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Abstract

Can international trade enable transmission of infectious diseases? We consider illicit trade in live animals as a potential vector for spreading infectious animal diseases. We proxy illicit trade in live animals through asymmetry in mirror trade statistics, which has been used in the trade literature to uncover evidence on smuggling across items like antiques, cultural property, or natural resources. We collect a comprehensive dataset that covers about 130 countries and the six live animal categories in the Harmonized System (HS) over a sixteen-year period, to study the link between discrepancies in mirror trade statistics and infectious animal diseases. Our results imply that a 1% increase in illicit trade in an HS4 live animal category is associated with a 0.3% to 0.4% rise in infections. We explore the mechanisms and find that mis-classifying or under-pricing an imported species are the channels through which illicit trade impacts animal health. We also find evidence that illicit trade in live animals is associated with infections in humans. Overall, our results suggest that illicit trade in live animals is an important source of spreading infectious diseases.

Keywords

Illicit trade; Missing imports; Disease; Live animals

1 Introduction*

In 1995 an illegally imported monkey brought a deadly Ebola-like virus into the United States. While that is the premise of a popular American medical disaster movie,[1] it encapsulates a real phenomenon. For instance, illicit trade in wildlife is responsible for spreading pathogens like Avian influenza, Newcastle disease, or retroviral infections that can jump species barriers to infect wildlife, domestic animals, and human beings (Gómez and Aguirre, 2008). In Saudi Arabia, most cases of Brucellosis in sheep and cattle are reportedly due to unscreened imports from Africa (Fèvre et al., 2006). The illicit nature of such trade flows however implies that we do not have a credible estimate of the impact on local animal health, and whether policy measures can limit the spread of infectious diseases from live animals.

In this paper we take a novel approach to estimate the disease impact from illicit trade in live animals.[2] We measure illicit trade through discrepancies in mirror trade statistics that are reported by trading partner countries, a methodology that has been used to uncover evidence on smuggling of items such as antiques and cultural artifacts, mineral resources and electronics (Fisman and Wei, 2009; Vézina, 2015; Rotunno and Vézina, 2017).[3] We consider the impact of illicit trade on infection cases in animals, using previously unexplored data on animal-related diseases.[4]

We hypothesize that illicit trade in live animals is positively related to the spread of infectious animal diseases. This is likely for three reasons. First, legal imports un-

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[1]For a synopsis of the movie, entilted "Outbreak", see `https://www.rogerebert.com/reviews/outbreak-1995`.

[2]The use of economic tools to detect and quantify harm from behaviour that is not directly observable has been classified as "forensic economics" (Zitzewitz, 2012).

[3]Morgenstern (1950) and Bhagwati (1974) were the first to suggest that discrepancies in mirror trade statistics could be due to illicit transactions in international trade.

[4]As outlined later in the paper, the main focus on animal health, instead of human health, is due to the nature of available data rather than an under-appreciation of the consequences that illegal live animal trade might have for humans.

dergo standardized testing and quarantine procedures before entering the domestic market (Rappole and Hubálek, 2006). Illicit imports can circumvent testing or quarantine protocols and are hence more likely to introduce pathogens in the local environment. Second, illicit trade is carried out through practices that can enable pathogens to jump between species. For instance, wild-caught animals are bundled in consignments carrying similarly looking captive breds (Wyatt et al., 2018). The close contact between animals can enable the spread of pathogens from wild-caught to captive breds. Third, tariff and non-tariff measures might not be able to restrict illicit trade, and might even incentivize it.

We investigate the link between illicit trade and infectious animal diseases through a comprehensive dataset that covers about 130 countries and the six four-digit product categories of live animals in the Harmonized System (HS) classification of traded products, over the period from 2004 to 2019. Since illicit trade is not directly observable, we use a proxy measure which is referred as 'missing imports' in the tariff evasion literature (Fisman and Wei, 2004). We compute missing imports as the difference between the value of exports reported by all partner countries to an importing country in a given live animal product category, and the equivalent value of imports reported by the importing country from all its partner countries. Data on missing imports at the importer-HS4 product-year level are matched to data on outbreak of diseases in the importing country which are specific to species included within an HS4 product category. We carry out the matching by exploiting detailed information on approximately ninety-five thousand disease outbreaks worldwide.

The empirical analysis proceeds in several steps. We first show that missing imports are a reasonable proxy for illicit trade, using two complementary approaches. We show that missing imports in live animals are positively associated with import tariffs, which is in line with evidence that higher tariffs incentivize traders to mis-represent the consignment value (Fisman and Wei, 2004; Javorcik and Narciso, 2008; Rotunno and Vézina, 2012; Beverelli and Ticku, 2020). We further document a positive association between missing imports and the number of illegally imported live wildlife specimens that are confiscated by customs agencies. Assuming that a share of falsely declared imports are seized at customs, the positive association suggests that missing imports capture illicit trade in live animals.

We next examine the relationship between missing imports and infection cases in the associated animal species. We document a positive association between missing imports and the number of infection cases in a specification that controls for importer-product and year fixed effects, as well as accounts for importer-specific time trends which capture slowly evolving institutional change or the diffusion of disease-related knowledge. The association is also robust to controlling for missing imports in meat and animal fodder, which can spread certain infectious diseases in animals, local stock of animals, and other country-level measures of economic development, economic geography, health infrastructure, and customs quality. Our estimates imply that a 1% increase in missing imports is associated with a 0.3% to 0.4% increase in the number of infections among species that are included in a given HS4 product category.

The main challenge for causally interpreting these estimates stems from potentially omitted variables that vary within an importer-product over time. A key concern is that policy measures that restrict animal trade might be jointly correlated with illicit trade and infection cases. For example, import tariffs can affect disease outbreaks through curtailing the legal trade of live animals. However, there is also evidence that tariffs are positively correlated with missing imports (Fisman and Wei, 2004; Javorcik and Narciso, 2008; Rotunno and Vézina, 2012). Omitting import tariffs can lead to under-estimate the true effect of missing imports on infection cases. Similarly, measures to prevent the entry of infected animals into the country, through quarantine or certification requirements, or through outright import bans, can also incentivize illicit trade of live animals. Another concern is that an importing country may systematically test its local animal stock for infections in product categories where it experiences higher evasion, which can bias our estimate upwards. We collect data on different policy measures through which a country can restrict the trade of animal species or screen for infections its animal stock in a given product category, and show that the association between missing imports and infection cases is robust to controlling for the confounding policy variables.

Despite controlling for a number of country-specific time varying variables, as well as accounting for country-specific time trends, we might still omit some country-level variables that determine the relationship between missing imports and infection cases. We conduct a placebo test where we randomly assign missing imports across product categories within the same importer-year. The estimated coefficients of missing imports that are incorrectly assigned to product categories across one hundred thousand random draws converge to zero. The close to zero effect of missing imports across incorrectly assigned product categories, even when the importer-year dimension is held constant, suggests that time-varying country-level omitted variables are unlikely to drive the association between missing imports and infection cases.

We complement the series of identification checks through a case study analysis, where we use an exogenous shock that facilitated the illegal trafficking of wild animals, to assess its contribution to the spread of infectious animal diseases worldwide. Specifically, we focus on the creation of the Golden Triangle Special Economic Zone in 2007 along the international borders of Laos, Thailand and Myanmar ('GT countries'). The creation of the special economic zone bolstered the illegal trade of wildlife (OECD, 2019), for at least a few years until a coordinated international response against it. We use a difference-in-differences setting with continuous treatment, to show that countries with a higher pre-treatment exposure to missing imports in wildlife from GT countries, also recorded a higher number of animal infections in the short-term following the creation of the special economic zone.

Next we turn to the mechanisms and ask which evasionary practices in commercial trade of live animals can explain the relationship between missing imports and infection cases. Practices such as mis-classification of species and mis-declaration of consignment value are identified in the criminology literature as some of the methods through which live animal species are trafficked (Wyatt et al., 2018). Incidentally, the tariff evasion literature has developed proxies to measure evasion through mis-classification across product categories or through the under-reporting of consignment value (Fisman and Wei, 2004; Javorcik and Narciso, 2008; Rotunno and Vézina, 2012). We use these proxies and find that missing imports are associated with higher infection cases in live animal categories that are likely to be mis-classified to evade taxes. We also find evidence that missing imports are associated with higher infection cases in live animal categories where evasion can take place through under-reporting of unit prices.

In a final empirical exercise we assess whether illicit trade in live animals can impact human health through spreading zoonotic diseases. We find that missing imports are positively linked to infection cases in humans at both the intensive and the extensive margins. However, these results should be interpreted with some caution since we observe very few instances of infections spreading to humans in the dataset.

