assess the economic impact of a foot and mouth disease outbreak (Buetre *et al.* 2013; Forbes and van Halderen, 2014). Similarly, in the United States, the Department of Homeland Security has modelled the costs of a FMD outbreak originating from a National Bio and Agro-Defense Facility (Department of Homeland Security, 2012). Schroeder *et al.* (2015) survey recent modelling studies focused on the United States. These papers generally rely on assumptions about the likely time taken for market access to be restored after an outbreak.

Many studies of animal diseases rely on simulation studies, with little econometric work using cross country data to assess impacts on trade. Hence, important issues for modelling have not been thoroughly considered; these include whether a disease outbreak has persistent effects even after it is eradicated and whether official recognition of disease-free status can facilitate trade after disease eradication. In the broader literature on the impact of product standards and food safety standards on trade flows, the gravity model is the most common approach (Ferro, Otsuki and Wilson 2015 and Wilson, Otsuki and Majumdsar 2003). Drawing upon this approach, our modelling is further informed by the body of work applying gravity models to the impact of Sanitary and Phytosanitary (SPS) measures; many of which are aimed at preventing the introduction of diseases. Perhaps the most comprehensive research into SPS measures is Crivelli and Gröschl (2016), who estimate a gravity model examining different effects of SPS measures in the WTO database of specific trade concerns, considering trade at the relatively disaggregated (HS4) level.<sup>2</sup> The SPS measures include: conformity assessments and certification requirements; testing, inspection and approval procedures; and product characteristics, including requirements for quarantine treatment, pesticide residue levels, labeling or geographic application of measures.

Some studies focus more narrowly on meat. Yang, Reed and Saghaian (2013) apply a gravity model to international pork trade, finding that a FMD outbreak does reduce exports during the period of the outbreak, with impacts that may depend on whether a vaccination or slaughter policy is in place. Schlueter, Wieck and Heckeley (2009) utilize a gravity model to assess the effect of six classes of SPS regulatory measures on meat trade between the world's ten largest exporters and ten largest importers. More detailed analysis is available in Schlueter (2009). A more limited analysis by Tapia *et al.* (2011) considers Germany and Argentina and the sanitary measures affecting their beef trade.

Other than Yang, Reed and Saghaian (2013) none of these papers take into account the disease circumstances of an exporting country. This can matter because effects of an importing country's measures may depend on the exporting country's actual or perceived SPS status. Thus, an exporter may find a particular measure more or less stringent due to its disease status.

### **3. Data and Methods**

To analyze impacts of FMD outbreaks and of official international recognition of disease-free status we use International Animal Health Organization [OIE] data (<http://www.oie.int>). Two FMD outbreak variables (*FMD outbreak exporter* and *FMD outbreak both*) are derived from OIE databases. Between 1996 and 2004, these recorded the number of cases of FMD and the year in which an outbreak was last recorded. From 2005, the OIE uses categories for disease presence or absence; we consider there to be no outbreak if the country was classified as 'Never reported' or 'Disease not reported during this period'.

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<sup>2</sup> This is more detailed than similar earlier work by Disdier, Fontagné and Mimouni (2008).

For recent outbreaks (*Recent FMD exporter* and *Recent FMD both*) we consider a range of time windows, ranging from an outbreak in the previous year to an outbreak sometime in the last six years. As we explain in the results section, however, a window of the past five years appears most appropriate. The question of how long trade would be affected after an outbreak is of key interest for policy modellers and a range of approaches has been taken. For instance, the New Zealand Ministry of Primary Industries estimates that trade would recover the year after, even for a large outbreak (Forbes and van Halderen 2014). In contrast, the Australian Bureau of Agricultural and Resource Economics and Sciences (Buetre *et al.* 2013) assume that after a large outbreak beef exports would recover only slowly, increasing to 80% of original levels the tenth year after the outbreak. Earlier work by the Australian Productivity Commission (2002) assumed full recovery by the eighth year.

Separately from outbreaks, the OIE also officially recognize countries as being free from FMD. Our data on official disease status comes from historical records of OIE resolutions. The variables *FMD risk status exporter* and *FMD risk status both* consider a country to be recognized as FMD-free if the OIE recognizes the entire country as FMD-free, if FMD vaccination was not practiced, and if there was no recorded outbreak of FMD that year.

We distinguish between a country with FMD exporting to countries with, and without, FMD since biosecurity and consumer responses may be quite different if the importing country already has FMD. We also control for the official FMD status of the importing country through including the variable *No FMD importer*. We calculate, based on the data used below, that FMD-free markets command higher prices; import prices are 132 percent higher, on average, than for markets that are not FMD-free.

The other main disease affecting international beef trade is BSE. Data on outbreaks of this disease are also available from the OIE.<sup>3</sup> The dummy variable *BSE occurrence exporter* equals one if the exporting country has experienced at least one case of BSE but their trading partner has not. The variable *BSE occurrence both* equals one if both the exporter and importer have experienced at least one case of BSE. As with FMD, we distinguish between a country that has experienced BSE exporting to countries with, and without, BSE due to the likelihood of different biosecurity and consumer responses. However, unlike with FMD, we do not take into account the BSE risk status as recognized by the OIE because there does not appear to be sufficient variation over the period; for instance, after its three BSE cases between 2003 and 2006, the United States was not able to achieve a 'negligible risk' status until 2013.<sup>4</sup> We also control for the BSE status of the importing country through including the variable *No BSE importer*.

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<sup>3</sup> <http://www.oie.int/animal-health-in-the-world/bse-specific-data/annual-incidence-rate/>

<sup>4</sup> Unlike FMD, we do not distinguish between an outbreak period and the periods after an outbreak because of the limited number of cases - in our panel just 26 countries had an instance of BSE.

Beef trade data are from imports of products in HS headings 0201 and 0202 (fresh and frozen beef) from the UN COMTRADE database; we use import data which are considered to be more accurate.<sup>5</sup> GDP data are from the *World Development Indicators*. Beef production data are from FAO for 'cattle meat' production, which covers beef and veal.<sup>6</sup> As these values were expressed in tonnes of dressed carcass weight, we multiplied them by the average import price of carcasses (HS020110 and 020220) in that year to get data in monetary terms.<sup>7</sup> Typical gravity model controls which affect trading costs and thus trade flows - distance, contiguity, colonial history and a common legal system - are taken from the widely used CEPII database.<sup>8</sup> The existence of a regional trade agreement between two trading partners is based on data available in the CEPII database. As these data are only available until 2006, we update by adding new agreements that enter into force from 2006 and are notified to the WTO.<sup>9</sup>

Tariffs are from the World Trade Organization's Integrated Tariff Data Base (IDB).<sup>10</sup> This contains both the MFN tariff rate applied generally to all countries and the preferential rate applied to some countries, for instance when a RTA is in place. Data are missing for some years but since tariffs typically are relatively stable over time, where there was a gap between reported rates, the rate from the last available year was assumed to be in place until superseded by a new reported rate. Specific tariff rates were converted to *ad valorem* equivalents using data on the average price of imports in the same HS 6 digit subheading for that year, adjusted by national currency information within the WTO dataset.

