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Abstract

We identify the causal effect of global livestock trade on the spread of infectious animal diseases through an exogenous increase in the demand for imported livestock. The instrumental variable approach exploits an increase in halal livestock imports in Muslim countries during the major religious festival, Eid al-Adha. Using monthly data for 123 countries, five livestock categories, and sixteen years, we find an imports-to-infections elasticity of about 0.75. The relationship is stronger for countries that are likely to import infected livestock from their partners, or that are endowed with large domestic livestock. These results highlight transmission through trade from origin to destination.

Keywords

Identity International Trade, Livestock Diseases, Religious Festivals, Eid-al-Adha

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1 Introduction

International trade of livestock has substantially increased in the past two decades. According to data from the Food and Agriculture Organization of the United Nations (FAO), the number of exported live animals more than doubled between 2004 and 2019, going from 940 millions to almost two billion units.[1] This rise in trading livestock is associated with animals being transported over increasingly greater distances, primarily because of the consolidation of the slaughterhouse industry.[2]

Expanding global livestock trade could contribute to the transmission of contagious animal diseases. The potential connection has been highlighted both in the scientific literature[3] as well as by the health authorities and the media, especially during the COVID-19 pandemic.[4] There is, however, a lack of comprehensive evidence establishing a clear link between global livestock trade and the spread of infectious animal diseases.

This paper offers new insights into the role of global livestock trade in the worldwide transmission of infectious animal diseases. Our empirical analysis combines high-frequency data with an innovative instrumental variable design to establish a causal relationship between importing livestock and the spread of related animal diseases in the destination country. A standard OLS (Ordinary Least Squares) approach to gauge the connection between importing livestock and the spread of infectious animal diseases is likely to produce biased estimates because of reverse causality. A higher prevalence of livestock infections in the importing country can influence the import of associated livestock species through various channels. For instance, a greater prevalence of livestock infections might reduce the demand for importing livestock or prompt the government to prohibit such

[1]FAOSTAT, Crops and livestock products, available at `https://www.fao.org/faostat/en/#data/TCL`. The years 2004 and 2019 correspond to the first and last year in our sample.

[2]"'Something is wrong': why the live animal trade is booming in Europe" (The Guardian, 24 January 2020).

[3]In a 2015 study published in a BioMed journal, Hardstaff et al. (2015) argue that "[a]nimal trade is an effective way of introducing, maintaining and spreading animal diseases, as observed with the spread of different strains of foot and mouth disease in Africa, the Middle East and Asia and the spread of bovine spongiform encephalopathy (BSE), for example, into Oman and Canada through the importation of infected cattle".

[4]A news article in the Guardian was ominously titled "'Live animals are the largest source of infection': dangers of the export trade" (The Guardian, 21 January 2020).

imports. This would bias the estimate of livestock imports on disease prevalence to zero. Conversely, a higher prevalence of infections in the importing country might lead to an increased demand for imported livestock over domestic ones, which would bias the estimate in the opposite direction.

To address this potential endogeneity issue, we introduce a novel instrument that takes advantage of an exogenous shock: the surge in the import of live animals in Muslim countries during the festival of Eid al-Adha, also known as the "Feast of the Sacrifice". During this four-days festival Muslims ritually sacrifice an animal, distributing it equally among family, relatives, friends, and the less fortunate. We anticipate an increase in the import of "halal" animals (i.e. animals whose meat can be consumed according to the Islamic dietary law) for sacrificial purposes in Muslim countries during Eid al-Adha which is unrelated to the prevalence of livestock infections. This forms the basis of our identification strategy, where we use a binary variable that equals one if the livestock category is halal and the time period corresponds to the month of Eid al-Adha to instrument the import of animals in a specific livestock category within a sample of Muslim countries. The approach allows to isolate the effect of imports that is likely independent of a disease-induced change in consumer demand or government interventions.

We extend the model by introducing non-Muslim countries as a placebo group to construct another instrument that exploits the surge in imports of halal livestock animals in Muslim countries during the month of Eid al-Adha, relative to a control group of non-halal livestock imports in non-Muslim countries. The first stage of the extended instrumental variable model is akin to a triple difference-in-difference estimator, and the specification allows us to control for any seasonality in livestock diseases that might coincide with the month of Eid-al-Adha.

To conduct the empirical analysis, we utilize data from the FAO EMPRES-i database, which encompasses roughly ninety-five thousand instances of animal disease outbreaks across the globe spanning the years 2004 to 2019. To establish a connection between these outbreaks and international trade in livestock, we match the disease data with monthly trade information from UN Comtrade, focusing on five specific four-digit product categories within the Harmonized System (HS) classification of traded goods.[5] The linkage is achieved by considering the timing of each outbreak and the description of the affected animals. Livestock-related disease outbreaks comprise 87% of all animal disease outbreaks that are recorded in FAO's EMPRES-i.[6]

Results from the IV specification show a one percent increase in the import of livestock in Muslim countries causes a 0.47 percent increase in infections in related animal species (the corresponding OLS coefficient is close to zero in magnitude). The import-to-infections elasticity is even larger in the extended IV model where we can include a more restrictive set of fixed effects. In the extended model, a one percent increase in livestock imports causes a 0.74 percent increase in infections in related species in the destination country.

Our empirical design controls for potentially omitted variables that might mediate the link between the instrument and the prevalence of livestock infections and that may vary within importing country over time, within livestock product over time, and within importer-product categories. To further bolster the instrument's validity, we demonstrate that the instrument is uncorrelated to the prevalence of infections in an alternative model in which we utilize the import of livestock meat as the endogenous variable. Livestock meat is a closely related product, yet one that does not mediate the link between the instrument and livestock infections. The lack of a significant association between the instrument and livestock infections in cases where imports are unlikely to be the determining factor suggests that we are indeed capturing a relationship between the Eid al-Adha festival and livestock imports that is due to a surge in halal livestock imports in Muslim countries.

We then turn to investigate the channels through which livestock imports can contribute

[5] The matching exercise is based on the correspondence that we develop in an earlier paper (Beverelli and Ticku, 2021).

[6] In contrast, about 7% of the outbreaks are related to wild animals, while for the remainder outbreaks we could not identify the HS-category from the affected animals' description. We exclude disease outbreaks that affect wild animals because it is difficult to classify the product category as halal or non-halal. While most animal species in this category are wild and therefore not halal, the category also includes some species like camels, rabbits and hares, or birds without talons, that are considered halal.

to a rise in infection cases at the destination. We hypothesize that a proportion of livestock imports are infected, which contributes to the number of infected livestock on entering the destination. The proportion of infected animals among livestock imports is likely to be determined by the supply chain characteristics. Importing from countries that simultaneously experience an acute disease outbreak or exert low effort on disease surveillance is likely to result in having a higher share of contaminated imports. Similarly, distance to trading partners could contribute to contaminated imports, since livestock animals are clubbed together in closed environments over a long duration, which increases the threat of a disease transmission en route. The importing country's customs characteristics, such as delay in consignment clearance or poor handling, could further contribute to contaminating the livestock imports. Finally, having entered the destination, infected imports can directly add to the number of infected animals at the destination or they can mix with local livestock to create a contagion.