This paper makes a two-fold contribution to the literature. Our first contribution is to the economic literature on trade and health. Early empirical literature had postulated that income gains from globalization and international trade would raise global health standards (Dollar, 2001; Owen and Wu, 2007). On the contrary, human history is replete with examples of international commerce enabling the spread of communicable diseases (Harrison, 2012; Boerner and Severgnini, 2014). We know of two studies that assess contemporary trade practices and communicable diseases. Oster (2012) finds that exports facilitated the incidence of HIV in Africa. She interprets the result to suggest that higher exports increase the movement of people in the logistics sector, which facilitates transmission of disease through sexual activity. In contrast, we provide evidence that illicit practices used in trading of live animals can be directly responsible for spreading infectious diseases. Closest to our research, Borsky et al. (2020) focus on international wildlife trade and find that stringency of trade agreements decrease the number of animals traded and therefore the potential of spreading zoonotic diseases. Our analysis however shows that measures to restrict international trade of animals might not be effective in reducing disease impact which occurs through illicit trade practices.

There is also a substantial qualitative research outside economics that discusses the role of licit and illicit trade channels in spreading infectious diseases (Karesh et al., 2005; Fèvre et al., 2006; Chomel et al., 2007; Smith et al., 2012; Beltran Alcrudo et al., 2019). We are only aware of one study that quantifies the introduction of infectious diseases in the European Union via channels such as legal trade of animals and meat, illegal trade, pets, human travel, and windborne vectors (Simons et al., 2019). A concern with Simons et al. (2019) is that they use unpublished statistics of seizures from the United Kingdom's border agency to proxy illegal imports into the European Union. In contrast, our empirical analysis employs a proxy of illicit trade that has been used in the economics literature to capture smuggling across various items, and captures more precisely the link between illicit trade of animals and diseases outbreak worldwide.

Our second contribution is to develop an intersection between a growing literature on the spread of infectious diseases and the literature on illicit trade. New research in light of the COVID-19 pandemic has highlighted the role of the environment, demography, and government policies in determining its transmission (Borjas, 2020; Carleton and Meng, 2020; Chinazzi et al., 2020). Instead of focusing on a specific zoonotic disease, we consider a variety of pathogens that are known to afflict animal species, some of which can also cross over to human beings. We can therefore study the spread of infectious diseases over a longer time horizon as well as focus on a specific channel of transmission through international trade, which has important policy implications. Our work is similar in spirit to Chimeli and Soares (2017), who estimate the social cost of illicit trade in the form of escalating violence. Our work highlights that illicit trade can impose high social cost through harming animal and human health.

2 Background: infection risk from illicit live animals trade

Globalization has accelerated the trans-border movement of live animals (The Guardian, 2020). Animal species therefore face a higher threat from pathogens that can cause infectious diseases. Importing of infected live animals can lead to disease outbreaks that can be quite costly to the destination countries (Beltran Alcrudo et al., 2019). Since the mid-nineties, livestock diseases are estimated to have cost the global economy over US$ 80 billion (Karesh et al., 2005). Further, there is a risk of infecting humans who come in contact with afflicted animals.[5]

As discussed in the introduction, while both licit and illicit trade of animals can transmit diseases, illicit trade carries a higher risk of spreading infections (Beltran Alcrudo

[5] In a list of 1,415 pathogens that can affect humans, about 60% are zoonotic, i.e. they are transmitted from animal species to humans (Karesh et al., 2005). A 2012 study by the International Livestock Research Institute (ILRI, 2012) estimated that some 56 zoonoses were together responsible for around 2.5 billion cases of human illness and 2.7 million human deaths a year.

et al., 2019). Illicit trade in live animals typically occurs in the form of tax evasion in large commercial imports, import of illegal wildlife, and informal import for personal use (Beltran Alcrudo et al., 2019).

The first category involves commercial enterprises that engage in tax avoidance by entering the country through under-staffed port locations, or through deliberate falsification of cargo shipments. The falsification can occur through mis-classification of species to a similar variety, or by declaring lower values or lesser volumes. Mis-classification across species can circumvent border control measures which are introduced in anticipation of a specific infectious disease. For instance, a consignment of 'domestic chicken' that is mis-labeled as 'other live birds' may escape testing and quarantine protocols to avoid introducing a disease that affects poultry. Significant variation in tariff rates across similar looking live animals can also incentivize bundling of different species that can enable the spread of pathogens (Wyatt et al., 2018). Moreover, the falsification of consignment details can occur by declaring lower values or lesser volumes, which can reduce the chance of inspection by customs officials (Wyatt and Cao, 2015). This should especially be the case if customs officials systematically inspect consignments of a higher value with the objective of maximizing tariff revenue.[6]

The second category of illicit animal trade involves smuggling of illegal wildlife, such as of endangered animal species whose trade may be prohibited, but is highly lucrative due to their value as exotic pets or their utility in traditional medicine (Van Uhm, 2016). Common practices that involve smuggling of illegal wildlife include mis-labeling illegal wildlife as a legally traded, declaring 'wild caught animals' as 'captive-breds', and obtaining certificates from corrupt officials (Van Uhm, 2016). As in the science fiction movie cited in the introduction, there are also instances where a legal shipment of live animals is mixed with protected illegal species to avoid detection (Wyatt, 2013), which can enable transmission of pathogens across species. After entering the destination, wildlife is

[6]Even in a country with advanced customs administration like the United States, only 25% of wildlife shipments that are declared at the border are inspected (Williams and Grante, 2009). Customs officials are likely to inspect more valuable consignments to ascertain their true value, in order to maximize import tariff revenues. Under-staffing of trained officials is yet another issue. The US Fish and Wildlife Service (FWS) is in charge of monitoring or detecting illicit trade in endangered species, invasive species, or regulated wildlife. In 2006 the FWS had posted a mere 112 wildlife officials at 38 ports of entry across country. In that year about 185,000 shipments were declared across US ports (Williams and Grante, 2009).

typically sold in wet markets where it comes in contact with other domestic animals and humans.[7] The close contact with unscreened imported wildlife can pass on pathogens to native wildlife, domestic animals, and humans (Karesh et al., 2005).

Third, and finally, there are small-scale operations where animals are imported into the country through concealment in passenger luggage (Beltran Alcrudo et al., 2019). Such methods can particularly expose humans to zoonotic diseases.

The qualitative evidence presented in this section highlights the relationship between illicit trade in live animals and the spread of infectious animal diseases. The various forms of illicit imports discussed above can lead to disease outbreaks in destination countries, through eluding monitoring protocols, transmitting pathogens amongst different varieties of animal specimens, as well as through creating a close proximity between infected animals and human beings. The empirical methodology that we discuss next focuses on the evasionary practices in commercial trade of live animals, and their association with the spread of infectious animal diseases.

3 Data

We construct a dataset that covers about 130 countries and the six live 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); 0105 (poultry, fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea fowls); and 0106 (live animals not elsewhere classified). We focus on the period from 2004 to 2019, for which data on animal diseases is available. This section describes the main variables and their sources.

3.1 Animal diseases

We obtain data on animal diseases from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). The database contains daily information on the outbreak

[7]For instance in wet markets in Guangzhou, China, wildlife like civets, wild boars, hedge hogs etc. are (or used to be) sold alongside domestic dogs, cats and rabbits (Karesh et al., 2005). In fact, early evidence attributed the origin of COVID-19 to a wet market in Wuhan, China (Aguirre et al., 2020).

of thirty-two animal diseases, which is obtained from the World Organization for Animal Health (OIE) and the national health agencies. The data comprises of approximately ninety-five thousand disease outbreaks that occurred worldwide during the period from 2004 to 2019. The database records the number of animals of a species infected by a specific disease outbreak, and its consequences in terms of animal fatalities as well as the human response in the form of slaughtering infected animals. Our analysis focuses on recorded infection cases since both animal deaths and subsequent human actions are likely to be determined by country-specific institutional characteristics.

Out of the thirty-one diseases with confirmed cases in the EMPRES-i database, the OIE classifies fifteen diseases as affecting a single class of species, fourteen diseases as affecting multiple species, and two as 'other diseases' (see appendix Table A-1).[8] While it is straightforward to match diseases that affect a single species to an HS4 live animal category, it is complicated to match diseases that affect multiple species. To overcome this challenge and precisely assign diseases to an animal category k (four digit HS heading), we use descriptions of the species affected by each outbreak that are available in the raw data. The matching strategy is discussed in detail in Section A of the appendix.

All infection cases specific to live animals in HS heading k during year t are summed across all locations within each country j, which yields a dependent variable, $Infections_{jkt}$, which varies by importing country, HS heading, and year. The infection cases are aggregated at the jkt dimension to ensure consistency with trade data.[9] The dependent variable is set to zero if no cases were reported in any location of country j in HS heading k and year t.[10]

[8]One disease covered in the database, Rinderpest, is only observed in unconfirmed cases. We exclude all unconfirmed cases from the dataset to reduce measurement error. This leads to the exclusion of Rinderpest from the sample.