Our data starts in 1996 – the first year the OIE data, detailed above, became available. Also, in 1996 a link was found between consuming BSE-infected meat and a variant of Creutzfeldt-Jacob disease, transforming BSE into a major concern in international trade. Our time-series ends in 2013. In terms of the cross-sectional element of our panel, we have data for 195 countries, although some data are missing for some countries and years.

### 3.1 Gravity Modelling Methodology

A gravity model posits that trade between two countries depends on their incomes and bilateral transaction costs, such as those arising from distance, which are often referred to as

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<sup>5</sup> From <http://comtrade.un.org/> which is reported in current US\$. As these are official statistics they exclude product smuggled or otherwise informally traded.

<sup>6</sup> [http://faostat3.fao.org/faostat-gateway/go/to/download/Q/\\*E](http://faostat3.fao.org/faostat-gateway/go/to/download/Q/*E)

<sup>7</sup> <http://databank.worldbank.org/data/databases/commodity-price-data>

<sup>8</sup> [http://www.cepii.fr/cepii/en/bdd\\_modele/bdd.asp](http://www.cepii.fr/cepii/en/bdd_modele/bdd.asp). As an example, Crevelli and Groschl (2012) use GDP, population, distance, adjacency, common language, 'ever colony', 'common colonizer', 'colonizer post 1945' and 'common religion' as their gravity controls. A weighted average tariff is included for robustness.

<sup>9</sup> <http://rtais.wto.org/UI/PublicMaintainRTAHome.aspx>. A RTA is considered to be in force for a given year if its date of entry into force was on or before 1 January of that year.

<sup>10</sup> <http://tariffdata.wto.org>

'multilateral resistance'.<sup>11</sup> Disease or pest status can enter the model as another multilateral resistance term; as used by Yang *et al.* (2013). Methodological underpinnings of gravity modelling and estimation issues are addressed in Anderson and Wincoop (2003) and Helpman, Melitz and Rubinstein (2008), among others. A useful summary is provided by Shepherd (2013), while Bergeijk and Brakman (2010) present a survey of gravity models.

Two principal estimation techniques are applied in contemporary work: the Poisson pseudo-maximum likelihood approach, as applied in Yang *et al.* (2013) and Schlueter *et al.* (2009); and, the Heckman selection approach, as applied in Crivelli and Gröschl (2016) and Ferro *et al.* (2015). Both approaches account for the fact that zero trade flows are frequent, particularly in disaggregated data, and these zero trade flows are often explained by high trade costs. The Heckman selection approach has the advantage of estimating the impact of disease outbreaks on both the probability of trade occurring between countries – the 'selection equation' may show if prohibitive restrictions are imposed – and impacts on the volume of trade, where the 'outcome equation' could show how trade is reduced by compliance requirements.

There are two main ways to implement Heckman selection estimates. One has selection and outcome equations estimated simultaneously using a maximum likelihood estimator. (See Shepherd (2013) for more detail and Crivelli and Gröschl (2016) for an example). Alternatively, Helpman *et al.* (2008) propose the HMR estimator to control for firm heterogeneity using two-step estimation. (See WTO 2012 for a discussion and Ferro *et al.* 2015 for an example). We use both but focus our discussion on the results of the HMR estimator. As a robustness check we also estimate the first step of the HMR estimator with a logit rather than probit specification. These results, set out in our sensitivity analysis section 4.3, are consistent with the main results from the HMR specification but show a greater selection effect of FMD and BSE on the probability that a country exports to a market free of these diseases.

Given the economic theory underpinning modern gravity models, demand and supply must both be incorporated into the model (Anderson and Wincoop 2003). In our model, the GDP of the importing country reflects demand and their own beef production captures any production shocks that might affect their import demand. Supply is incorporated principally through beef production in the exporting country but we also allow for any changes in the GDP of the exporting country which may lead to increased domestic demand and thus less beef being exported. We include typical gravity control variables, along with both exporter and importer fixed effects that control for country specific factors affecting beef imports or exports. We initially included time fixed effects, but these showed clear evidence of a time

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<sup>11</sup> Recent examples applied to agricultural trade include Ferro *et al.* (2015), Yang *et al.* (2013), Crivelli and Gröschl (2012) and Schlueter *et al.* (2009).



trend and were absorbing some of the information related to outbreaks in particular years, so we use a linear time trend instead. Our initial specification is summarized in Table 1.

The selection equation for the Heckman and HMR estimators requires that a variable affects the probability of trade occurring between two countries but not the volume of trade, if it occurs. We use common language between the importer and exporter. To determine if this variable was appropriate, we first estimated the equation with common language in both the selection and outcome equation, with a variable for common religion in the selection equation.<sup>12</sup> This showed that common language had no statistically significant effect on the volume of trade, so it was an appropriate choice for the exclusion restriction.

**Table 1: Summary of Variables Included in Initial Specification**

Variable	Description	Expected Effect on the Value of Trade (if it Occurs)	Expected Effect on the Probability of Trade Occurring
<i>FMD outbreak exporter</i>	Exporter has a FMD outbreak; importer recognized as FMD free	-ve	-ve
<i>FMD outbreak both</i>	Exporter has a FMD outbreak; importer not recognized as FMD free	Uncertain	Uncertain
<i>No FMD importer</i>	Importer recognized as FMD free	Uncertain	Uncertain
<i>FMD risk status exporter</i>	Exporter not recognized as FMD free; importer recognized as FMD free	-ve	-ve
<i>FMD risk status both</i>	Exporter not recognized as FMD free; importer not recognized as FMD free	+ve/Uncertain	+ve/Uncertain
<i>Recent FMD exporter</i>	Exporter has had a FMD outbreak in preceding (4) years; importer recognized as FMD free	-ve	-ve
<i>Recent FMD both</i>	Exporter has had a FMD outbreak in preceding (4) years; importer not recognized as FMD free	+ve/Uncertain	+ve/Uncertain
<i>BSE occurrence exporter</i>	Exporting country has had a case of BSE but importing country has not	-ve	-ve
<i>BSE occurrence both</i>	Both trading partners have had a case of BSE	Uncertain	Uncertain
<i>No BSE importer year</i>	Importing country has had a case of BSE Time trend	Uncertain +ve	Uncertain +ve
<i>GDP importer</i>	Nominal GDP in importing country (expressed in logarithmic form)	+ve	+ve
<i>GDP exporter</i>	Nominal GDP in exporting country (expressed in logarithmic form)	-ve	-ve
<i>Beef production exporter</i>	Nominal beef production in exporting country (expressed in logarithmic form)	+ve	+ve
<i>Beef production importer</i>	Nominal beef production in importing country (expressed in logarithmic form)	-ve	-ve
<i>Tariff</i>	Applicable tariff rate for beef imports	-ve	-ve
<i>Distance</i>	Distance between trading partners	-ve	-ve
<i>Contiguity</i>	Trading partners are contiguous	+ve	+ve
<i>Colony</i>	A colonial relationship has ever existed between partners	+ve	+ve
<i>Common legal system</i>	Trading partners have a common legal system	+ve	+ve
<i>RTA</i>	A RTA is in force between trading partners	+ve	+ve
<i>Common language</i>	Official language is the same	NA <sup>a</sup>	+ve

<sup>a</sup> Common language is the exclusion restriction and so only appears in the selection equation.