We create measures to proxy different supply chain characteristics that can mediate the relationship between livestock imports and infection cases at the destination. We find that countries that are likely to import a higher share of infected livestock due to an acute outbreak among their partners also observe a stronger effect of livestock imports on related infections. Further, the effect of livestock imports on infections depends on the size of local livestock, which rules out that livestock imports mechanically increase the number of infected animals at the destination. Our results indicate that the imported livestock animals, some of which could be infected, interact with the domestic livestock to spread infections.

The paper primarily contributes to the literature on international trade and health. The literature has identified six pathways by which trade flows and trade policy can affect health outcomes (Cyrus, 2018): through impacts on living standards, on inequality, on labor market conditions, on the environment, on access to particular types of food, and through changes in the regulatory space.[7] Furthermore, economic historians have high-

[7]Empirical literature suggesting that international trade would improve global health standards by raising income (first mechanism) includes Dollar (2001) and Owen and Wu (2007). Concerning the second

lighted the role of international commerce in enabling the spread of infectious diseases throughout history (Harrison, 2012; Boerner and Severgnini, 2014). The impact of contemporary trade practices on the spread of communicable diseases, however, remains largely unexplored. Recent studies have focused on trade-induced human mobility as an enabler of the spread of communicable diseases (Oster, 2012; Lin et al., 2022; Antràs et al., 2023). We complement these papers by identifying the role of traded goods in spreading communicable diseases. In an earlier study (Beverelli and Ticku, 2021), we focused on the role of illicit practices in trading of live animals as a source of spreading animals diseases. This paper focuses on the role of authorized livestock trade, and uses an instrumental variable design to identify a causal relationship between trade and infectious animal diseases.

The paper also speaks to a literature that links the observance of religious rituals to health and well-being (Almond and Mazumder, 2011; Campante and Yanagizawa-Drott, 2015; Majid, 2015; Schwab and Armah, 2019). The role of Ramadan fasting on socio-economic outcomes in Muslim countries is especially highlighted in this literature. The negative impact on health is anticipated through complications during pregnancy or through excessive consumption of meat. We contribute to the existing literature by highlighting how the trade of halal livestock can serve as an additional channel through which religious rituals in Muslim countries might influence health outcomes.

mechanism, trade has been show to have quantitatively small impacts on inequality (see Helpman, 2018 for a review), but there is no conclusive evidence of a causal link from inequality to health (see the discussion in Cyrus, 2018). Studies such as Colantone et al. (2019), Adda and Fawaz (2020), and Erten and Keskin (2021) have shown that trade negatively impacts human health through adverse changes in labor market conditions (third mechanism). The link between trade and environmental outcomes is theoretically ambiguous and empirically unclear (see WTO, 2022 for a review), therefore it is uncertain whether trade affects health outcomes through its environmental impacts (fourth mechanism). Evidence that trade can contribute to worsening health outcomes by easening access to 'junk' food (fifth mechanism) is provided, among others, by Miljkovic et al. (2015) and Giuntella et al. (2020). Finally, concerning the sixth mechanism, while on the one hand trade agreements may tie the hands of governments in the design of health regulations, they may also raise the overall stringency of health regulations, and/or spur innovation in the health sector by fostering intellectual property protection (see Kyle and Qian, 2014 for evidence from the WTO TRIPS Agreement).

2 Data

We construct a dataset that covers 123 countries and the five livestock animal categories of the Harmonized System (HS) four-digit classification: 0101 (horses, asses, mules and hinnies); 0102 (bovine animals); 0103 (swine); 0104 (sheep and goats); and 0105 (poultry, fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea fowls). We use monthly data covering the period from 2004 to 2019, for which the data on livestock diseases is available. This section describes the main variables and their sources.

2.1 Livestock diseases

Data on animal diseases are from FAO's EMPRES Global Animal Disease Information System (EMPRES-i).[8] The database contains daily information on the outbreak of thirty-two animal diseases, which is obtained from the World Organization for Animal Health (OIE) and the national health agencies. Between 2004 and 2019, approximately ninety-five thousand disease outbreaks occurring worldwide are recorded in EMPRES-i. Information is available on the number of animals infected, the resulting deaths, as well as human response like slaughtering infected animals. Since both animal deaths and subsequent human actions are likely to depend on the quality of health infrastructure, we focus on recorded infection cases.

To precisely assign infection cases to an animal category k (four digit HS heading), we use a matching strategy detailed in Appendix A of Beverelli and Ticku (2021). We focus on thirty-one diseases with confirmed cases in the EMPRES-i database, and we use textual analysis of the description on the species affected by each outbreak that is included in the raw FAO's EMPRES-i data.[9] The results, displayed in Table A-3 of Beverelli and Ticku

[8] Available at `https://empres-i.apps.fao.org`.

[9] To provide an example, in the Republic of Korea between January and April 2015 there were 159 reported outbreaks of foot and mouth disease (FMD). In 120 of these cases, there is information on the number of animals infected. 114 of these 120 cases are described as affecting "Domestic (dom.) swine". Based on this unambiguous description, the 85,442 infections associated with these 114 cases are assigned to HS category 0103. Five other cases are described as affecting "Dom. cattle". Again, since this is an unambiguous description, the six infections associated with these five cases are assigned to HS category 0102. The remaining case is described as affecting "Dom. swine, dom. cattle". Since the assignment to an animal category would not be clean, we disregard the 382 infections associated with this case.

(2021), show that 2% of the 94,711 disease outbreaks recorded in the FAO's EMPRES-i database between 2004 and 2019 affect HS heading 0101; 14% affect HS heading 0102; 26% affect HS heading 0103; 14% affect HS heading 0104; and 33% affected HS heading 0105.[10]

To construct the variable of interest (infections), which varies by importing country, HS4 product, and month/year, all infection cases specific to HS4 category k during month/year t are summed within each country j.

2.2 Livestock trade

We measure livestock imports as log value of imports reported by importer j from all countries (M_{jkt}) in HS4 category k in month/year t. Livestock import data are sourced from UN Comtrade and they are available monthly for the entire sample period.[11] Imports are reported in values (USD) since the number of units are not reported at the monthly level in the UN Comtrade database. For a (small) subset of countries, monthly data on livestock prices, in local currency units, are available from FAO.[12] These are used in estimations reported Section B of the online appendix.

2.3 Other variables

We collect data for a number of control variables that vary across the importer-HS4 (jk) dimension over time. We include precautions at the border, the number of screening measures, and the number of surveillance measures that were issued by importer j on HS4 category k bi-annually.[13] Border precautions are applied at the border posts to restrict the introduction of a livestock disease into the country and can range from quarantine,

[10]Disease outbreaks affecting HS heading 0106 (7%) and disease outbreaks where no HS heading could be assigned (7%) are excluded from our analysis.

[11]Logs of livestock imports are used as dependent variable in the empirical analysis. Logs are taken after adding a small constant of 0.01 to the number of infections. We use alternative transformations of the dependent variable in Section E of the online appendix: (i) an inverse hyperbolic sine (IHS) transformation, and (ii) a binary outcome, to address the concern with taking a log transformation of zeroes after adding a constant.

[12]FAOSTAT, Producer Prices, available at `https://www.fao.org/faostat/en/#data/PP`.