[9]Trade data are reported by a country each year for an HS product category. While trade data are available at a finer level than a four-digit product classification, it was only feasible to match animal diseases to the four-digit live animal categories.

[10]We present a sensitivity check in Section 5.2 relaxing the assumption that the dependent variable is set to zero if no infection cases were reported, i.e., without replacing missing values with zeros. The results are unchanged.

3.2 Illicit trade

Illicit trade in live animals is not directly observable and it has to be to measured through a proxy. We follow the literature on tariff evasion and proxy illicit trade through discrepancies in mirror trade statistics for live animals that are reported by partner countries. We compute the discrepancies, which are referred in the tariff evasion literature as 'missing imports', as the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category k in year t (X_{jkt}) and the log value of imports (augmented by one) reported by importer j from all countries (M_{jkt}):[11]

$$mi_{jkt} \equiv \ln\left(1 + X_{jkt}\right) - \ln\left(1 + M_{jkt}\right). \tag{1}$$

Trade data used to calculate 'missing imports' are obtained from UN COMTRADE and are available annually for the entire sample period.

3.3 Other variables

We collect data for a number of control variables that vary across the importer-product-year (jkt) and importer-year (jt) dimensions. Among variables that vary across the jkt dimension, we include five policy measures that can be associated with a disease outbreak. Our first measure is the Most-Favoured-Nation (MFN) tariff that is imposed by importing country j on product k in year t. We obtain tariff information from UNCTAD TRAINS and WTO IDB.[12] The second measure, 'Import ban', is a binary variable equal to one if the importing country j imposed an emergency Sanitary and Phytosanitary (SPS) measure to stop importing product k in year t from any partner country. The variable is constructed from textual analysis of WTO Integrated Trade Intelligence Portal (I-TIP) data.[13] The next three measures are, respectively, the number of precautions at the border,

[11] In a robustness exercise discussed in appendix Section F, we show that adding a small constant, rather than one, to the value of exports and imports before taking logs does not affect the results.

[12] We refer to WTO IDB if data is missing in UNCTAD TRAINS. There are gaps in coverage across countries, sectors and years. We do not attempt to fill these gaps, except in the rare cases in which, within each jk combination, two identical tariffs rates in years $t-1$ and $t+1$ respectively precede and follow a missing value in year t. In such cases, we replace the missing value with the value reported in $t-1$ and $t+1$.

[13] The WTO SPS Agreement does not require WTO members to notify every SPS measure. The general notification obligations of Annex B of the agreement apply only when an international standard, guideline or recommendation does not exist, or the content of a proposed SPS regulation is not substantially the same

the number of screening measures, and the number of surveillance measures that were issued by importer j on HS heading k in year t.[14] Border precautions are applied at the border posts to prevent introduction of a disease into the country and can range from quarantine, 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. Besides policy measures, we also collect data on the stock of animals in importer j in product category k in year t. The data are obtained from FAOSTAT.

The control variables which vary at the jt dimension include missing imports in HS chapter 02 (Meat and edible meat offal) and in HS heading 0504 (Guts, bladders and stomachs of animals other than fish), which are constructed in the same way as mi_{jkt} in equation (1), and from the same data sources as described in Section 3.2; GDP per capita in current US$ (in logs), sourced from IMF's World Economic Outlook (WEO) data, April 2021 edition; health expenditure as percentage of GDP, sourced from the World Health Organization's Global Health Expenditure database; the quality of port infrastructure, sourced from the World Economic Forum's Global Competitiveness Report; time to import (the time associated with importing a standardized cargo of goods by sea transport, calculated in calendar days), sourced from the World Bank's Doing Business Indicators, 2006-2015 methodology; and remoteness.[15]

as the content of an international standard, guideline or recommendation (in the case of animal health and zoonoses, the standards, guidelines and recommendations of reference are those developed by the OIE), and if the regulation may have a significant effect on trade of other Members. The data on import bans we collect through WTO I-TIP, therefore, do not necessarily cover all emergency SPS measures imposed by WTO members. Other non-tariff measures (NTMs) available across countries on World Bank World Integrated Trade Solution (WITS) cannot be used in this study because they are recorded only as of 2012 (2010 for the European Union).

[14]The data on border precautions, screening, and surveillance measures are obtained from the OIE. The raw data contain information both on the type of disease and on the species affected (Birds; Buffaloes; Camelidae; Cats; Cattle; Cervidae; Dogs; Equidae; Goats; Rabbits; Rabbits/hares; Sheep; Sheep/goats; Swine). The matching with HS headings is straightforward.

[15]Remoteness is computed, for country j in year t, 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 t. Data on bilateral distances are from CEPII's *GeoDist* (Mayer and Zignago, 2011), while GDP data are from IMF WEO.

A detailed description of all variables used in the empirical analysis and their sources can be found in Table A-4 in the appendix, while Table A-5 in the appendix presents the in-sample summary statistics.

4 Empirical Strategy

4.1 Baseline specification

To estimate the link between illicit import of live animals and the spread of infectious animal diseases in the destination country, we regress the sum of infection cases on the proxy for evasion in commercial import of live animals, controlling for importer-product and year fixed effects, as well as, in the most conservative specifications, country-specific linear time trends. The latter capture potential correlated trends between a disease outbreak and evasionary trade in live animals that could vary across countries.

The empirical specification takes the following form:

$$Infections_{jkt} = \beta mi_{jkt} + \gamma' \mathbf{z}_{jkt} + \lambda_{jk} + \mu_t + \omega_j t + \epsilon_{jkt}, \quad (2)$$

where $Infections_{jkt}$ and mi_{jkt} (missing imports) were defined in Section 3 above. The vector $\mathbf{z}_{jkt}$ collects control variables that vary along all dimensions of the data (policy measures and stock of animals) or within country over time (illicit import of meat products, income, economic geography and other institutional characteristics). The model also includes importer-product fixed effects (λ_{jk}) and year fixed effects (μ_t). In a more conservative specification, we also add country-specific linear time trends ($\omega_j t$).

Since the dependent variable is a count of infection cases, we estimate the model using a Poisson pseudo-maximum-likelihood estimator (PPML). The estimation technique is prefered to a log-linearized model that is estimated using Ordinary Least Squares (OLS), since the estimates can be biased under heteroskedasticity in the latter instance (Silva and Tenreyro, 2006). In addition, the PPML estimator provides a natural way to deal with zeroes in the dependent variable. Disease outbreaks can exhibit both serial and spatial auto-correlation. Therefore, we cluster standard errors at country-level and year-level to permit valid inference if errors are auto-correlated within country, as well as within years across countries (Cameron et al., 2011).[16] The coefficient of interest in equation (2) is β, which measures the elasticity of infection cases to missing imports.

4.2 Threats to identification

Omitted variables The main challenge for causal identification stems from omitted variables. The inclusion of importer-product (jk) and year (t) fixed effects implies that any confounding variable should vary within an importer-product over time. We also employ a more conservative specification, which includes importer-product and year fixed effects along with country-level linear time trends ($\omega_j t$). These trends should account for any smoothly evolving changes over time, for example, the diffusion of disease-related knowledge or changes in government policy that might jointly affect infection cases and illicit trade (Oster, 2012).[17] Another issue is that policy measures that restrict trade of live animals might be correlated with infection cases and illicit trade. For instance, import tariffs can reduce disease outbreaks through curtailing licit trade of live animals. The positive relationship between import tariffs and missing imports is also well established in the tariff evasion literature (Fisman and Wei, 2004; Javorcik and Narciso, 2008; Rotunno and Vézina, 2012). Omitting import tariffs can therefore lead to under-estimating the true effect of missing imports on new infections. Similarly, policy measures to avoid introducing a disease into the country, such as import bans or quarantine or certification requirements at the border, can incentivize illicit trade in associated animal species.[18] Next, countries might implement behind-the-border measures such as screening (i.e. testing) and surveillance (i.e. continuous investigation), in anticipation of or in response to illicit trade, for example when border controls are ineffective at curbing such trade, or even encourage it. Enhanced screening or surveillance is also likely to be correlated with in-

[16] In a robustness exercise discussed in appendix Section F, we cluster standard errors at the country level for inference if errors are only auto-correlated within country.

[17] For example, a government might engage in trade facilitation reforms that reduce trade costs while better managing trade risks. Trade facilitation reforms affect traders' incentives to engage in illicit trade practices, and could be a source of omitted variable bias which is controlled for by country-specific time trends.

[18] Vézina (2015) provides evidence that trade barriers such as bans or taxes are associated with illegal trade in natural resources.

fection cases. We investigate whether confounding policy variables, that vary within an importer-product over time, might drive the relationship between missing imports and infection cases.