<sup>12</sup> This is from <http://scholar.harvard.edu/helpman/pages/data-1>. We only use this to check if common language is a plausible exclusion restriction because using the common religion variable limits our sample size.

## 4. Results

The results of the selection and outcome equations for our initial specification (as outlined in Table 1) are reported in Table 2. If a country that had no recent history of FMD has an outbreak, they can be expected to export to approximately 12-13% fewer FMD-free markets, but to 5-7% more markets not recognized as FMD-free.<sup>13</sup> These effects are shown on the coefficients on *FMD outbreak exporter* and *FMD outbreak both*. Independently of currently having an FMD outbreak, and of official disease status, a recent outbreak (defined as occurring any time in the preceding five years) reduces the probability of exporting to a FMD free market by between 11-13%, while raising the odds of exporting to a non FMD free market by up to 6%. In addition to these market participation effects, the value of exports is up to 17% lower for a same-year FMD outbreak and about 23% lower for a recent outbreak (using the results of the HMR model in column (1) of Table 2).<sup>14</sup> These trade effects are conditional on beef production in the exporting country, so to the extent that an FMD outbreak reduces production (for example, due to slaughter and disposal) there is an additional pathway to reduced exports (given the elasticity of 0.7 for export values with respect to production in the exporting country).

Even after controlling for actual FMD outbreaks, whether current or in the past five years, there appear to be additional effects on beef trade from the official recognition of disease risk status. A country not recognised as FMD-free is 8% more likely to export to countries also not recognised as FMD-free, according to results for the variable *FMD risk status both*. However, we caution that the FMD status variables are highly correlated with current or past outbreaks, so it is difficult to separate the two sets of effects. In order to ensure that our findings are not contaminated by multicollinearity, we also report estimates that omit these risk status variables, in columns (3), (4), (7) and (8). The general pattern of results for the current and recent FMD outbreak variables are the same, with or without the risk status variables, although the selection towards import markets that also have FMD gets a bit stronger.

The models in Table 2 are also informative about trade effects of BSE. A country that has developed BSE is about 12% less likely to export to a market that has not had BSE. The value of trade that does take place is reduced by 20% according to the HMR model, and by 30% according to the Heckman model. Again there is evidence of market switching, with a country that has had BSE exporting significantly more to other countries that have also had BSE.<sup>15</sup>

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<sup>13</sup> Outbreaks may occur partway through the year so annual imports will be non-zero even if they are prohibited for the rest of the year; hence, estimates of the reduction in the number of markets are likely to be conservative.

<sup>14</sup> Since the dependent variable is in logarithms, percentage changes are estimated as  $(\exp(\beta_j) - 1) \times 100$ .

<sup>15</sup> It must, however, be borne in mind that there are a limited number of countries that have experienced BSE, which means that there are even fewer sets of trading partners that have both

**Table 2: Results from Estimation of Initial Specification**  
where a FMD Outbreak Affects Exports for the Following Five Years