[13]To analyse the potential mechanisms through which livestock imports might contribute to the surge in infections at the destination, we also use the number of screening measures and the number of surveillance measures in partner countries (i.e. exporters), weighted by the initial share of exports.

certification of health status in the exporting country, details on the zone or herd of origin of the imported animal, or testing of animals before loading the consignment. Screening measures are diagnostic tests carried out systematically either within the framework of a control programme for the disease, or for qualifying herds/flocks as free from the disease. Surveillance measures continuously investigate a given population to detect the occurrence of disease for control purposes, and may involve testing a part of the population. The data on border precautions, screening, and surveillance measures are obtained from the OIE.[14]

We further collect annual data on: (i) the stock of animals in importer j in HS4 product k;[15] (ii) (i) GDP per capita, in current US$ (in logs), sourced from IMF's World Economic Outlook (WEO) data, April 2021 edition; and (ii) remoteness, computed as the weighted sum of bilateral distances between j and each foreign country e, with weights given by e's share of world GDP in year y.[16]

Table A-1 of the online appendix reports in-sample summary statistics of the main variables used in the analysis.

3 Empirical Strategy

During the last fifteen years, we observe a clear co-movement between livestock trade and the number of disease outbreaks, as shown in Figure A-1 in Section A of the online appendix. This overall trend indicates that livestock imports and disease outbreaks are correlated. We leverage disaggregated data to subsequently identify a robust, causal relationship between livestock imports and the spread of associated animal diseases.

The relationship between livestock imports and the prevalence of related animal diseases

[14] The raw data, from the OIE's WAHIS database, are available at `https://wahis.woah.org/#/dashboards/control-measure-dashboard`, and contain information both on the type of disease and on the species affected. The matching of the latter with HS headings is straightforward.

[15] FAOSTAT, Crops and livestock products, available at `https://www.fao.org/faostat/en/#data/QCL`.

[16] Data on bilateral distances are from CEPII's *GeoDist* (Mayer and Zignago, 2011).

in the destination country is represented, in reduced form, by the following equation:

$$log(infections)_{jkt} = \beta_1 log(imports)_{jkt} + \gamma_{jt} + \omega_{kt} + \lambda_{jky} + \epsilon_{jkt}, \tag{1}$$

where $log(infections)_{jkt}$ is the log of infection cases in importer j among animal species included in the livestock category k in month/year t. The explanatory variable is the log of imports in importer j of animal species included in HS4 product k in month/year t.

The model includes the most restrictive set of fixed-effects possible. Importer-month/year fixed effects (γ_{jt}) account for importer-specific variation in economic activity or customs behavior; HS4 product-month/year fixed effects (ω_{kt}) account for seasonal fluctuations in imports or the evolution of diseases that are specific to livestock category k; and importer-HS4 product-year (λ_{jky}) fixed effects account for all policies related to an importer-HS4 product that vary gradually. We cluster standard errors at country level to permit valid inference if errors are auto-correlated within country. The coefficient of interest β_1 measures the percent increase in the number of infection cases that corresponds to a one percent increase in the import of livestock.

3.1 Threats to identification

Despite including a rich battery of fixed effects to account for potential omitted variables, OLS estimation of the coefficient of interest β_1 in equation (1) is likely to be biased due to reverse causality. More livestock infections in the importing country can simultaneously affect the import of associated livestock species through different pathways. First, more livestock infections can dampen import demand for the associated animal species. Figure A-2 of the online appendix illustrates the potential reverse causality through the example of Netherlands, where cattle imports fell sharply in 2001-02 due to the emergence of mad cow disease (BSE) and foot and mouth disease (FMD) (Achterbosch and Dopfer, 2006), and took another couple of years to return to the pre-outbreak levels. Second, more livestock infections might compel the government to increase trade barriers or even impose an outright import ban on the associated livestock. For instance, Saudi Arabia banned livestock imports from several African countries in 2000 to fight the Rift Valley fever.[17] The decline in imports due to more infections, either through reduction in demand or through state action, would create a downward bias in the OLS estimate. Third, more infection cases in importing country might substitute local demand towards imported livestock, which would bias the OLS estimate upwards. In summary, the potential reverse causality could severely bias the OLS estimate of livestock imports on animal infections, and the direction of this bias is a priori unclear.

3.2 Instrumental variable estimation

We use a "natural natural experiment" (Rosenzweig and Wolpin, 2000) to identify an exogenous change in the import demand for livestock. Specifically, we take advantage of an exogenous surge in the import of halal live animals in Muslim countries during the four days of Eid al-Adha (Feast of the Sacrifice).[18] During the festival, Muslims are obliged to sacrifice animals, which are shared in three equal parts: for family, for relatives and friends, and for the poor. We expect a surge in the import of halal live animals in Muslim countries around the festival period. The import surge due to the festival is plausibly independent of an infections-induced change in consumer demand or state action.

Based on the identifying assumption, we propose an instrumental variable design to estimate the causal effect of livestock imports on the prevalence of diseases that afflict related species in importing Muslim countries. The first stage takes the following form:

$$log(imports)_{jkt} = \delta \mathbf{Z}_{kt} + \gamma_{jt} + \lambda_{jk} + \mu_{jkt}, \qquad (2)$$

where $\mathbf{Z}_{kt}$ is a binary variable (halal × Eid al-Adha) that equals one if HS4 live animal product k is halal, and t is the month/year in which Eid al-Adha takes place.

To categorize a country as Muslim we use the classification by Brown (2016), which iden-

[17] "Saudi Arabia bans livestock imports", The New Humanitarian (19 September 2000).

[18] Eid al-Adha follows the Islamic lunar calendar, falling on the tenth day of Dhu al-Hijjah. In the international calendar, the dates vary from year to year, shifting approximately 11 days earlier each year. So, for instance, while the festival occurred in November during the first year of the sample (2004), it shifted to June in the last year, 2019.

tifies countries in which Islam was the preferred religion of the country's governing regime in year 2000. This measure is preferred over a simple population measure (i.e., the share of Muslims in the importing country j), since it captures the relative political power of religions within a country, which would impact adherence to religious customs. Nevertheless, Brown's measure corresponds well to the distribution of the Muslim population (see Figure A-3 of the online appendix). Our sample includes 42 countries where Islam was the preferred religion. According to data from the PEW Research Center, the average Muslim population share in 1990 in these countries was approximately 67%, while the Muslim population share in the rest of the countries in the sample was about 2.5%.

We classify livestock type as halal or non-halal depending on whether a livestock animal is fit for consumption under the Islamic dietary law. Halal livestock include HS4 categories 0102 (bovine animals), 0104 (sheep and goats) and 0105 (poultry, fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea fowls). The control group (non-halal) includes HS4 categories 0101 (horses, asses, mules and hinnies) and 0103 (swine).[19]

The second stage takes the following form:

$$log(infections)_{jkt} = \beta_2 \mathbf{log}\widehat{(\mathbf{imports})}_{jkt} + \gamma_{jt} + \lambda_{jk} + \epsilon_{jkt}. \tag{3}$$

The coefficient β_2 is a LATE of livestock imports on the prevalence of infections; a one percent increase in imports of halal livestock due to Eid al-Adha in Muslim countries causes a β_2 percent increase in infections in related species.[20]

3.2.1 Non-Muslim countries as placebo

The approach described by equations (2) and (3) is restricted to the subset of Muslim countries in the sample. We also leverage the richness of our dataset, which comprises both Muslim and non-Muslim countries, to propose an alternative instrument, $\mathbf{Z}_1$. This is

[19] While consumption of donkeys and their cross-breeds is regarded as haram (forbidden), eating horse meat is regarded as makruh (disapproved), therefore its consumption should be avoided.