Measurement issues Another concern is about the measurement of illicit trade. First, missing imports may be estimated with a measurement error. Discrepancy in the values of mirror trade statistics can arise as exports are recorded in free on board (FOB) terms, while imports are calculated including the cost of insurance and freight (CIF). It is reasonable to think that the systematic components of such discrepancy are absorbed by fixed effects, and therefore are not correlated with the errors. For instance, freight and insurance cost may systematically differ across animal categories, within or across countries. Such systematic differences are accounted for by importer-product fixed effects.[19] In appendix Section G, we also conduct a robustness check where we exclude observations where reported exports from all partner countries are smaller than imports reported by the importing country, which is likely to occur because imports are inclusive of insurance and freight costs (CIF).

One may also wonder whether missing imports is at all a good proxy for illicit trade in live animals. In defense of our approach, there is evidence that discrepancies in mirror trade statistics capture illicit trade in a diverse set of items, such as antiques, timber and mineral products (Fisman and Wei, 2009; Vézina, 2015). In addition, we conduct empirical tests to assess whether missing imports capture illicit trade in live animals. First, we look at the association between missing imports and import tariffs. The tariff evasion literature suggests that higher tariffs incentivize importers to mis-represent the consignment value to evade taxes (Fisman and Wei, 2004). A positive correlation between missing imports and import tariffs would suggest that missing imports is a suitable proxy for illicit trade in live animals. Second, we collect country-level data on the number of illegally imported live animal specimens that were confiscated by customs authorities.[20] These specimens are confiscated on account of distorted paperwork or concealing contraband live animals

[19]Country-specific time trends, included in some estimations, further account for the systematic variation in missing imports within country, for instance due to gradual reforms affecting the logistics sector.

[20]The data are obtained from the CITES Trade Database. CITES is the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

in the shipments (D'Cruze and Macdonald, 2016). Assuming that a proportion of illicit imports are seized by custom authorities, a positive association between missing imports – aggregated across all live animal categories within each country and year – and the number of seizures would give further credence that missing imports capture illicit trade in live animals.

Reverse causality The final challenge for causal identification is potential reverse causality, specifically if infection cases affect illicit trade. A disease outbreak can potentially reduce demand for the associated imported products. For instance, the demand for imported beef in South Korea fell by 47% in value between 2003 and 2004, following the reporting of Bovine spongiform encephalopathy or 'mad cow disease' in December 2003 (Giamalva, 2013). While the import demand recovered in subsequent years, it did not reach the 2003 levels even by the end of the decade (Giamalva, 2013). The theory on tariff evasion suggests that the benefit from mis-representing consignment value is a positive function of the size of imports (Yang, 2008; Javorcik and Narciso, 2017).[21] In results reported in appendix Table A-6, we find a negative association between licit imports and infection cases, which we interpret as evidence that the latter reduces import demand. A disease outbreak is likely to reduce missing imports in associated animal specimen through its negative impact on import demand. This reverse causality feedback would lead to under-estimate the elasticity of new infection cases to missing imports, implying that our estimates are a lower bound of the true effect.

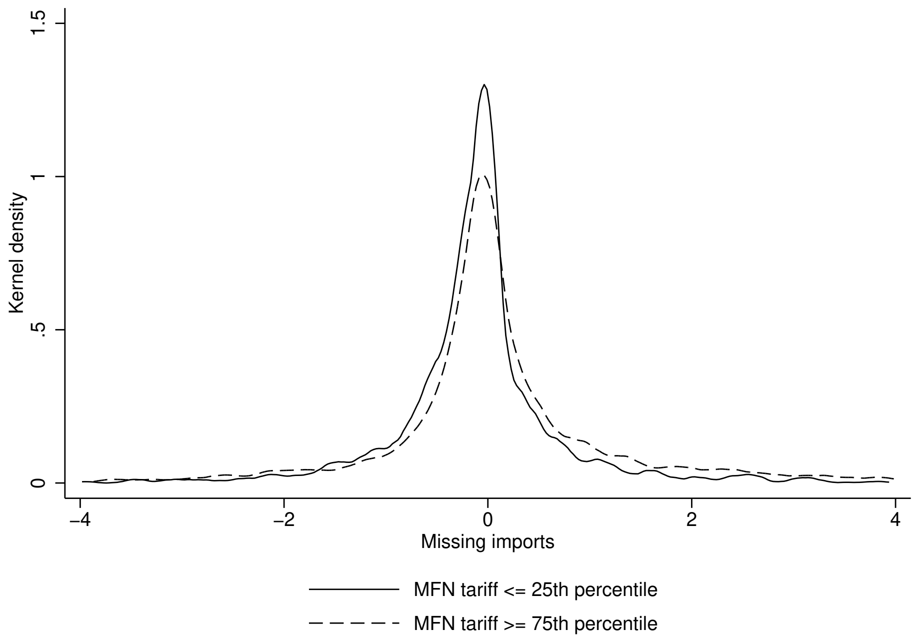
5 Results

5.1 Missing imports as a proxy for illicit trade in live animals

Before estimating the relationship between missing imports and infection cases, we assess whether missing imports is a suitable proxy for illicit trade in live animals. Figure 1 graphically illustrates the relationship between missing imports and import tariffs. The

[21] According to Yang (2008) the net benefit from evasion is the difference between the value of tariff evaded from smuggling and the cost of evasion. The value of tariff evaded itself is increasing in the smuggling rate, the tariff rate, and the size of imports.

Figure 1: Import tariffs and illicit trade in live animals



Notes: For exposition clarity, the Kernel densities of missing imports are shown for values of missing imports between the 1st and the 98th percentile (respectively, -4 and 4). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. MFN tariff is the Most-Favoured-Nation tariff imposed by importing country j on live animal category (HS heading) k in year t, sourced from UNCTAD TRAINS and (in case of missing information) from WTO IDB. See Section 3 and online appendix Table A-4 for detailed variables' description.

right-skew in the distribution of missing imports at high tariff rates suggests that imports are systematically under-reported in comparison to exports when tariffs are high.

This relationship is confirmed in column (1) of appendix Table A-7, which estimates the effect of MFN tariffs on missing imports by OLS. This specification controls for importer, HS4 product, and year fixed effects. The effect is statistically significant at 5% level. The point estimate implies that a one percentage-point increase in tariff rate is associated with a 0.12% increase in missing imports. The estimated tariff semi-elasticity of missing imports in live animals is comparable to but slightly smaller in magnitude than tariff semi-elasticities estimated in recent studies covering a large set of countries and an exhaustive list of product categories.[22] In column (2) we estimate the relationship between missing imports and the number of confiscated animal specimens using a PPML

[22] Beverelli and Ticku (2020) estimate a tariff semi-elasticity of 0.2 to 0.3% in a sample that includes over 120 countries and around 5000 HS6 product categories during the years 2012, 2015 and 2017. Bussy (2020) estimates a tariff semi-elasticity of 0.16% in a sample that spans 197 countries and around 5000 HS6 product categories during the years 1988-2017.

specification, where we control for importer and year fixed effects.[23] The coefficient is positive and statistically significant at 5% level. The point estimate implies that a 1% increase in missing imports is associated with a 1.6% increase in the number of confiscated animal specimens. Overall, the results in Figure 1 and appendix Table A-7 suggest that missing imports is a suitable measure for illicit trade in live animals.

5.2 Missing imports and infection cases

Baseline results Column (1) of Table 1 reports the association between missing imports and infection cases, after controlling for importer-product and year fixed effects. The effect is positive and statistically significant at 1% level. The point estimate implies that a 1% increase in missing imports is associated with a 0.4% increase in the number of infection cases. In column (2), we additionally include country-specific linear time trends to control for slowly evolving country-specific omitted variables such as trade liberalization or diffusion of disease-related knowledge. The magnitude is slightly reduced to 0.27 and the effect is statistically significant at 10% level. Overall, Table 1 highlights a robust positive association between our measure of illicit imports and infection cases in the destination country.

Tables A-8 to A-10 in the appendix present results which correspond to the specification in column (1) of Table 1, but include additional control variables. In appendix Table A-8 we control for missing imports in meat products (HS code 02) and meat products that are generally used as animal fodder (HS code 0504). These estimations address the concern that communicable diseases such as Bovine spongiform encephalopathy ('mad cow disease') may be caused by contaminated animal fodder. In appendix Table A-9 we introduce a number of country-level variables capturing the level of economic development, the quality of health services, and customs characteristics, which could be correlated with missing imports and with the number of infections cases. Finally, in appendix Table A-10 we control for the stock of animals in an HS4 category that is available in a country in a given year. These estimations addresses the concern that import demand can be cor-

[23] We calculate missing imports in unit quantities rather than in values as the confiscation variable is measured in number of units instead of consignment value.