	Helpman, Melitz and Rubinstein Model				Heckman Selection Model			
	Including Status Variables		Excluding Status Variables		Including Status Variables		Excluding Status Variables	
	Outcome (1)	Selection (2)	Outcome (3)	Selection (4)	Outcome (5)	Selection (6)	Outcome (7)	Selection (8)
<i>FMD outbreak exporter</i>	-0.191* (0.0984)	-0.121*** (0.0288)	-0.121 (0.0922)	-0.130*** (0.0274)	-0.167 (0.118)	-0.124*** (0.0353)	-0.120 (0.106)	-0.134*** (0.0321)
<i>FMD outbreak both</i>	-0.0157 (0.0814)	0.0505** (0.0239)	-0.00431 (0.0780)	0.0693*** (0.0230)	-0.0506 (0.103)	0.0519* (0.0283)	-0.0213 (0.0934)	0.0703*** (0.0258)
<i>No FMD importer</i>	-0.643*** (0.112)	-0.0841** (0.0380)	-0.594*** (0.107)	-0.117*** (0.0352)	-0.638*** (0.130)	-0.0766 (0.0482)	-0.629*** (0.118)	-0.110*** (0.0424)
<i>FMD risk status exporter</i>	0.240** (0.110)	0.00190 (0.0341)	.....	.....	0.200 (0.148)	-0.000864 (0.0469)	.....	.....
<i>FMD risk status both</i>	0.120 (0.109)	0.0836** (0.0327)	.....	.....	0.183 (0.152)	0.0805* (0.0429)	.....	.....
<i>Recent FMD exporter</i>	-0.262*** (0.0769)	-0.113*** (0.0262)	-0.219*** (0.0735)	-0.134*** (0.0240)	-0.261*** (0.0876)	-0.109*** (0.0333)	-0.246*** (0.0865)	-0.131*** (0.0318)
<i>Recent FMD both</i>	-0.366*** (0.0772)	0.0397* (0.0232)	-0.377*** (0.0724)	0.0611*** (0.0217)	-0.417*** (0.0975)	0.0407 (0.0276)	-0.405*** (0.0988)	0.0618** (0.0271)
<i>BSE occurrence exporter</i>	-0.233*** (0.0718)	-0.122*** (0.0233)	-0.229*** (0.0718)	-0.123*** (0.0233)	-0.356*** (0.0969)	-0.124*** (0.0325)	-0.356*** (0.0972)	-0.125*** (0.0325)
<i>BSE occurrence both</i>	0.142* (0.0845)	0.0516 (0.0315)	0.134 (0.0844)	0.0582* (0.0314)	0.441*** (0.135)	0.0623 (0.0568)	0.440*** (0.136)	0.0689 (0.0568)
<i>No BSE importer</i>	0.00578 (0.0868)	-0.0260 (0.0288)	-0.00202 (0.0867)	-0.0232 (0.0288)	0.112 (0.123)	-0.0203 (0.0399)	0.108 (0.124)	-0.0176 (0.0399)
Gravity Model Control Variables								
<i>GDP importer</i>	0.544*** (0.0738)	0.0628*** (0.0225)	0.542*** (0.0738)	0.0634*** (0.0225)	0.566*** (0.104)	0.0627** (0.0311)	0.564*** (0.104)	0.0633** (0.0311)
<i>GDP exporter</i>	-0.0963 (0.0770)	-0.0163 (0.0232)	-0.104 (0.0768)	-0.0191 (0.0231)	-0.146 (0.104)	-0.0177 (0.0310)	-0.157 (0.103)	-0.0202 (0.0311)
<i>Beef production exporter</i>	0.699*** (0.0812)	0.00668 (0.0238)	0.696*** (0.0811)	0.00606 (0.0239)	0.703*** (0.0990)	0.0105 (0.0312)	0.701*** (0.0989)	0.00987 (0.0312)
<i>Beef production importer</i>	-0.108 (0.0664)	0.00589 (0.0187)	-0.113* (0.0664)	0.00444 (0.0187)	-0.116 (0.0824)	0.00357 (0.0262)	-0.121 (0.0825)	0.00215 (0.0263)
<i>Tariff</i>	0.00194* (0.00103)	-0.00153*** (0.000304)	0.00182* (0.00102)	-0.00148*** (0.000302)	0.00133 (0.00184)	-0.00154*** (0.000558)	0.00130 (0.00184)	-0.00149*** (0.000558)
<i>Distance</i>	-1.53*** (0.136)	-0.680*** (0.00999)	-1.52*** (0.136)	-0.681*** (0.00999)	-1.607*** (0.0784)	-0.683*** (0.0228)	-1.608*** (0.0781)	-0.684*** (0.0228)
<i>Contiguity</i>	0.556*** (0.0925)	0.312*** (0.0267)	0.557*** (0.0927)	0.312*** (0.0267)	0.938*** (0.180)	0.321*** (0.0659)	0.940*** (0.180)	0.321*** (0.0659)
<i>Common language</i>	.....	0.309*** (0.0188)	.....	0.308*** (0.0188)	.....	0.306*** (0.0424)	.....	0.305*** (0.0424)
<i>Colony</i>	0.580*** (0.110)	0.339*** (0.0286)	0.578*** (0.111)	0.339*** (0.0286)	0.677*** (0.208)	0.330*** (0.0708)	0.677*** (0.208)	0.330*** (0.0708)
<i>Common legal system</i>	0.437*** (0.0510)	0.130*** (0.0120)	0.435*** (0.0511)	0.130*** (0.0120)	0.473*** (0.0942)	0.134*** (0.0275)	0.473*** (0.0942)	0.134*** (0.0276)
<i>RTA</i>	0.454*** (0.0743)	0.232*** (0.0177)	0.438*** (0.0742)	0.238*** (0.0175)	0.370*** (0.132)	0.238*** (0.0393)	0.363*** (0.130)	0.243*** (0.0391)
<i>Year</i>	0.00930 (0.00883)	0.0203*** (0.00268)	0.0102 (0.00882)	0.0206*** (0.00267)	0.0174* (0.0103)	0.0208*** (0.00348)	0.0187* (0.0102)	0.0210*** (0.00347)
Importer/Exporter FE	YES	YES	YES	YES	YES	YES	YES	YES
Number of Observations	23628	385100	23628	385100	23628	387349	23628	387349
Number of Censored Obs		361472		361472		363721		363721
Lambda						0.740*** (0.0574)		0.740*** (0.0573)

Note: Robust standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

experienced BSE. Thus the incidence of trade between countries that both have experienced BSE is small and estimates are less precise.

Amongst the control variables, a 10% increase in importing country GDP leads to a 5.5% increase in beef demand from each supplying country. Moreover, richer countries source beef from a larger number of exporters.<sup>16</sup> Beef production in the exporting country affects the value of exports to a given market but not the probability of trade occurring. A RTA between countries raises the likelihood of trade occurring by 23-24% and the volume of trade is increased by 57% in the HMR model and by 45% in the Heckman model. These large effects may be because RTAs promote transparency (Lejárraga, Shepherd and van Tongeren 2013) and potentially reduce non-tariff barriers (see, for instance, Winchester 2009) and are in addition to the effects of a reduction in tariffs – which have a negative effect on the probability of trade occurring but a less precisely estimated effect on the value of trade, if it occurs. The distance and contiguity between countries, their common legal system, and a colonial history all have the expected effects.

The final notable result from Table 2 is that if the selection and outcome equation are estimated simultaneously, a statistically significant positive selection term ( $\lambda$ , on the inverse Mills ratio) is apparent.<sup>17</sup> Thus, the unobserved factors that affect the probability of beef trade between two countries also affect the volume of that trade. This correlation in the unobservable terms highlights the importance of using selection models rather than restricting the sample to the (non-random) sub-set of country-pairs where trade actually occurred.

#### **4.1 Robustness Analyses: Searching Over Alternative Windows for 'Recent' Outbreaks**

To see if the results in Table 2 depend on how 'recent' is defined, we estimated HMR and Heckman models for windows ranging from one year (that is, an outbreak the previous year) to six years. The results are in Appendix Table 1a for our full specification and in Table 1b for a truncated specification without the risk status variables. The effect of a recent outbreak on both market participation and the value of trade becomes stronger as the time window lengthens, albeit with effects on market participation that begin to decrease from the five year window onwards. For the smallest possible window, that considers outbreaks occurring one year previously, the pattern of results are quite different than in all of the other variants. We also considered model selection tests based on Akaike and Bayesian Information Criterion (AIC and BIC), where the lower values that are preferred are seen when using the longer windows. On balance we consider a five-year window to be the best compromise between statistical fit for the model as a whole and the significance of key disease outbreak variables. The remainder of our analysis focuses on results from this framework.

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<sup>16</sup> We use GDP of the exporting country to proxy for income changes that might affect domestic beef demand and thus beef exports, but did not find this to be significant.

<sup>17</sup> Also notable is that the fixed effects for exporters and importers are jointly statistically significant, as confirmed by likelihood ratio tests.

## 4.2 Sensitivity Analyses: An Alternative, More Structured, Specification

The model outlined in Table 1, whose estimates are in Table 2, is relatively unstructured, in the sense that contemporaneous and previous disease outbreaks, and the official recognition of disease status, all entered the model in an unconstrained way. In Table 3 we outline another specification that imposes more structure, in order to capture a common progression where a country may eradicate a disease, and then obtain official recognition of disease-free status but may still encounter market access challenges if FMD has only recently been eradicated. To capture this effect, we introduce four new variables: *FMD risk without outbreak exporter*, *FMD risk without outbreak both*, *FMD recent without risk status exporter*, and *FMD recent without risk status both*. These variables capture different combinations of either having FMD or not, and official recognition as FMD-free or not.