[20] Note that a Poisson model is not feasible in our setting as it is difficult to estimate with endogenous regressors and many fixed effects (Bellégo et al., 2022).

a binary variable (Muslim × halal × Eid al-Adha) that equals one if the importing country j is Muslim, HS4 live animal product k is halal, and t is the month/year in which Eid al-Adha takes place. The IV specification using $\mathbf{Z}_1$ is based on the full sample. The first stage is conceptually similar to a triple difference-in-difference estimation (Gruber, 1994), where non-Muslim countries act as a placebo group, and the specification can include more restrictive fixed effects to satisfy the exclusion restriction. Particularly, we can control for the evolution of diseases specific to halal animals around the time of Eid al-Adha, which might be due to factors other than the import of halal livestock animals, by including product-month (kt) fixed effects.

The first stage of the alternative IV estimation takes the following form:

$$log(imports)_{jkt} = \delta \mathbf{Z}_{1jkt} + \gamma_{jt} + \omega_{kt} + \lambda_{jky} + \mu_{jkt}. \tag{4}$$

The second stage takes the following form:

$$log(infections)_{jkt} = \beta_3 \mathbf{log(\widehat{imports})}_{jkt} + \gamma_{jt} + \omega_{kt} + \lambda_{jky} + \epsilon_{jkt}. \tag{5}$$

4 Results

4.1 First stage and reduced form dynamics in Muslim countries

Before turning to the instrumental variable analysis, we examine if Eid al-Adha causes a significant increase in the import of halal livestock animals in Muslim countries. We modify the first stage equation (2) and regress livestock imports on a set of instruments that interact the halal dummy with indicators for the months before, the month of, and the months after Eid al-Adha. The resulting equation is akin to an event study that captures the evolution of halal livestock imports within Muslim countries relative to the control group (non-halal livestock) around the month of Eid al-Adha:

$$log(imports)_{jkt} = \sum_{\tau=-q}^{-1} \alpha_\tau \mathbf{Z}_{k\tau} + \sum_{\tau=0}^{m} \gamma_\tau \mathbf{Z}_{k\tau} + \gamma_{jt} + \lambda_{jk} + \mu_{jkt}. \tag{6}$$

A corresponding reduced-form equation reveals the dynamics of infections that affect halal livestock animals around the month of Eid al-Adha.

$$log(infections)_{jkt} = \sum_{\tau=-q}^{-1} \alpha_\tau \mathbf{Z}_{k\tau} + \sum_{\tau=0}^{m} \gamma_\tau \mathbf{Z}_{k\tau} + \gamma_{jt} + \lambda_{jk} + \epsilon_{jkt}. \tag{7}$$

Figure 1 shows the dynamic estimates of Eid al-Adha's impact on livestock imports and infection cases within Muslim countries. There are no pre-trends in halal livestock imports or related infections in the months prior to Eid al-Adha.[21] Both imports and infections related to halal livestock increase sharply in the month of Eid al-Adha, and they dissipate in subsequent months. These dynamics highlight a festival-driven surge in halal livestock imports and related animal infections in Muslim countries, which we use next to identify the effect of livestock imports on animal infections.[22,23]

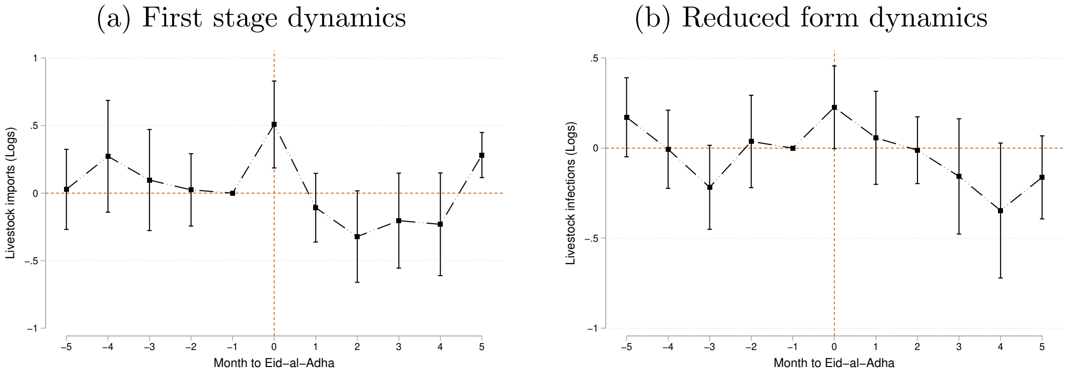
Figure 1 also shows the non-persistence of infection cases in the months following Eid al-Adha. This could be due to the fact that the pathogens do not survive in the new environment for a long time. The transmission of pathogens, in fact, depends both on the survival rate of the pathogen and the proximity to other animals. For instance, a study on livestock in Tanzania shows that transmission risk is more sensitive to the survival of the pathogen in the local environment than it is to the transmission distance (Ekwem et al., 2021). The pathogen survival versus transmission distance trade-off might explain why

[21] The $t-2$ month in Figure 1 corresponds to the month of Eid al-Fitr, which is an equally important festival for Muslims but it does not mandate a ritual animal sacrifice. The dynamic estimates show that neither livestock imports nor infections surge during the month of Eid al-Fitr, which suggests that we are capturing an effect that is due to the rise in demand for halal livestock animals for sacrifice during Eid al-Adha.

[22] The specification underlying Figure 1 includes importer-product and importer-month/year fixed effects. The same pattern is obtained from less conservative specifications using importer-product and month/year fixed effects.

[23] In Section B of the online appendix we assess the price dynamics of livestock products for a subsample of Muslim countries for which monthly price data are available. We do not find any significant increase in halal livestock prices around Eid al-Adha and conclude that the surge in livestock imports is driven by an increase in livestock units.

Figure 1: First stage and reduced form dynamics in Muslim countries



Notes: The month prior to Eid al-Adha is treated as the reference month and it is set to 0. 95% confidence intervals are reported by the vertical bars. Importer-product (jk) and importer-month/year (jt) fixed effects are included in the estimations (respectively, equation (6) for panel (a), and equation (7) for panel (b)).

the surge in infection cases dissipates in the months following Eid al-Adha. Alternatively, the lack of persistence might be due to the decline in imports of halal livestock following the month of Eid al-Adha.[24]

4.2 Livestock imports and animal infections

Columns (1) to (3) of Table 1 shows the OLS results of estimating equation (1) for the sample of Muslim countries.[25] The coefficients of interest are small in magnitude and are imprecisely estimated. Columns (4)-(6) show the corresponding findings from the IV estimation. The first stage results from equation (2) suggest that the coefficient on the festival instrument (δ) is both positively and strongly correlated to livestock imports (the corresponding KP-F stat is well clear of the conventional threshold for a strong instrument). The second stage result from equation (3) shows that imports cause an increase in infections in related species in the destination country. The point estimate in column (6), with the most restrictive set of fixed effects, and after controlling for the size

[24] In Table A-2 of the online appendix, we estimate the effect of livestock imports on future infections (month t+1 and t+2 respectively), after controlling for future imports (months t+1 to t+4). We fail to find a significant effect of livestock imports on future infections.