Table 1: Baseline estimations

	(1)	(2)
Missing imports	0.395***	0.266*
	(0.135)	(0.147)
Importer-specific time trend	no	yes
No. of importers	136	136
Years included	2004-2019	2004-2019
Observations	6,021	6,021

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in column (1); importer-HS heading (jk), year (t), and importer-specific time trend ($j \times$ time trend) included in column (2). HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and appendix Table A-4 for detailed variables' description.

related with local animal stock, which in turn may determine the number of infection cases. Moreover, we control for a country's remoteness to international trade, which can simultaneously impact illicit trade and the introduction of infectious animal diseases.[24] As shown in appendix Tables A-8 to A-10, the coefficient of interest β is robust to the inclusion of these confounding variables, and its magnitude ranges between 0.34 to 0.47, which is remarkably similar to the baseline estimate.

Sensitivity checks We test whether the main result in column (1) of Table 1 is sensitive to alternative model and data specifications. The results are presented in appendix Tables A-11 and A-12. In column (1) of appendix Table A-11 we cluster standard errors at the country level for inference if errors are only auto-correlated within country. The standard error is similar to the one reported in the baseline specification. In column (2) we estimate the main effect after excluding years 2004 and 2019 respectively. This is necessitated for two reasons. In 2004 the number of new infections is about six times larger than the sample average. The high number of cases is mainly driven by the outbreak of

[24]A country's remoteness can be related to missing imports in two ways. First, in remote countries it might just be costlier to evade using alternative entry routes. Second, trading in live animals is likely to experience high iceberg costs, which can explain the discrepancies in mirror trade statistics. Remoteness is also likely linked to infection cases, although the sign of the relationship is ambiguous ex ante. On the one hand, remote countries can be protected from the introduction of virulent pathogens. On the other hand, local animal species might be more susceptible to the introduction of new pathogens. For a discussion of the ambiguous links between a country's exposure to international mobility and expected harm from epidemics, see Clemens and Ginn (2020).

the 'mad cow disease' in December 2003. Similarly, in 2019 the missing imports data are only available for 39 countries. We exclude 2004 and 2019 to ensure that the results are not driven by these outlier years. Results presented in column (2) of appendix Table A-11 confirm that our results are robust to excluding these years. In column (3) we use a more conservative version of the dependent variable, without any replacement of missing values with zeros. Although this significantly reduces the number of observations, the point estimate is quite similar to the corresponding estimate in column (1) of Table 1. In column (4), we calculate missing imports by taking an inverse hyperbolic sine transformations of exports and imports. The results are robust to this alternative construction of missing imports. Finally, in column (5) we focus only on the HS categories 0101-0105, which include most of the livestock animals. The robustness of the baseline effect to the exclusion of HS category 0106 suggests that evasionary practices in the trading of livestock animals are significantly associated with infectious animal diseases.

Another sensitivity test concerns the definition of missing imports. Adding one to the log of exports and imports (see equation (1)) might be considered arbitrary. We replace this number with parameter a, and re-estimate the baseline model of column (1) of Table 1 1,000 times, using 1,000 different values of $a \in [0.01, ..., 10]$ (in steps of 0.01). The coefficient of interest (the elasticity of infections to missing imports) is positive and statistically significant in every estimation. Appendix Table A-12 reports summary statistics for the vector of estimated coefficients, and shows that both the mean and the median are similar to the coefficient estimated in column (1) of Table 1.[25] We conclude that the results are unaffected by the choice of the constant that is added to exports and imports in the definition of missing imports.

5.3 Identification issues

In Section 4.2 we argued that the main challenge for causal interpretation stems from confounding factors that vary within importer-product over time. Policy measures that control the introduction of animal diseases by restricting import of live animals might encourage evasionary practices. Furthermore, behind-the-border screening and surveil-

[25]The estimated coefficient is larger, the larger the parameter a.

lance measures might be implemented in response to, or in anticipation of, such evasionary practices at the border. These measures are also likely to impact infection cases through restricting legal trade or through improved detection. In Table 2 we control for five types of policy measures, which vary along all the three dimensions of the data, that could give rise to an omitted variable bias. In column (1) we control for the MFN tariff rate (see discussion in Section 5.1 on the correlation between tariffs and missing imports). Reassuringly, even after controlling for import tariffs, the coefficient on missing imports remains positive, statistically significant and it is very similar in magnitude to the corresponding coefficient in column (1) of Table 1. We obtain similar results in column (2) where we control for border precautions, in column (3) where we include a measure of emergency import bans, in column (4) where we control for screening measures, in column (5) where we control for surveillance measures, and in column (6) where we control for all the policy measures at the same time. Overall, these results suggest that confounding policy measures do not determine the relationship between missing imports and infection cases.

Next, we conduct a placebo test to address the concern that despite including a number of importer-specific time-varying variables, as well as accounting for importer-specific linear time trends, we may still omit country-level variables that determine the relationship between missing imports and infection cases. We randomly assign missing imports across product categories within the same importer-year and estimate a specification that corresponds to column (1) of Table 1, after excluding observations where the random assignment matches the correct assignment.

Panel (a) of Figure 2 plots the sampling distribution of the coefficient of interest, obtained from 100,000 estimations incorrectly assigning product categories while holding the country-year constant. The coefficient of interest converges to zero when we incorrectly assign product categories. Panel (b) plots the distribution of the coefficient of interest across the same set of restricted samples, when we correctly assign the product categories. The distribution with correct assignment is starkly different, and the coefficient converges to 0.25, which is closer to our baseline effect. The close to zero effect of missing imports across incorrectly assigned product categories, even when the importer-year di-

Table 2: Accounting for confounding policy measures

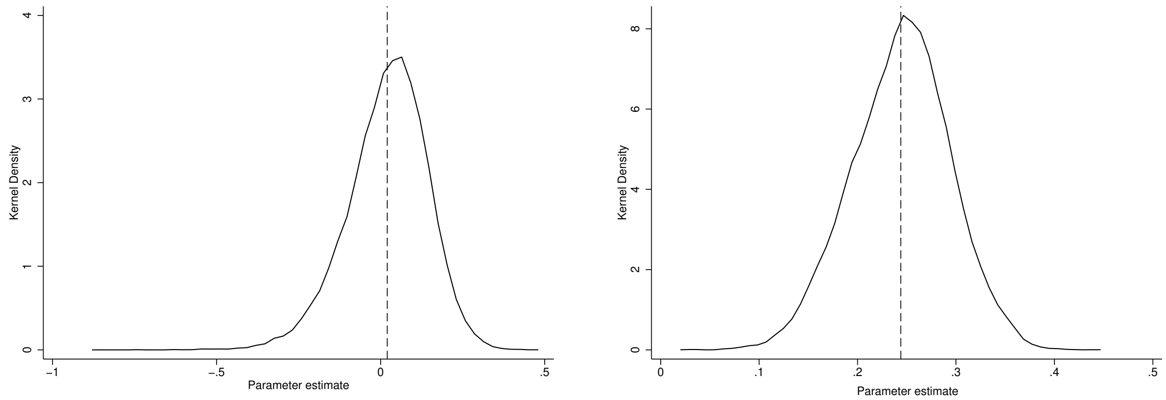
	(1)	(2)	(3)	(4)	(5)	(6)
Missing imports	0.409***	0.392***	0.379***	0.427**	0.409***	0.493**
	(0.139)	(0.130)	(0.136)	(0.175)	(0.137)	(0.196)
MFN tariff	-0.009					0.055
	(0.087)					(0.066)
Border precautions		-0.050				-0.139
		(0.083)				(0.155)
Emergency import ban			0.841			0.974
			(0.633)			(0.678)
Screening measures				0.126		0.329
				(0.128)		(0.278)
Surveillance measures					-0.067	-0.235
					(0.111)	(0.197)
No. of importers	129	136	136	136	136	129
Years included	2004-2018	2004-2019	2004-2019	2004-2019	2004-2019	2004-2018
Observations	5,102	6,021	6,021	6,021	6,021	5,102

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. MFN tariff is the Most-Favoured-Nation tariff imposed by importing country j on live animal category (HS heading) k in year t, sourced from UNCTAD TRAINS and (in case of missing information) from WTO IDB. Border precautions is the number of precautions at the border issued by importing country j on diseases affecting live animal category (HS heading) k in year t, sourced from the OIE-WAHIS database. Emergency import ban is a dummy equal to one if importing country j imposed an emergency Sanitary and Phytosanitary (SPS) measure to stop importing in live animal category (HS heading) k in year t. Screening measures is the number of diagnostic tests conducted by importing country j on diseases affecting live animal category (HS heading) k in year t, sourced from the OIE-WAHIS database. Surveillance measures is the number of continuous investigation measures implemented by importing country j on diseases affecting live animal category (HS heading) k in year t, sourced from the OIE-WAHIS database. Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in all specifications. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

mension is held constant, suggests that omitted time-varying country-level variables are unlikely to drive the relationship between missing imports and infection cases.