**Table 3: Summary of Alternative FMD Variables**

Variable	Description	Expected Sign in Outcome Equation	Expected Sign in Selection Equation
<i>FMD outbreak exporter</i>	If exporter country has a FMD outbreak and importer is recognized as FMD free.	-ve	-ve
<i>FMD outbreak both</i>	If exporter has a FMD outbreak and importer is not recognized as FMD free.	Uncertain	Uncertain
<i>No FMD importer</i>	If importing country is recognized as FMD free.	Uncertain	Uncertain
<i>FMD risk without outbreak exporter</i>	If exporter does not have a FMD outbreak, but is not recognized as FMD free while importer is recognized as FMD free.	-ve	-ve
<i>FMD risk without outbreak both</i>	If exporter does not have a FMD outbreak and both importer and exporter are not recognized as FMD free.	+ve/ Uncertain	+ve/ Uncertain
<i>FMD recent without risk status exporter</i>	If exporter has had a FMD outbreak in preceding 5 years but is recognized as FMD free; importer is recognized as FMD free.	-ve	-ve
<i>FMD recent without risk status both</i>	If exporter has had a FMD outbreak in preceding 5 years but is recognized as FMD free; importer not recognized as FMD free.	+ve/ Uncertain	+ve/ Uncertain

**Table 4: Results with Alternative Specification of FMD Variables**

Variables	Helpman Melitz and Rubinstein		Heckman Selection Model	
	Outcome (1)	Selection (2)	Outcome (3)	Selection (4)
<i>FMD outbreak exporter</i>	-0.0718 (0.121)	-0.222*** (0.0356)	-0.0972 (0.148)	-0.226*** (0.0456)
<i>FMD outbreak both</i>	-0.065 (0.116)	0.191*** (0.0331)	-0.0660 (0.152)	0.190*** (0.0404)
<i>No FMD importer</i>	-0.402*** (0.0874)	0.0329 (0.0288)	-0.396*** (0.102)	0.0363 (0.0377)
<i>FMD risk without outbreak exporter</i>	0.127 (0.108)	-0.0643* (0.0329)	0.0857 (0.146)	-0.0649 (0.0454)
<i>FMD risk without outbreak both</i>	-0.0845 (0.107)	0.116*** (0.0318)	-0.0523 (0.155)	0.113*** (0.0423)
<i>FMD recent without risk status exporter</i>	-0.226*** (0.100)	-0.104*** (0.0379)	-0.238** (0.118)	-0.0965* (0.0520)
<i>FMD recent without risk status both</i>	-0.660*** (0.113)	0.0347 (0.0353)	-0.733*** (0.152)	0.0338 (0.0459)
<i>BSE occurrence exporter</i>	-0.211*** (0.0718)	-0.120*** (0.0232)	-0.338*** (0.0969)	-0.122*** (0.0323)
<i>BSE occurrence both</i>	0.156* (0.0846)	0.0583* (0.0314)	0.461*** (0.135)	0.0687 (0.0567)
<i>No BSE importer</i>	0.0121 (0.0868)	-0.0209 (0.0287)	0.118 (0.123)	-0.0151 (0.0398)
Gravity Model Control Variables				
<i>GDP importer</i>	0.526*** (0.0736)	0.0598*** (0.0224)	0.550*** (0.104)	0.0597* (0.0309)
<i>GDP exporter</i>	-0.0524 (0.0766)	-0.0156 (0.0229)	-0.100 (0.104)	-0.0169 (0.0307)
<i>Beef production exporter</i>	0.705*** (0.0810)	0.0127 (0.0236)	0.709*** (0.0986)	0.0164 (0.0308)
<i>Beef production importer</i>	-0.114** (0.0662)	0.00630 (0.0185)	-0.119 (0.0823)	0.00411 (0.0260)
<i>Tariff</i>	0.00188** (0.00103)	-0.00152*** (0.000303)	0.00125 (0.00184)	-0.00153*** (0.000556)
<i>Distance</i>	-1.47*** (0.136)	-0.677*** (0.00989)	-1.580*** (0.0787)	-0.680*** (0.0228)
<i>Contiguity</i>	0.544*** (0.0927)	0.313*** (0.0264)	0.938*** (0.179)	0.323*** (0.0655)
<i>Common language</i>	.....	0.305*** (0.0185)	.....	0.301*** (0.0419)
<i>Colony</i>	0.579*** (0.112)	0.347*** (0.0284)	0.701*** (0.208)	0.339*** (0.0705)
<i>Common legal system</i>	0.439*** (0.0504)	0.125*** (0.0118)	0.482*** (0.0934)	0.130*** (0.0275)
<i>RTA</i>	0.448*** (0.0744)	0.233*** (0.0175)	0.374*** (0.132)	0.239*** (0.0391)
<i>year</i>	0.00685 (0.00881)	0.0201*** (0.00266)	0.0157 (0.0103)	0.0205*** (0.00347)
Importer/Exporter FE	YES	YES	YES	YES
Number of Observations	23842	373763	23822	397818
Number of Censored Observations		349921		373976
Lambda				0.735*** (0.0570)

Note: Robust standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

The HMR and Heckman selection estimates of this more structured model are reported in Table 4.<sup>18</sup> The interpretation of FMD estimates from this specification can be illustrated by considering an exporter that is making advances in the eradication of FMD. If a country eradicates FMD, the coefficient on the *FMD outbreak exporter* suggests it can expect to export to 22% more FMD-free markets. Almost as many markets (specifically, 19%) that are not FMD-free would be substituted away from.

If an exporter is then able to obtain official recognition of being FMD-free (without vaccination), they could expect to continue to substitute away from those markets that are not FMD-free towards higher value markets that are FMD-free. Specifically, the results in Table 4 suggest that an exporting country which does not have an FMD outbreak but is not recognized as FMD-free is 6% less likely to export to a FMD-free market, according to the coefficient on *FMD risk without outbreak exporter*. Conversely, this exporter is 12% more likely to export to a non FMD-free market, according to the coefficient on *FMD risk without outbreak both*. In other words, independently of actual outbreaks, there is a trade effect that follows from official recognition of disease-free status; these results are consistent with the estimates from our first, less structured, specification.

Obtaining FMD-free status is not sufficient to negate the trade effects of a recent FMD outbreak. An exporter that was recognized as FMD-free without vaccination but that had an FMD outbreak within the preceding five years is likely to export to 10% fewer countries that are without FMD, according to the coefficient on the *FMD without risk status exporter*. For this exporter, the export values to all markets are also reduced quite substantially.

### 4.3 Sensitivity Analysis: Use of a Logit Specification

Tables 5 and 6 show the results of estimating a HMR specification with a logit specification for the market participation equation rather than with a probit equation as used previously. These tables can be compared with Tables 2 and 4 respectively. The main difference is that both FMD and BSE appear to have a much larger effect on the probability of trade occurring in the logit specification; these effects are typically twice as large as the earlier estimates.