[25] We alternatively include jk and t fixed effects (in columns (1) and (2)) or jk and jt fixed effects (in column (3)), and always exclude kt fixed effects. This is done to keep symmetry with the corresponding IV regressions of columns (4)-(5), where it is not possible to include kt fixed effects, with which the halal × Eid al-Adha instrument would be perfectly collinear. Therefore, we add, as control variables, the log of stock, and, in regressions without jt fixed effects, the log of GDP per capita and log remoteness.

Table 1: Livestock imports and infection cases (Muslim countries)

	(1)	(2)	(3)	(4)	(5)	(6)
Log imports	-0.028	-0.032	-0.030	0.312*	0.316*	0.466*
	(0.029)	(0.029)	(0.026)	(0.176)	(0.164)	(0.262)
Log GDP pc		0.263			0.072	
		(0.251)			(0.322)	
Log stock		-0.128	-0.559		-0.322	-0.591
		(0.185)	(0.349)		(0.266)	(0.401)
Log remoteness		1.387			0.694	
		(1.912)			(2.209)	
Observations	9,309	8,735	7,957	9,309	8,735	7,957
R-squared	0.167	0.172	0.420			
Model	OLS	OLS	OLS	IV	IV	IV
Importer-Product FE	✓	✓	✓	✓	✓	✓
Month/Year FE	✓	✓		✓	✓	
Importer-Month/Year FE			✓			✓
First stage coeff.				0.493	0.606	0.524
First stage s.e.				0.124	0.153	0.157
KP F stat				16.07	15.65	11.08

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable: log of infections. Robust standard errors clustered by country in parentheses. First stage coefficients and standard errors are on the instrument $\mathbf{Z}_{kt}$ (halal × Eid al-Adha).

of domestic livestock, implies that a 1 percent increase in imports causes a 0.47 percent increase in infections in related animal species. The coefficient from the IV estimation, which is significantly larger in magnitude than the OLS estimate, suggests that the OLS estimate is biased downwards due to reverse causality.

Table 2 shows results for the full sample of countries, where the instrument ($\mathbf{Z}_1$) uses non-Muslim countries as an additional placebo. While the OLS correlation between livestock imports and infection cases continues to be insignificant (column (1)), the imports-to-infections elasticity is even larger when compared to the results in Table 1. Further, in columns (4) to (6) we show that the elasticity is unaffected by including additional policy controls related to animal health, respectively border precautions, screening measures, and surveillance measures, introduced to regulate the outbreak of diseases that affect livestock category k by the importing country j.

Table 2: Livestock imports and infection cases (Full sample)

	(1)	(2)	(3)	(4)	(5)	(6)
Log imports	0.014	0.744**	0.808*	0.744**	0.731**	0.745**
	(0.011)	(0.370)	(0.443)	(0.370)	(0.366)	(0.369)
Log stock			-0.400			
			(0.248)			
Border precautions				-0.001		
				(0.027)		
Screenings					0.106**	
					(0.044)	
Surveillence						-0.008
						(0.034)
Observations	36,282	34,833	34,583	34,833	34,833	34,833
R-squared	0.677					
Model	OLS	IV	IV	IV	IV	IV
Importer-Product-Year FE	✓	✓		✓	✓	✓
Importer-Product FE			✓			
Importer-Month/Year FE	✓	✓	✓	✓	✓	✓
Product-Month/Year FE	✓	✓	✓	✓	✓	✓
First stage coeff.		0.465	0.463	0.465	0.465	0.465
First stage s.e.		0.160	0.182	0.160	0.160	0.160
KP F-stat		9.244	6.475	9.252	9.239	9.285

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable: log of infections. Robust standard errors clustered by country in parentheses. First stage coefficients and standard errors are on the instrument $\mathbf{Z}_{1jkt}$ (Muslim × halal × Eid al-Adha).

4.2.1 A placebo test for the exclusion restriction: meat imports

Even though the relationship between livestock imports and animal infections is robust to controlling for any omitted factors that may vary within the importing country over time, within products over time, and within importer-products, there might still be some omitted factors that mediate the relationship between the instrument and the prevalence of infectious diseases. We perform a placebo test to show that the instrument is unlikely to be associated with infection cases except through a surge in halal livestock imports during Eid al-Adha. We use the import of a closely related product, livestock product k meat, as a placebo, since the instrument can not affect livestock infections through the import of halal livestock meat.[26] Table 3 presents results that compare the reduced form effect of the festival instrument on livestock infections when live animal k imports are the endogenous variable (column (1)) to when meat k imports are the endogenous variable

[26]While there might be a higher demand for halal meat around Eid al-Adha in Muslim countries, meat imports are not directly related to the transmission of diseases to animals because livestock meat product is for human consumption and is not used for animal fodder.

Table 3: Exclusion restriction check (reduced form)

	(1)	(2)
$\mathbf{Z}_1$	0.374***	0.136
	(0.142)	(0.138)
Observations	34,833	43,727
R-squared	0.680	0.687
Model	OLS	OLS
Endogenous variable	Livestock imports	Livestock meat imports
Importer-Product-Year FE	✓	✓
Importer-Month/Year FE	✓	✓
Product-Month/Year FE	✓	✓

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable: log of infections. Robust standard errors clustered by country in parentheses. Column (1): reduced form effect of the festival instrument $\mathbf{Z}_1$ on livestock infections when livestock imports are the endogenous variable. Column (2): reduced form effect of the festival instrument $\mathbf{Z}_1$ on livestock infections when meat imports are the endogenous variable.

(column (2)). While the instrument is significantly correlated to livestock infections in the sample in which livestock imports are an endogenous variable, the correlation between the instrument and livestock infections is statistically not different from zero when livestock meat imports are an endogenous variable. The lack of association between the instrument and livestock infections when imports are unlikely to mediate the relationship between the instrument and infections suggests that we are capturing a link between the Eid al-Adha festival and livestock imports that is not due to factors other than a surge of halal livestock imports in Muslim countries.

4.3 Mechanisms: Supply chain characteristics and animal infections

We investigate the mechanisms through which livestock imports might create a surge in infection cases at the destination. We conjecture that a certain proportion of imported livestock is infected, which contributes to the number of infection cases at destination on entry. The proportion of infected animals among livestock imports is likely to be determined, along the supply chain, by: (i) characteristics of the country where the imported livestock originates, (ii) travel time, and (iii) clearance time and handling at the customs. A country is likely to import a higher share of infected livestock if the partners countries are simultaneously experiencing an acute disease outbreak or if they exert low effort on disease surveillance. The likelihood of importing a higher share of infected livestock might also depend on the distance to trading partners since duration of travel and high stocking density en route can affect the spread of infections through the consignment (Greger, 1997). Thirdly, delay at customs and poor handling of consignment will also affect the share of infected amongst the imported livestock. Finally, upon entering the destination country, the imported livestock might affect infection cases through an "import effect" or a "contagion effect". A pure import effect would occur because the increase in livestock imports, a part of which are infected, mechanically increases the infection cases at the destination. Alternatively, the results could be driven by a contagion effect, i.e. the imported animals that are infected come in contact with local livestock and this results in a contagion.