Next, in appendix Table A-13 we address the concern that discrepancies in mirror trade statistics can arise due to how exports and imports are respectively calculated. If imports are systematically different from exports since they also include the cost of insurance and freight (CIF), and we are merely capturing a spurious correlation, we would expect missing imports smaller than zero (i.e., exports are smaller than imports) to also be correlated with infection cases. In fact, appendix Table A-13 shows that the positive association between missing imports and infection cases is only found in the sub-sample where exports are larger than imports ($mi_{jkt} > 0$), or when imports are systematically under-reported. On the other hand, we find no association between missing imports and infection cases when exports are systematically smaller than imports ($mi_{jkt} \leq 0$). These

Figure 2: Placebo test



(a) Random assignment (b) Correct assignment

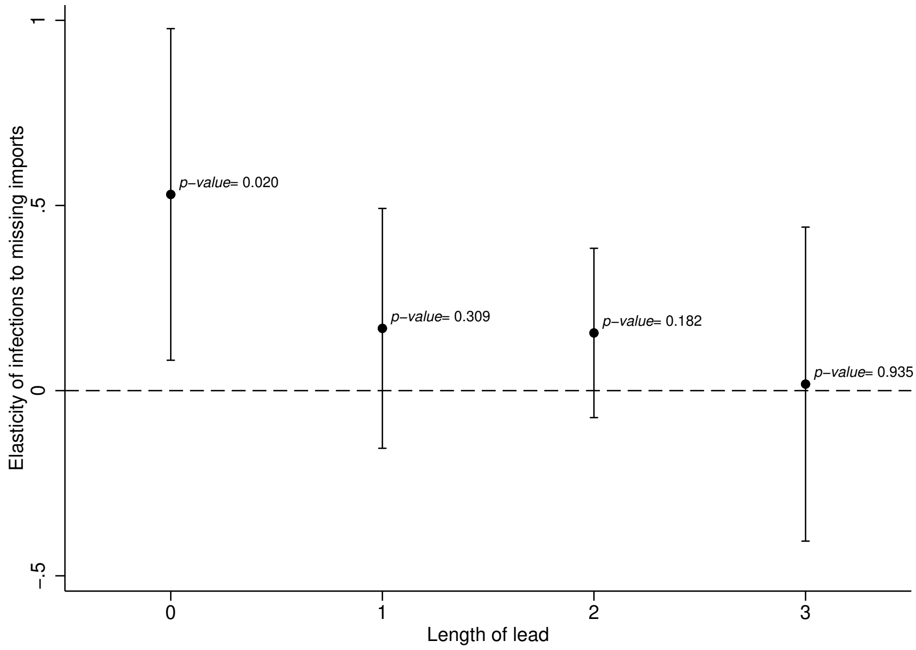
Notes: Panel (a) depicts a sampling distribution of the coefficients of missing imports from 100,000 regressions with the same specification as column (1) of Table 1, after randomly assigning missing imports across product categories k in the same importing country j and in the same year t. The coefficients are estimated after excluding observations where the random assignment matches the actual assignment. Panel (b) depicts the distribution of the coefficients of missing imports with the same specification and across the same set of restricted samples, when product categories are assigned correctly. Dashed vertical lines represent sample means. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Importer-HS heading (jk) and year (t) fixed effects included. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and appendix Table A-4 for detailed variables' description.

results suggest that we are not merely capturing a spurious correlation between discrepancies in mirror trade statistics, that arise due to how exports and imports are respectively recorded, and infection cases in live animals.

In a final check that is similar to Oster (2012), we explore the causality issue broadly to see if future missing imports drive present infection cases. If this was the case, it would indicate some omitted variables or cast reservation on the specification. We consider a specification that regresses the number of new infection cases in year t on missing imports in year t, along with missing imports in year $t+1$ to year $t+3$. Figure 3 shows the effect of contemporaneous and future missing imports on infection cases. We find that the effect of missing imports in lead years is statistically not different from zero. The contemporaneous effect of missing imports continues to be statistically significant and it is conspicuously larger in magnitude than the lead effects.

Together, the results presented in this section support a causal interpretation, i.e., an increase in missing imports in a given HS4 product category results in a higher number

Figure 3: Current and future missing imports and infection cases



Notes: Estimated coefficients from a modified version of the model in column (1) of Table 1, where in addition to missing imports in year t we also include missing imports in year $t+1$ to year $t+3$. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports in year $t+s$, $s \in [0,1,2,3]$ is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k, sourced from UN COMTRADE. Point estimates in circles. Importer-HS heading (jk) and year (t) fixed effects included. Number of importers: 121. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. Years included: 2004-2016. Observations: 3,797. See Section 3 and appendix Table A-4 for detailed variables' description.

of infection cases in related animal species.

5.4 Case study: Golden Triangle Special Economic Zone, illicit wildlife trade, and infection cases

So far we have presented a number of robustness checks to rule out a spurious relationship between missing imports and infection cases in live animals. In the following section, we use a difference-in-differences framework to support the case for a causal relationship between missing imports and infection cases. Specifically, we use an exogenous event that facilitated the illegal trafficking of wild animals in its aftermath, to assess its contribution to the spread of infectious animal diseases worldwide.

In 2007, the Golden Triangle Special Economic Zone (GT SEZ) was created on a 3,000 acre land that the Laos government leased for ninety-nine years to a casino tycoon-owned

Chinese firm (Diana, 2017). The Special Economic Zone (SEZ) is located at the international borders of Laos, Myanmar, and Thailand (see Figure A-1 in the appendix), in a region that has historically been known for trafficking of narcotics, humans, and wildlife (Environmental Investigation Agency, 2015).[26] Since its creation, the lack of transparency and legal ambiguities in the SEZ have bolstered various illicit activities including the illegal trade of wildlife (OECD, 2019), putting the GT SEZ under the spotlight as a major illegal wildlife trade hub. The animal species and their products traded in the SEZ include black bears, elephants, pangolins, rhinos, serows, tigers, and turtles (Environmental Investigation Agency, 2015; Gomez et al., 2016; WWF, 2017; Gomez and Shepherd, 2018; OECD, 2019).

Recently, environmental groups have led an effort to deter illegal wildlife trafficking from the GT SEZ. For instance, the Environmental Investigation Agency (EIA) published a report in 2015 that described the GT SEZ as an "illegal wildlife supermarket" (Environmental Investigation Agency, 2015). The investigation spurred the Laotian authorities to conduct raids on four businesses selling illegal wildlife products inside the GT SEZ.[27] In 2018 the US Treasury imposed sanctions on the casino company that operates the GT SEZ, on accounts of drug, human, and wildlife trafficking, as well as for involvement in child prostitution.[28]

We hypothesize that the creation of the GT SEZ facilitated trafficking of wildlife into and out of Laos, Myanmar, and Thailand (henceforth 'GT countries'), at least in the first few years after the SEZ's inception, before attracting global civil society's scrutiny. Therefore, countries that were exposed to higher missing imports in wildlife from GT countries would also have experienced a short-term increase in infection cases following the creation of the SEZ.

[26]The issue of illicit trade in Special Economic Zones is a general one, which recently attracted attention even in the G20. In a communique dated 22 September 2020, the G20 Trade and Investment Ministerial Meeting guarded "against the risk of illicit trade" in SEZs. In particular, France noted that "counterfeiting, money laundering, drug smuggling or even illicit practices benefiting to terrorist groups might indeed take advantage of different legislations, legal loopholes or unseen practices taking place in SEZs", and the United States "noted concern that SEZs may attract the interest of criminal actors who want to take advantage of the relaxed oversight and softened customs controls to manufacture and distribute illicit goods". See http://www.g20.utoronto.ca/2020/G20SS_Communique_TIMM_EN.pdf.

[27]A video is available at https://www.facebook.com/159023380915975/videos/485943378223972.

[28]"Treasury Sanctions the Zhao Wei Transnational Criminal Organization", US Department of the Treasury, 30 January 2018, available at https://home.treasury.gov/news/press-releases/sm0272.

Figure 4 compares the evolution of infection cases in countries with a high exposure to missing imports in HS heading 0106, which contains wildlife, from GT countries to the evolution of infection cases in low exposure countries. We consider all animal infection cases in HS chapter 01 since unscreened import of wildlife can transmit diseases to both native wildlife and domestic animals (Karesh et al., 2005).[29] The infection cases in high exposure countries are similar to those in the low exposure countries in years prior to the creation of the SEZ in 2007. From 2008 onward the high exposure countries experienced a significant increase in infection cases relative to the low exposure countries. The gap however tapers off after 2015, which is likely due to the increase in enforcement against illicit trafficking of wild animals from the SEZ.