For example, the estimates from the logit estimator imply that during a FMD outbreak the probability of exporting to a FMD free market is reduced by 29% whereas there was just a 13% reduction with the probit specification. Conversely, the probability of exporting to a market that is not FMD-free increases by 13% for a current outbreak, compared to a 7% rise shown by the probit specification (these effects are shown by *FMD outbreak exporter* and *FMD outbreak both*). Using a window of the five years following an outbreak, the logit model suggests that the probability of exporting to a FMD-free market is reduced by 24% to

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<sup>18</sup> With the alternative specification, there is minimal change in the estimated coefficients on variables other than those relating to FMD so these results are not discussed.

26% while this persistent effect was estimated by probit as just a 13% fall in the odds of exporting to these markets (as seen from *Recent FMD exporter*). Meanwhile, an outbreak within the previous five years increases the odds of exporting to a market that is not FMD-free by between 9% and 11%, whereas this substitution into lower valued markets was just 6% with the probit specification. For outbreaks of BSE, the logit model suggests that a country that has developed BSE is 23% less likely to export to a market that has not had BSE (and conditional on trade occurring, the value of exports goes down 19%); in contrast, the probit specification had a fall in the odds of exporting to BSE-free markets of just 12%.

The increased effects of outbreaks, of risk, and of official recognition, on the likelihood of trade occurring under the logit model compared to the probit model also shows up in our more structured specification (the one based on Table 3). The estimates from the logit estimator imply that if a country eradicates FMD, it can expect to export to 49% more FMD free markets, whereas the expected increase was just 22% with the probit estimator. Conversely, eradicating FMD facilitates substitution away from non-FMD markets: the logit estimator implies that a country estimates to 31% fewer markets that are not FMD-free whereas the probit estimator suggests that this substitution effect was to just 19% fewer markets that are not FMD-free (these effects are shown by *FMD outbreak exporter* and *FMD outbreak both* in Tables 4 and 6).

The results from the logit estimator imply that an exporting country which does not have an FMD outbreak but is not recognized as FMD-free is 13% less likely to export to a FMD-free market, whereas the result from the probit specification was 6%. Conversely, with the logit estimator an exporting country which does not have an FMD outbreak but is not recognized as FMD-free is 16% more likely to export to a non FMD-free market, whereas the estimated effect was 12% with the probit estimator (these effects are shown by *FMD risk without outbreak exporter* and *FMD risk without outbreak both*). With the logit estimator, an exporter that is recognized as FMD-free without vaccination but which has experienced FMD within the preceding five years is likely to export to 23% fewer countries without FMD, whereas the estimated effect was 10% from probit estimation (see *FMD recent without risk status exporter* and *FMD recent without risk status both*).



**Table 5: Results from Estimation of Initial Specification**  
Logit Estimation

Variables	HMR with Logit (Including Status Variables)		HMR with Logit (Excluding Status Variables)	
	Outcome	Selection	Outcome	Selection
	(1)	(2)	(1)	(2)
<i>FMD outbreak exporter</i>	-0.186* (0.0986)	-0.284*** (0.0561)	-0.110 (0.0921)	-0.289*** (0.0534)
<i>FMD outbreak both</i>	-0.00916 (0.0811)	0.112** (0.0455)	-0.007 (0.0774)	0.129*** (0.0436)
<i>No FMD importer</i>	-0.644*** (0.112)	-0.216*** (0.0712)	-0.586*** (0.106)	-0.238*** (0.0664)
<i>FMD risk status exporter</i>	0.239** (0.110)	0.0196 (0.0653)	.....	.....
<i>FMD risk status both</i>	0.0847 (0.108)	0.0797 (0.0627)	.....	.....
<i>Recent FMD exporter</i>	-0.252*** (0.0767)	-0.244*** (0.0493)	-0.205*** (0.0724)	-0.258*** (0.0453)
<i>Recent FMD both</i>	-0.364*** (0.0770)	0.0893** (0.0440)	-0.386*** (0.0719)	0.107*** (0.0410)
<i>BSE occurrence exporter</i>	-0.215*** (0.0709)	-0.232*** (0.0433)	-0.210*** (0.0708)	-0.233*** (0.0433)
<i>BSE occurrence both</i>	0.136 (0.0833)	-0.0366 (0.0587)	0.128 (0.0832)	-0.0326 (0.0585)
<i>No BSE importer</i>	-0.00427 (0.0869)	-0.114** (0.0548)	-0.0128 (0.0868)	-0.111** (0.0548)
<b>Gravity Model Control Variables</b>				
<i>GDP importer</i>	0.525*** (0.0734)	0.128*** (0.0429)	0.521*** (0.0734)	0.129*** (0.0429)
<i>GDP exporter</i>	-0.0813 (0.0766)	-0.0118 (0.0436)	-0.0886 (0.0764)	-0.0150 (0.0435)
<i>Beef production exporter</i>	0.691*** (0.0808)	-0.00117 (0.0469)	0.689*** (0.0808)	-0.00235 (0.0469)
<i>Beef production importer</i>	-0.105 (0.0661)	0.0127 (0.0360)	-0.110* (0.0661)	0.0112 (0.0360)
<i>Tariff</i>	0.0023** (0.00102)	-0.00299*** (0.000596)	0.00218** (0.00101)	-0.00295*** (0.000595)
<i>Distance</i>	-1.465*** (0.126)	-1.333*** (0.0190)	-1.46*** (0.126)	-1.334*** (0.0190)
<i>Contiguity</i>	0.592*** (0.0880)	0.592*** (0.0510)	0.594*** (0.0881)	0.592*** (0.0510)
<i>Common language</i>	.....	0.654*** (0.0363)	.....	0.652*** (0.0362)
<i>Colony</i>	0.522*** (0.104)	0.620*** (0.0561)	0.521*** (0.1038)	0.621*** (0.0561)
<i>Common legal system</i>	0.415*** (0.0492)	0.248*** (0.0228)	0.413*** (0.0492)	0.248*** (0.0228)
<i>RTA</i>	0.429*** (0.0723)	0.458*** (0.0339)	0.410*** (0.0717)	0.461*** (0.0337)
<i>Year</i>	0.00739 (0.00862)	0.0382*** (0.00505)	0.00821 (0.00860)	0.0386*** (0.00503)

Note: Robust standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 6: Results from Estimation of Alternative Specification**  
Logit Estimation