We sequentially analyze the supply chain characteristics that could enable the transmission of animal infections through trade. We create three measures of origin characteristics that could influence the likelihood of country j importing infected livestock: (i) the weighted average of infections in k across partner countries (exporters) in a given month/year t, where weights are determined by the initial bilateral share of exports; (ii) the weighted average of screening measures (reported bi-annually) in place for livestock k across partner countries; and (iii) the weighted average of surveillance measures (reported bi-annually) in place for livestock k across partner countries.[27] We create three binary variables that classify the likelihood of importing infected livestock by partner characteristics, which equal one if the weighted average is above the sample mean.[28] The first binary measure should augment the likelihood of importing infected livestock, while the latter two measures should constrain the likelihood of doing so. We interact these binary variables with livestock imports to check whether the effects of livestock imports are higher if imports are sourced from origin countries experiencing more infections, and/or lower if imports are sourced from origin countries implementing more screening

[27] We use the detailed trade matrix from FAOSTAT (available at `https://www.fao.org/faostat/en/#data/TM`) to create initial import shares. To minimize loss of information, the initial year is set to 2010.

[28] We respectively denote these three variables 'High weighted infections partners', 'High weighted screening partners', and 'High weighted surveillance partners'.

Table 4: Mechanisms

Infections source	(1) Origin	(2) Origin	(3) Origin	(4) Transit	(5) Customs	(6) Destination
Log imports	0.699*	-0.237	0.341	0.882	0.831	-1.087
	(0.357)	(2.827)	(1.253)	(0.550)	(0.531)	(1.139)
Interaction term	0.435***	4.116	2.467	-0.281	-0.146	4.774*
	(0.163)	(11.801)	(7.861)	(0.505)	(0.484)	(2.561)
Dummy high weighted infection partners	-5.957**					
	(2.373)					
Dummy high weighted screening partners		-52.291				
		(149.378)				
Dummy high weighted surveillance partners			-31.182			
			(98.966)			
Observations	34,833	34,833	34,833	34,833	34,833	34,833
KP F-stat	15.08	0.0754	0.244	3.045	4.307	2.263
Importer-Product-Year FE	✓	✓	✓	✓	✓	✓
Importer-Month/Year FE	✓	✓	✓	✓	✓	✓
Product-Month/Year FE	✓	✓	✓	✓	✓	✓

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable: log of infections. Robust standard errors clustered by country in parentheses. The **Interaction term** is the interaction between log imports and the control variable that is included in each column. In column (4) imports are interacted with High remoteness, a binary measure of an importing country's remoteness. The remoteness measure varies by importer-year and it is absorbed by importer-month/year fixed effects. In column (5) imports are interacted with High customs quality, a binary measure of customs quality. Customs quality varies by importer-year and it is absorbed by importer-month/year fixed effects. In column (6) imports are interacted with High stock, a binary domestic livestock size measure. The domestic livestock data vary by importer-product-year and the variable is absorbed by importer-product-year fixed effects.

and surveillance measures.

Next, we proxy travel time through the remoteness of country j from its partner countries. We create a binary variable that equals one if the remoteness score is above the sample mean, and interact it with livestock imports. To proxy for customs quality, we use the quality of port infrastructure, as reported in the World Economic Forum's Global Competitiveness Report. In this case, too, we use a binary transformation of the variable, creating a dummy equal to one if it is above the sample mean, and interact it with livestock imports. Finally, to measure the contagion effect we conjecture that the likelihood of imported infected livestock coming in contact with domestic livestock increases with the size of the latter. Accordingly, we create a binary variable that equals one if the livestock size k in country j in year y is above the sample mean, and interact it with livestock imports.[29]

Results in column (1) of Table 4 suggest that imported livestock is related to a greater prevalence in infection cases when imports originate from partner countries that simulta-

[29]The three variables constructed as described in this paragraph are respectively denoted 'High remoteness', 'High customs quality', and 'High stock'.

neously experience a disease outbreak in related species.[30] Screening measures (column (2)) or surveillance measures (column (3)) implemented in partner countries, as well as travel time (column (4)) or customs quality (column (5)), conversely, do not mediate the effect of imported livestock on infection cases. Finally, results presented in column (6) indicate that the effect of livestock imports on reported infection cases is present only in countries with substantial domestic livestock. We thus rule out that livestock imports mechanically increase the number of infections in the importing country. The results of Table 4, together, support the contagion explanation of our findings, i.e., the baseline effect is driven by the interaction between infected imported animals and the domestic livestock.[31]

4.4 Robustness checks

We conduct a battery of robustness checks on the main results, including alternative transformations of the outcome variable, sub-sample analysis, and an over-identified IV specification. The results, displayed in Table A-4 and discussed in Section E of the online appendix, show the robustness of our findings.

5 Conclusion

Animal diseases threaten livestock populations and can damage the economy through negative impacts on affected economic activities: the farming sector, as well as upstream and downstream sectors such as the animal feeds and the meat processing sectors. Moreover, they can potentially harm humans, who can contract zoonotic diseases through direct contact with infected animals, or indirectly by consumption of contaminated food or water, inhalation, arthropod vectors (such as flies, ticks, and mosquitoes) and pests.

This paper considers the potential role of the rapidly expanding global livestock trade in

[30] To quantify the effect, the imports-to-infections elasticity for a country at the 75^{th} percentile of livestock imports, and with high weighted average of infections in partner countries, is equal to $= 0.699 + 14.70 \times 0.435 - 5.958 = 1.14$.

[31] In columns (2)-(6) of Table 4 the first stage correlations become weak. To address the concern that the results might be affected by a weak instrument problem, in Section D of the online appendix we show results of reduced form estimations that replicate qualitatively the results of Table 4.

the spread of infectious diseases. Exploiting exogenous variation in import demand for live animals suitable for sacrifice during the Eid Al-Adha religious festival in Muslim countries, it estimates the causal link between livestock trade and infectious animal diseases, and studies the mechanisms behind this link. Evidence from more than 120 countries, over a sixteen-year period, shows that commercial livestock imports are systematically related to infectious diseases in associated animal species. The relationship is stronger for countries whose partners experience acute disease outbreaks. The relationship is also stronger for countries where imported animals, some of whom are infected, can interact with domestic livestock to create a contagion. These results support the conclusion that trade leads to infectious livestock diseases through a contagion effect.

Our analysis suggests that generic border prohibitions and local surveillance might not be sufficient to limit the trade-induced transmission of infectious diseases, and that focusing on exposure to disease in partner countries could be a better safeguard.

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For Online Publication

Supplement to "Global Livestock Trade and Infectious Diseases"