The above discussion and the descriptive evidence from Figure 4 motivate the following difference-in-differences (DD) specification with continuous treatment, where we estimate the effect of the SEZ on infection cases in importing countries, conditional on their pre-treatment exposure to missing imports in HS heading 0106 from GT countries:

$$Infections_{jt}^{GT} = \beta Exposure_j^W \times Post_t + \lambda_j + \mu_t + \omega_j t + \epsilon_{jt}, \qquad (3)$$

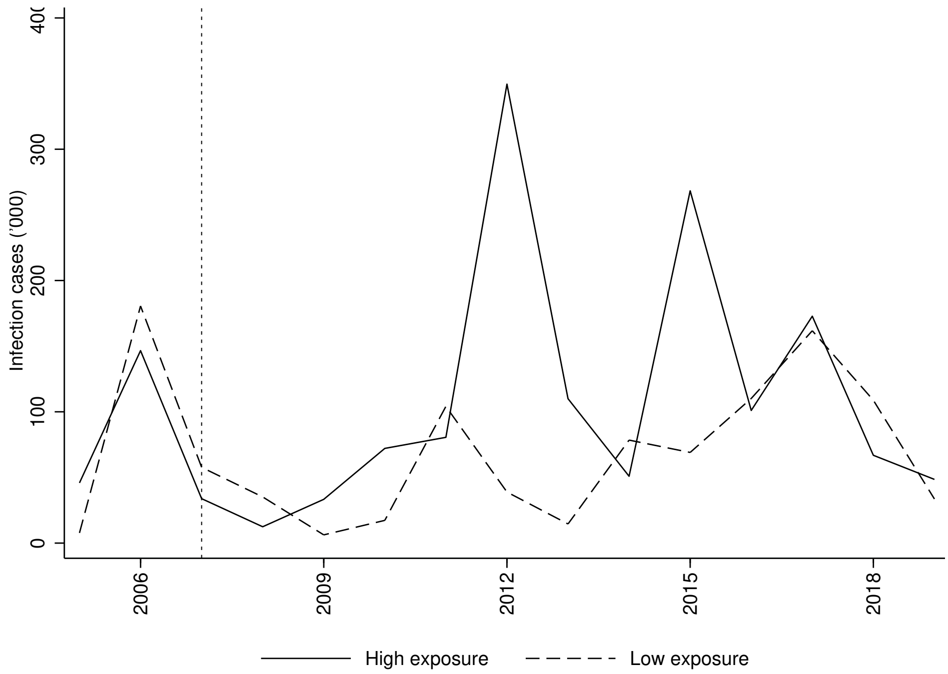
where $Infections_{jt}^{GT}$ is the count of infection cases in importer j in year t. $Exposure_j^W$ measures missing imports in HS heading 0106, which contains wildlife (therefore the W superscript), from GT countries in importer j in three years prior (2004-06) to the creation of the GT SEZ.[30] $Post_t$ is a dummy variable that equals one if $t \geq 2008$. β is the coefficient of interest that measures the increase in the number of infections following the creation of the SEZ, conditional on an importing country's prior exposure to missing imports from the GT countries.

The results from the DD specification are presented in Table 3. Columns (1), (3), and (5) report the results of estimations that include importer and year fixed effects. Columns

[29]For instance, Avian influenza that affects domestic poultry was isolated in two mountain hawk eagles that were illegally imported to Belgium from Thailand (Karesh et al., 2005). Paramyxovirus, which is a highly fatal disease for domestic poultry, entered Italy through a consignment of parrots, lovebirds, and finches that were imported from Pakistan (Karesh et al., 2005).

[30]To construct $Exposure_j^W$, we treat the three GT SEZ countries, Laos, Myanmar, and Thailand, as a unique exporter e. We then compute missing imports in importer j in year $s \in [2004, 2005, 2006]$ in HS heading 0106 as $mi_{js} \equiv \ln(1 + X_{ejs}) - \ln(1 + M_{ejs})$. We finally compute the 2004-2006 average: $Exposure_j^W \equiv (1/3)\sum_s mi_{js}$.

Figure 4: Illicit trade from GT SEZ and infection cases



Notes: The vertical line represents the year when the Golden Triangle Special Economic Zone (GT SEZ) was created, i.e. 2007. High exposure countries are those where average missing imports from the GT SEZ countries were in the top 50th percentile during the 'pre-treatment' period (2004-2006). Low exposure countries are those where missing imports from the GT SEZ countries were in the bottom 50th percentile during the same period. For exposition clarity the trend in infection cases is depicted from 2005 onwards. See Section 3 and appendix Table A-4 for detailed variables' description.

(2), (4), and (6) report the results of estimations that include importer and year fixed effects, as well as country-specific linear time trends. The inclusion of country-specific linear time trends relaxes the common trend assumption and captures potential correlated trends between infection cases and illicit animal trade.

In columns (1)-(2) we estimate the effect of GT SEZ over the period 2004-2010. This sample covers three years before and three years after the creation of the GT SEZ in 2007.[31] The significant and positive coefficient on the interaction term suggests that countries with a higher prior exposure to missing imports in wildlife recorded a higher number of animal infections in the short-term following the creation of the GT SEZ. We obtain similar results in columns (4)-(6) when we extend the sample to the period until 2013. In columns (5)-(6) we consider the entire sample until 2019. In the full sample, the magnitude on the interaction term is greatly reduced, and the effect is statistically not different from zero when country-specific linear time trends are included.[32]

[31] Note that there is no data availability before 2004 in the FAO's EMPRES-i database.

[32] We also estimated specifications that control for the number of border precautions by importing coun-

Table 3: Golden Triangle Special Economic Zone regressions

Sample	2004-2010		2004-2013		2004-2019	
	(1)	(2)	(3)	(4)	(5)	(6)
Exposure × post	0.615**	0.894*	0.913***	0.693*	1.025***	0.073
	(0.306)	(0.515)	(0.353)	(0.420)	(0.340)	(0.295)
Importer-specific time trend	no	yes	no	yes	no	yes
No. of importers	114	114	117	117	126	126
Years included	2004-2010	2004-2010	2004-2013	2004-2013	2004-2019	2004-2019
Observations	798	798	1,170	1,170	2,016	2,016

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infections in live animals (HS 01) by importing country j and year t, ($Infections_{jt}^{GT}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Exposure is computed as missing imports in HS heading 0106 vis-à-vis 'Golden Triangle' (the sum of Laos, Myanmar, and Thailand), averaged in the 'pre-treatment' period (2004-2006), by importing country j. Missing imports are the difference between the log value of exports (augmented by one) reported by 'Golden Triangle' countries (the sum of Laos, Myanmar, and Thailand) to importing country j in HS heading 0106 in year t, and the log value of imports (augmented by one) reported by importing country j from 'Golden Triangle' countries (the sum of Laos, Myanmar, and Thailand) in HS heading 0106 in year t, sourced from UN COMTRADE. Post is a dummy equal to one in the 'post-treatment' period (from 2008 onward). Standard errors clustered at the country level in parentheses. Importer (j) and year (t) fixed effects included in columns (1), (3), and (5); importer (j), year (t), and importer-specific time trend (j × time trend) included in columns (2), (4), and (6). See Section 3 and appendix Table A-4 for detailed variables' description.

Overall, these results suggests that the creation of GT SEZ contributed significantly to the rise in infection cases in countries that were relatively more exposed to illicit imports in wildlife from Laos, Myanmar, and Thailand. However, this impact was relatively short-lived, perhaps due to the fact that illegal wildlife trade passing through the GT SEZ came under close scrutiny from civil society and national governments a few years after the GT SEZ was created.

The evidence thus far is silent on the channels through which missing imports impact infection cases. In the following section we investigate which evasionary practices highlighted in the tariff evasion literature can explain the relationship between missing imports and infection cases in live animals.

6 Channels of illicit trade and infection cases

The tariff evasion literature identifies three channels through which evasion can occur. First, tariff evasion can occur through the mis-classification of products, i.e. an importer could report a higher taxed product as a lower taxed variety (Fisman and Wei, 2004).

try j in year t affecting HS heading 0106. The results, available upon request, are similar to the ones reported in Table 3.

Second, tariff evasion can occur through the under-reporting of unit prices (Javorcik and Narciso, 2008; 2017). Finally, tariff evasion can occur through the under-declaration of product quantities (Rotunno and Vézina, 2012). In this section, we investigate whether the first two among these mechanisms could drive the positive association between illicit trade and disease spread. We leave aside the third mechanism because, to measure under-declaration of product quantities, different products should be measured in different units (e.g., kilos vs. number of items) – see Beverelli and Ticku (2020). This is not possible with the data at hand, since the quantity of traded live animals, when reported, is only reported in number of items.