Variables	Outcome	Selection
<i>FMD outbreak exporter</i>	-0.0622 (0.121)	-0.487*** (0.0690)
<i>FMD outbreak both</i>	-0.0945 (0.113)	0.314*** (0.0632)
<i>No FMD importer</i>	-0.412*** (0.0869)	0.0327 (0.0546)
<i>FMD risk without outbreak exporter</i>	0.128 (0.107)	-0.131** (0.0631)
<i>FMD risk without outbreak both</i>	-0.118 (0.105)	0.155** (0.0607)
<i>FMD recent without risk status exporter</i>	-0.227** (0.100)	-0.230*** (0.0696)
<i>FMD recent without risk status both</i>	-0.659*** (0.112)	0.0810 (0.0660)
<i>BSE occurrence exporter</i>	-0.195*** (0.0708)	-0.228*** (0.0430)
<i>BSE occurrence both</i>	0.153* (0.0833)	-0.0226 (0.0586)
<i>No BSE importer</i>	0.00215 (0.0868)	-0.103* (0.0546)
Gravity Model Control Variables		
<i>GDP importer</i>	0.507*** (0.0732)	0.122*** (0.0427)
<i>GDP exporter</i>	-0.038 (0.0762)	-0.0107 (0.0432)
<i>Beef production exporter</i>	0.698*** (0.0806)	0.0128 (0.0464)
<i>Beef production importer</i>	-0.113* (0.0660)	0.0124 (0.0357)
<i>Tariff</i>	0.00223** (0.00102)	-0.00300*** (0.000594)
<i>Distance</i>	-1.41*** (0.126)	-1.328*** (0.0189)
<i>Contiguity</i>	0.583*** (0.0879)	0.592*** (0.0507)
<i>Common language</i>	.....	0.647*** (0.0359)
<i>Colony</i>	0.526*** (0.105)	0.635*** (0.0558)
<i>Common legal system</i>	0.420*** (0.0486)	0.239*** (0.0227)
<i>RTA</i>	0.425*** (0.0722)	0.458*** (0.0337)
<i>Year</i>	0.00517 (0.00861)	0.0379*** (0.00502)

Note: Robust standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## 5. Discussion and Conclusions

The results reported here add to the literature that examines the impact of animal diseases on international trade. In particular, we have shown how the widely used gravity model of international trade can provide meaningful estimates of the implications for exporters of an outbreak of diseases such as FMD and BSE, both during and after an outbreak. A key insight from our analysis is that there is clear evidence that even after FMD is eradicated, an outbreak will continue to affect exports in the medium term. Regaining official recognition of FMD-free status may assist in recovering access to markets, which is important for exporters because there is clear evidence of there a shift in the export profile towards lower value markets that are not recognized as FMD-free following an outbreak.

For countries that are free of FMD, our results suggest that the modelling of potential impacts of an FMD outbreak should incorporate these medium-run substitution effects. If these effects are ignored, one is likely to significantly understate the costs of an outbreak, and this may lead to insufficient resources being allocated to biosecurity. Our analysis suggests that incorporating trade effects that last for five years after an outbreak is consistent with the patterns in the international trade data, as revealed in our gravity models. Moreover, given the evidence of potential substitution towards lower value markets that are not FMD-free, policy makers and exporters in FMD free countries may wish to develop relationships and market access arrangements to facilitate exports to these markets if an outbreak does occur.

For countries that are not free of FMD, we show that if the disease were to be eradicated, after several years an exporter should be able to substitute towards higher value FMD-free markets. Moreover, there is an effect of official recognition of disease-free status, on top of the effects of actual (current or past) outbreaks. We see similar market-switching effects for outbreaks of BSE, although we are not able to separately estimate the effects of current and previous episodes or the effect of official recognition of disease-free status because there are far fewer episodes of BSE than of FMD in our data. An overall implication is that the value of these changes in export market profile should be taken into account when considering the benefits of disease eradication programs and of biosecurity efforts, more generally.

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**Appendix Table 1a: Effect of Varying Number of Years for which a 'Recent' FMD Outbreak Can Affect Exports**  
Including Risk Status Variables

Years Following an Outbreak Used in 'Recent FMD' Variable	Heckman, Melitz and Rubinstein Model						Heckman Selection Model					
	1	2	3	4	5	6	1	2	3	4	5	6
Selection Equation												
<i>FMD outbreak exporter</i>	-0.158*** (0.0282)	-0.100*** (0.0301)	-0.107*** (0.0293)	-0.115*** (0.0290)	-0.121*** (0.0288)	-0.138*** (0.0286)	-0.161*** (0.0346)	-0.103*** (0.0327)	-0.110*** (0.0341)	-0.118*** (0.0348)	-0.124*** (0.0353)	-0.142*** (0.0356)
<i>FMD outbreak both</i>	0.0650** (0.0255)	0.0408* (0.0243)	0.0441* (0.0241)	0.0461* (0.0239)	0.0505** (0.0239)	0.0528** (0.0239)	0.0657** (0.0255)	0.0418 (0.0261)	0.0452* (0.0272)	0.0474* (0.0278)	0.0519* (0.0283)	0.0544* (0.0287)
<i>FMD risk status exporter</i>	-0.0318 (0.0941)	-0.00634 (0.0322)	0.00105 (0.0327)	0.0103 (0.0335)	0.00190 (0.0341)	-0.0135 (0.0344)	-0.0401 (0.0863)	-0.00843 (0.0446)	-0.00100 (0.0448)	0.00841 (0.0460)	-0.000864 (0.0469)	-0.0169 (0.0475)
<i>FMD risk status both</i>	0.123 (0.0930)	0.0969*** (0.0312)	0.0925*** (0.0316)	0.0873*** (0.0323)	0.0836** (0.0327)	0.0896*** (0.0329)	0.113 (0.0826)	0.0925** (0.0418)	0.0884** (0.0419)	0.0835** (0.0425)	0.0805* (0.0429)	0.0873** (0.0430)
<i>Recent FMD exporter</i>	-0.00249 (0.0900)	-0.116*** (0.0279)	-0.119*** (0.0264)	-0.134*** (0.0260)	-0.113*** (0.0262)	-0.0897*** (0.0265)	0.00401 (0.0768)	-0.115*** (0.0293)	-0.118*** (0.0291)	-0.133*** (0.0310)	-0.109*** (0.0333)	-0.0842** (0.0353)
<i>Recent FMD both</i>	0.0241 (0.0256)	0.0631*** (0.0242)	0.0526** (0.0235)	0.0399* (0.0231)	0.0397* (0.0232)	0.0132 (0.0238)	0.0257 (0.0253)	0.0652** (0.0254)	0.0542** (0.0255)	0.0407 (0.0261)	0.0407 (0.0276)	0.0139 (0.0300)
Outcome Equation												
<i>FMD outbreak exporter</i>	-0.171* (0.0983)	-0.123 (0.0987)	-0.137 (0.0981)	-0.178* (0.0984)	-0.191* (0.0984)	-0.200** (0.099)	-0.180 (0.116)	-0.118 (0.108)	-0.132 (0.112)	-0.154 (0.116)	-0.167 (0.118)	-0.178 (0.118)
<i>FMD outbreak both</i>	-0.0193 (0.0849)	-0.0244 (0.0822)	-0.0124 (0.0814)	-0.0158 (0.0815)	-0.0157 (0.0814)	-0.0196 (0.0814)	-0.0356 (0.0926)	-0.0487 (0.0963)	-0.0369 (0.0996)	-0.0491 (0.102)	-0.0506 (0.103)	-0.0526 (0.105)
<i>FMD risk status exporter</i>	0.432 (0.2910)	0.308*** (0.1060)	0.282*** (0.107)	0.254** (0.109)	0.240** (0.110)	0.210* (0.111)	0.389 (0.264)	0.264* (0.143)	0.240* (0.143)	0.218 (0.146)	0.200 (0.148)	0.160 (0.149)
<i>FMD risk status both</i>	0.224 (0.2900)	0.0451 (0.1070)	0.0489 (0.107)	0.0667 (0.108)	0.120 (0.109)	0.174 (0.110)	0.283 (0.267)	0.107 (0.154)	0.11 (0.153)	0.127 (0.153)	0.183 (0.152)	0.236 (0.153)
<i>Recent FMD exporter</i>	-0.175 (0.2760)	-0.199*** (0.0885)	-0.152* (0.0824)	-0.182** (0.0798)	-0.262*** (0.0769)	-0.287*** (0.0760)	-0.174 (0.230)	-0.208** (0.0992)	-0.173* (0.090)	-0.186** (0.0871)	-0.261*** (0.0876)	-0.280*** (0.0914)
<i>Recent FMD both</i>	0.0699 (0.0699)	0.0111 (0.0809)	-0.0628 (0.0788)	-0.150* (0.0772)	-0.366*** (0.0772)	-0.516*** (0.0779)	0.0299 (0.0878)	-0.0321 (0.0893)	-0.106 (0.0926)	-0.198** (0.0939)	-0.417*** (0.0975)	-0.573*** (0.104)
AIC	86026.29	85648.66	85296.8	84817.07	84374.42	83983.83	193107	192414	191758.5	190939.6	190164.8	189490.4
BIC	89610.27	89228.48	88861.97	88354.65	87872.95	87467.94	200478.2	199710	199056.8	198196.8	197386.5	196621.8
Obs	384821	380008	375639	368902	361472	357445	408500	402670	397507	392504	197347.9	382514
DF	330	330	329	327	324	323	675	669	670	667	661	657
LL	-42683.15	-42494.33	-42319.4	-42081.53	-41863.21	-41668.91	-95878.52	-95537.98	-95209.24	-94802.8	-94421.4	-94088.18