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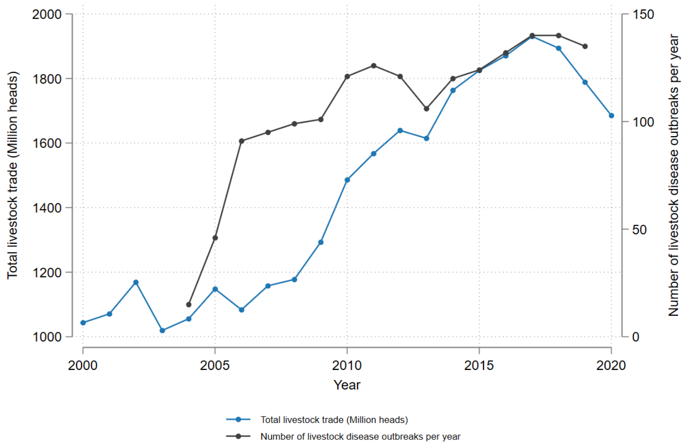
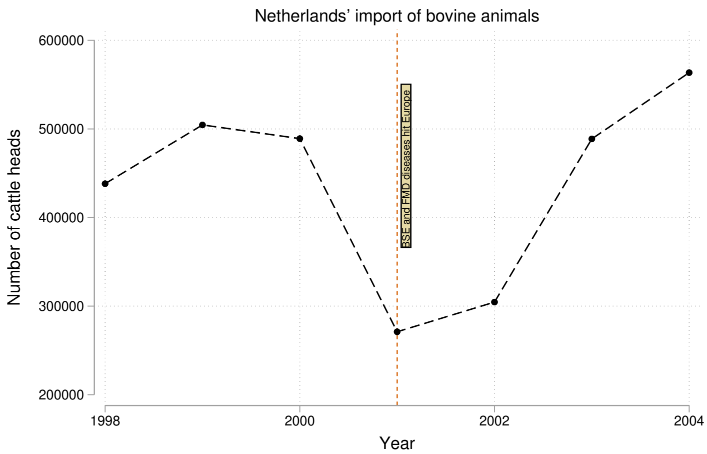
A Descriptive figures and tables

Figure A-1: Livestock trade and disease outbreaks



Notes: Data on the annual number of livestock heads traded are sourced from FAOSTAT. Data on livestock disease outbreaks are calculated from FAO's EMPRES-i database. The EMPRES-i database records animal disease data from 2004 onwards.

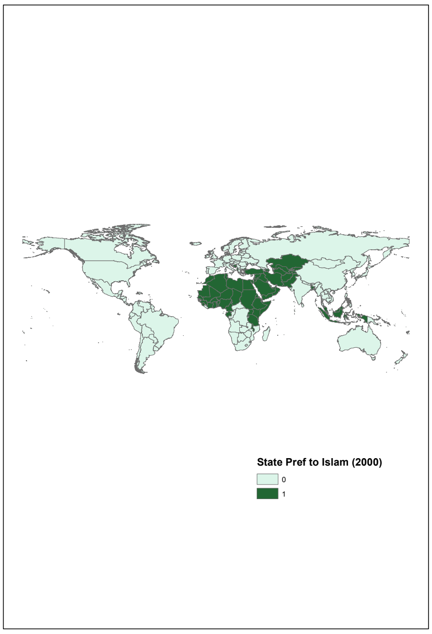
Figure A-2: Disease shocks and livestock imports: Case study of the Netherlands



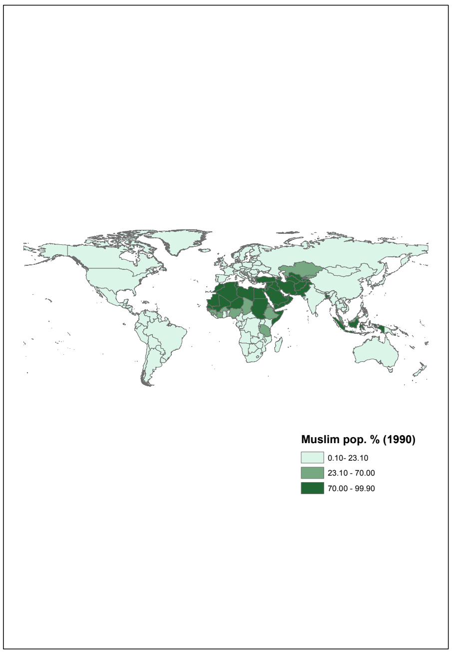
Notes: Data on the annual number of imported cattle heads are sourced from FAOSTAT.

Figure A-3: Classification of Muslim countries

(a) Islam preference



(b) Muslim %



Notes: Data on Islam preference in 2000 are from Brown (2016). Data on Muslim % (average Muslim population share) in 1990 are from the PEW Research Center (`https://www.pewforum.org/2011/01/27/table-muslim-population-by-country`).

Table A-1: In-sample descriptive statistics (main variables)

	Sample of Muslim countries				
Continuous variables	Mean	Median	Std Dev	Min	Max
Log infections	-4.35	-4.61	1.53	-4.61	12.94
Log imports	12.19	12.42	2.91	-4.61	20.91
Dummy variables	Mean	Median	Std Dev	Zeros	Ones
Halal	0.74	1	0.44	2,445	6,864
Eid al-Adha	0.08	0	0.28	8,523	786
	Full sample				
Continuous variables	Mean	Median	Std Dev	Min	Max
Log infections	-4.04	-4.61	2.24	-4.61	14.74
Log imports	12.79	13.00	2.70	-4.61	20.91
Dummy variables	Mean	Median	Std Dev	Zeros	Ones
Muslim	0.20	0	0.40	27,974	6,859
Halal	0.63	1	0.48	12,960	21,873
Eid al-Adha	0.08	0	0.28	31,903	2,930

Notes: Descriptive statistics for the sample of Muslim countries computed from the sample of column (3) of Table 1. Descriptive statistics for the full sample computed from the sample of column (3) of Table 2.

B Livestock prices around Eid al-Adha in Muslim countries

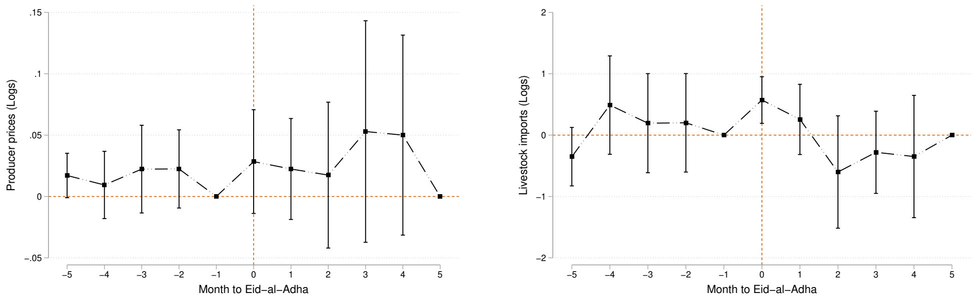
This section compares the dynamics of livestock product (k) prices, that we can collect for a subset of Muslim countries (17 out of 42 Muslim countries in our sample) from the FAO, to the import dynamics within the same group of countries. This helps us evaluate to what extent the rise in imports (measured in USD value) around Eid al-Adha is driven by prices versus quantities.

The top row of Figure A-4 presents the dynamics in a specification with importer-product and month/year-fixed effects and shows that livestock prices do not change around Eid al-Adha (panel (a)), where there is instead a clear surge in the total value of imports, as exhibited in panel (b). Qualitatively similar patterns are depicted in the bottom row of the figure, where we estimate the dynamics after controlling for importer-product and importer-month/year fixed effects (the latter account for the fact that livestock prices are measured in local currency units).