Note: Models reported in this table include the other variables shown in Table 2.

**Appendix Table 2b: Effect of Varying Number of Years for which a 'Recent' FMD Outbreak Can Affect Exports**  
 Excluding Risk Status Variables

Number of Years following an Outbreak used in 'Recent FMD' Variable	Heckman, Melitz and Rubinstein Model						Heckman Selection Model					
	1	2	3	4	5	6	1	2	3	4	5	6
<b>Selection Equation</b>												
<i>FMD outbreak exporter</i>	-0.213*** (0.0263)	-0.114*** (0.0290)	-0.117*** (0.0281)	-0.122*** (0.0277)	-0.130*** (0.0274)	-0.153*** (0.0272)	-0.215*** (0.0326)	-0.117*** (0.0298)	-0.120*** (0.0310)	-0.125*** (0.0316)	-0.134*** (0.0321)	-0.157*** (0.0324)
<i>FMD outbreak both</i>	0.0967*** (0.0251)	0.0622*** (0.0238)	0.0639*** (0.0235)	0.0646*** (0.0232)	0.0693*** (0.0230)	0.0742*** (0.0229)	0.0967*** (0.0242)	0.0624*** (0.0241)	0.0643*** (0.0248)	0.0653*** (0.0253)	0.0703*** (0.0258)	0.0756*** (0.0262)
<i>Recent FMD exporter</i>	0.0426 (0.0266)	-0.139*** (0.0265)	-0.141*** (0.0248)	-0.153*** (0.0241)	-0.134*** (0.0240)	-0.119*** (0.0242)	0.0403 (0.0314)	-0.138*** (0.0286)	-0.140*** (0.0289)	-0.152*** (0.0303)	-0.131*** (0.0318)	-0.114*** (0.0334)
<i>Recent FMD both</i>	0.0517** (0.0252)	0.0881*** (0.0232)	0.0757*** (0.0224)	0.0606*** (0.0218)	0.0611*** (0.0217)	0.0389* (0.0224)	0.0531** (0.0243)	0.0894*** (0.0244)	0.0765*** (0.0252)	0.0607** (0.0258)	0.0618** (0.0271)	0.0396 (0.0294)
<b>Outcome Equation</b>												
<i>FMD outbreak exporter</i>	-0.0904 (0.0950)	-0.0225 (0.0939)	-0.0463 (0.0930)	-0.0968 (0.0927)	-0.121 (0.0922)	-0.150 (0.0931)	-0.136 (0.113)	-0.0425 (0.0968)	-0.0654 (0.101)	-0.0949 (0.103)	-0.120 (0.106)	-0.152 (0.107)
<i>FMD outbreak both</i>	-0.0492 (0.0832)	-0.0385 (0.0796)	-0.0226 (0.0787)	-0.0198 (0.0783)	-0.00431 (0.078)	0.00927 (0.078)	-0.0468 (0.0872)	-0.0454 (0.0868)	-0.0299 (0.0895)	-0.0359 (0.0919)	-0.0213 (0.0934)	-0.00615 (0.0953)
<i>Recent FMD exporter</i>	0.1208 (0.0886)	-0.116 (0.0856)	-0.0817 (0.0793)	-0.126 (0.0768)	-0.219*** (0.0735)	-0.256*** (0.0723)	0.136 (0.104)	-0.155 (0.0984)	-0.133 (0.0909)	-0.155* (0.0874)	-0.246*** (0.0865)	-0.286*** (0.0888)
<i>Recent FMD both</i>	0.0278 (0.0817)	-0.0234 (0.0785)	-0.0988 (0.0755)	-0.178** (0.0729)	-0.377*** (0.0724)	-0.505*** (0.0726)	0.00393 (0.0848)	-0.0454 (0.0869)	-0.120 (0.0924)	-0.204** (0.0943)	-0.405*** (0.0988)	-0.538*** (0.105)
AIC	86053.86	85659.8	85304.82	84822.22	84379.18	83991.29	193107	193107	191758.5	190939.6	190164.8	189490.4
BIC	89616.12	89217.92	88848.32	88338.17	87856.11	87453.83	200478.2	200478.2	199056.8	198196.8	197347.9	196621.8
Obs	384821	380008	375639	368902	361472	357445	408500	402670	397507	392504	387349	382514
DF	328	328	327	325	322	321	675	669	670	667	661	657
LL	-42698.93	-42501.9	-42325.41	-42086.11	-41867.59	-41674.64	-95878.52	-95537.98	-95209.24	-94802.8	-94421.4	-94088.18

Note: Models reported in this table include the other variables shown in Table 2.