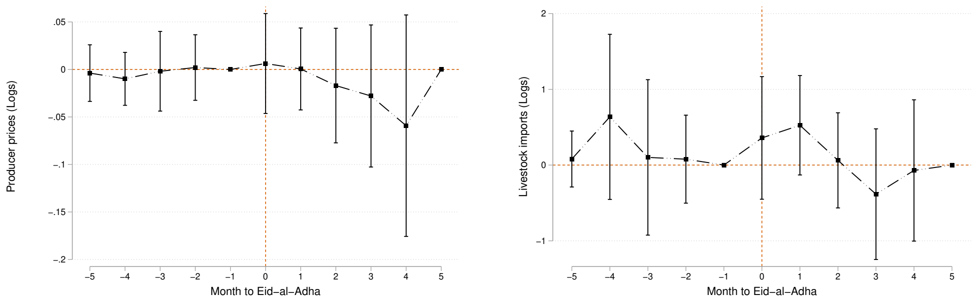
Figure A-4: Dynamics of halal livestock prices vs. imports around Eid al-Adha

(a) Dynamics of prices (b) Dynamics of imports

Importer-product (jk) and month/year (t) fixed effects



Importer-product (jk) and importer-month/year (jt) fixed effects



Notes: The month prior to Eid al-Adha is treated as the reference month and it is set to 0. 95% confidence intervals are reported by the vertical bars. Importer-product (jk) and month/year (t) fixed effects are included in the estimations.

C Livestock imports and future infections in Muslim countries

Table A-2 shows the effect of livestock imports within Muslim countries on future livestock infections (t+1 and t+2), after controlling for future livestock imports (from t+1 to t+4). We fail to find that the surge in livestock imports due to Eid al-Adha impacts future infections, even after controlling for the potential decline in livestock imports in future months.

Table A-2: Livestock imports and infection cases (Muslim countries)

VARIABLES	(1) Infections$_{t+1}$	(2) Infections$_{t+2}$	(3) Infections$_{t+1}$	(4) Infections$_{t+2}$
Log imports	-0.006	-0.043	0.220	0.041
	(0.220)	(0.177)	(0.248)	(0.245)
Log stock		-0.564	-0.390	-0.460
		(0.338)	(0.339)	(0.315)
Log imports$_{t+1}$			-0.034	0.013
			(0.093)	(0.077)
Log imports$_{t+2}$			-0.066	0.023
			(0.041)	(0.035)
Log imports$_{t+3}$			0.009	-0.045
			(0.040)	(0.036)
Log imports$_{t+4}$			-0.030	-0.009
			(0.044)	(0.034)
Observations	8,466	7,819	4,753	4,753
KP F-stat	11.78	10.81	8.328	8.328
Importer-Product FE	✓	✓	✓	✓
Importer-Month/Year FE	✓	✓	✓	✓

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable: log of infections. Robust standard errors clustered by country in parentheses.

D Reduced form estimations for mechanisms

In columns (2)-(6) of Table 4 the first stage correlations become weak when we introduce the interaction terms to capture the supply chain characteristics through which the livestock imports may affect livestock infections. To address this concern, in Table A-3 we estimate the reduced form correlations that correspond to columns (2) to (6) of Table 4.[32] Consistently with the IV results of Table 4, the interaction terms are statistically not different from zero except for the mechanism that accounts for the destination characteristics. We therefore rule out that the absence of a correlation between the interaction terms in columns (2)-(5) in Table 4 is due to a weak instrument problem.

[32]In Table A-3, columns are numbered starting from (2) to facilitate comparison with the corresponding columns of Table 4.

Table A-3: Mechanisms, reduced form

Infections source	(2) Origin	(3) Origin	(4) Transit	(5) Customs	(6) Destination
$\mathbf{Z}_1$	0.312*	0.339**	0.375**	0.405***	-0.185
	(0.162)	(0.149)	(0.152)	(0.149)	(0.272)
Interaction term	0.141	0.094	-0.002	-0.053	0.714***
	(0.168)	(0.198)	(0.218)	(0.189)	(0.252)
Dummy high weighted screening partners	-0.036				
	(0.149)				
Dummy high weighted surveillance partners		-0.067			
		(0.220)			
Observations	34,833	34,833	34,833	34,833	34,833
Model	OLS	OLS	OLS	OLS	OLS
Importer-Product-Year FE	✓	✓	✓	✓	✓
Importer-Month/Year FE	✓	✓	✓	✓	✓
Product-Month/Year FE	✓	✓	✓	✓	✓

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable: log of infections. Robust standard errors clustered by country in parentheses. See notes to Table 4 for the definition of the **Interaction term** in each corresponding column.

E Robustness checks

In this section we provide a battery of robustness checks on the main results.

We begin with alternative transformations of the outcome variable, to rule out a concern with the log transformation of zeroes (after adding a constant). In column (1) of Table A-4 we use an inverse hyperbolic sine transformation (IHS) of the number of livestock infections.[33] We find a positive effect of livestock imports on animal infections, which is almost statistically significant at 10% (p-value=0.105). In column (2) we use a binary outcome which equals one if at least one livestock infection was observed in importer j in HS-category k in month t. We find a robust positive effect of livestock imports on the likelihood of an infection in the associated animals. In column (3) we exclude years preceding 2010, because in the UN Comtrade data used for monthly imports only few countries report imports before this year. The results are very similar to the baseline result of column (3) of Table 1. In column (4), we exclude Saudi Arabia from the sample, because livestock demand in the country during Eid al-Adha is highly affected by the Hajj pilgrimage. This affects the type of livestock imported since Hajj pilgrims prefer to sacrifice larger ruminants, like cattle and sheep, to donate the meat to the poor (Mtimet

[33]The IHS transformation approximates the natural logarithm while allowing to keep zero-valued observations in the estimation (MacKinnon and Magee, 1990). The estimated coefficient is however not an elasticity and therefore it is not directly comparable to the baseline coefficient.

Table A-4: Robustness checks

	(1) IHS	(2) Binary dep. var.	(3) Years ≥ 2010	(4) Excl. SAU	(5) Overid. IV
Log imports	0.305	0.119**	0.797**	0.835**	0.680**
	(0.187)	(0.055)	(0.397)	(0.397)	(0.331)
Observations	34,833	35,474	33,892	34,715	34,833
KP F-stat	9.244	8.425	8.535	8.442	6.214
Importer-Product-Year FE	✓	✓	✓	✓	✓
Importer-Month/Year FE	✓	✓	✓	✓	✓
Product-Month/Year FE	✓	✓	✓	✓	✓

Notes: *p<0.10, **p<0.05,***p<0.01. In column (1) the dependent variable is the inverse hyperbolic sine (IHS) transformation of infections. In column (2) the dependent variable is a binary measure that equals one if at least one infection case was recorded by importer j in livestock HS category k in month t. In columns (3)-(5) the dependent variable is the log of infections. In column (6) the dependent variable is the log of *human* infections. Robust standard errors clustered by country in parentheses.

et al., 2021). Results are robust to the exclusion of Saudi Arabia. In column (5), we present results with an over-identified model, where imports are instrumented both by the "halal, Eid al-Adha, preference for Islam" interaction, and by an interaction "halal, Eid al-Adha, high Muslim population".[34] The results of this over-identified model are also in line with the baseline results.[35] Finally, in estimations available upon request, we experimented with alternative clustering structures of the standard errors. Clustering at country and year/month level, or a country and sector level does not affect the significance of the coefficient estimated in the baseline model of column (3) of Table 1. Based on the results from these checks, we view our findings as robust.

[34] We use a dummy equal to one if at least 50% of the population in j was Muslim in 1990 to construct the high Muslim population variable in this interaction.

[35] If we only use an instrument where the Muslim country is defined by the religious affiliation of the majority population in 1990, the elasticity coefficient in the second stage is somewhat smaller in magnitude and less precisely estimated than the baseline IV estimate (β_2=0.51, pvalue=0.125), but still larger than the OLS estimate.

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