To test whether illicit trade increases the spread of infectious diseases through mis-classification, we adopt two complementary approaches. In a first approach, we construct the dummy variable 'High MFN tariff w.r.t. HS 01', which equals one if the MFN tariff τ_{jkt} is larger than the average tariff on live animals (HS chapter 01) applied by importer j in year t, computed excluding HS heading k.[33] Intuitively, if this dummy variable is equal to one, a trader interested in minimizing tariff payment could mis-classify live animals across categories, declaring them as belonging to headings that are taxed less at the border. The 'High MFN tariff w.r.t. live animals' dummy variable is then interacted with missing imports. A positive coefficient on the interaction term would indicate that missing imports have a larger impact on the spread of infectious diseases in cases where traders have the incentive to mis-classify across live animal categories to evade import tariffs.

A problem with the 'High MFN tariff w.r.t. HS 01' dummy is that mis-reporting across different HS headings may not be feasible, because the HS headings are quite distinct categories of animals: it may simply not be feasible to declare a horse a cow. We propose a second approach to address this issue, which relies on a comparison between the MFN tariff on HS heading $k \in [0101, 0102, 0103, 0104, 0105]$ and the MFN tariff in HS heading 0106 (live animals not elsewhere classified). The idea is that it may still be fea-

[33] For instance, the tariff imposed by the importing country on live swine (HS heading 0103) is compared to the average tariff on other HS headings in chapter 01 (0101, 0102, 0104, 0105, and 0106). If it is larger than this average, the dummy takes value one. Note that such dummy varies along all the three dimensions of the dataset.

sible to mis-report live animals in 0101, 0102, 0103, 0104, and 0105 as live animals under 0106 if the animals are similar enough. For instance, as discussed in appendix Section I, 'Guinea fowls', which are classified in HS category 0105, could be mis-classified as 'other live birds' in HS category 0106. Similarly, 'wild goats', which are classified in HS category 0104, could be mis-classified as 'antelopes' in HS category 0106. The dummy 'High MFN tariff w.r.t. HS 0106' takes value one if the MFN tariff applied on HS heading $k \in [0101, 0102, 0103, 0104, 0105]$ is larger than the MFN tariff on HS heading 0106. This dummy is interacted with missing imports. A positive coefficient on the interaction between this dummy and missing imports would indicate that missing imports have a larger impact on infectious diseases in cases where mis-classification is incentivized. The results on the mis-reporting channel are presented in columns (1) and (2) of Table 4, and provide empirical support to the hypothesis that evasion through mis-classification is responsible for higher infections.[34]

Next we assess whether evasion of live animals through under-pricing results in higher infection cases. Differentiated products are those whose prices may range widely due to difference in product quality, and hence it may be difficult for customs officials to detect under-pricing of the consignment (Javorcik and Narciso, 2017). To test the under-reporting of unit prices channel, we interact missing imports with the 'Differentiated HS heading dummy'. As detailed in appendix Section J, we exploit the Rauch (1999)'s (conservative) classification and classify HS headings 0102, 0103, and 0104 as homogeneous, and HS headings 0101, 0105, and 0106 as differentiated.[35] Results presented in column (3) of Table 4 show that the effect of the interaction term is positive and statistically significant at 1% level. This confirms that evasion through under-reporting of unit prices is responsible for higher infection cases.

[34]In column (2) of Table 4, the coefficient on the interaction term is almost significant at 10% level, with p-value=0.107.

[35]The Rauch classification is at the four-digit level of aggregation of the SITC Rev. 2 classification. Standard crosswalks, available at `http://wits.worldbank.org/product_concordance.html`, are used to concord it to the HS 2007 classification.

Table 4: Mechanisms

Mechanism	Mis-classification		Under-reporting
	(1)	(2)	(3)
Missing imports	0.163**	0.322***	-0.657**
	(0.080)	(0.093)	(0.305)
High MFN tariff w.r.t. HS 01	1.591***		
	(0.586)		
High MFN tariff w.r.t. HS 01 × Missing imports	0.514***		
	(0.187)		
High MFN tariff w.r.t. HS 0106		1.402	
		(0.880)	
High MFN tariff w.r.t. HS 0106 × Missing imports		0.196	
		(0.121)	
Differentiated HS heading × Missing imports			1.136***
			(0.351)
No. of importers	129	133	136
Years included	2004-2018	2004-2019	2004-2019
Observations	5,102	4,814	6,021

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. High MFN tariff w.r.t. HS 01 (live animals) is a dummy equal to one if the MFN tariff applied by importing country j in live animal category (HS heading) k in year t is larger than the average tariff on live animals (HS chapter 01) applied by importer j in year t, computed excluding HS heading k. High MFN tariff w.r.t. HS 0106 is a dummy equal to one if the MFN tariff applied by importing country j in year t on HS heading $k \in [0101, 0102, 0103, 0104, 0105]$ is larger than the MFN tariff applied by importing country j in year t on HS heading 0106 (Animals; live, n.e.c. in chapter 01). Tariff data are sourced from UNCTAD TRAINS and (if data are missing in that database) WTO IDB. Differentiated HS heading is a dummy equal to one if live animal category (HS heading) k is differentiated, based on the Rauch (1999)'s (conservative) classification (see appendix Section J for details). Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in all specifications. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106 in columns (1) and (3); 0101, 0102, 0103, 0104, and 0105 in column (2). See Section 3 and appendix Table A-4 for detailed variables' description.

7 Illicit trade and human health

In our final exercise, we consider the implications of illicit trade on human health through the spread of zoonotic diseases. It is well known that contact with infected animals can transmit several diseases to humans. As reported in footnote 5, a large number of pathogens that can affect humans are zoonotic, and they are responsible for many cases of human illnesses and deaths. Furthermore, there is abundant evidence that the prevalence of infectious zoonotic diseases is linked to increasing volumes of animal trafficking and smuggling (Fisman and Laupland, 2010; Aguirre et al., 2020).[36]

[36] Pangolins are a prominent example. These animals – which are known to carry parasites and bacteria with zoonotic potential (Mohapatra et al., 2016), as well as coronaviruses (Bale, 2020) – are believed to be the most heavily trafficked wild mammals in the world. It is reported that almost almost nine hundred thousand pangolins have been smuggled during the past two decades, some of them dead, peeled of scales and frozen, others live (Quammen, 2020).

In this paper, we do not focus on the link between illicit trade in live animals and human health exclusively for data related reasons. FAO's EMPRES-i includes information on the number of humans infected and on the number of human casualties due to an infectious animal disease. The crossover of infections to humans is, however, very rare in the data. Less than 1% of infection cases in animals in our dataset are reported to also infect humans.

With this caveat in mind, in Table 5 we report the effect of missing imports on humans infected at both the intensive and extensive margins, respectively using the number of human infections and a dummy equal to one if at least one human infection related to an animal disease in country j, sector k and year t was reported. In column (1) we estimate the effect at the intensive margin through PPML and find a positive and statistically significant association between missing imports and infection cases in humans. The point estimate suggests that a 1% increase in missing imports of live animals is associated with a 0.35% increase in human infections. In column (2) we estimate the effect at the extensive margin through a conditional logit model. Once more we find a positive and statistically significant association between missing imports and the likelihood of observing a human infection. These results constitute preliminary evidence that illicit imports of live animals, in addition to threatening animal biodiversity, could also endanger human health through spreading zoonotic diseases.

Table 5: Human cases

Dependent variable	Human infections	Humans infected dummy
	(1)	(2)
Missing imports	0.351*	0.437*
	(0.182)	(0.229)
Model	PPML	Conditional logit
No. of importers	44	44
Years included	2004-2019	2004-2019
Observations	813	813

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable in column (1): number of observed human infection cases by importing country *j*, live animal category (HS heading) *k* and year *t*, sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Dependent variable in column (2): dummy equal to one if there is at least one observed human infection case by importing country *j*, live animal category (HS heading) *k* and year *t*, sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country *j* in live animal category (HS heading) *k* in year *t*, and the log value of imports (augmented by one) reported by importing country *j* from all countries in live animal category (HS heading) *k* in year *t*, sourced from UN COMTRADE. Standard errors clustered at the country and year level in parentheses. Importer-HS heading (*jk*) and year (*t*) fixed effects included in all specifications. HS headings included: 0102, 0103, 0104, 0105, and 0106. See Section 3 and appendix Table A-4 for detailed variables' description.

8 Conclusions

On October 18, 2004, two live eagles smuggled from Thailand were seized at Brussels International Airport. It was found that one of the two eagles had bilateral pneumonia, caused by Highly Pathogenic Avian Influenza (HPAI) H5N1 virus. Although this might well be the first scene of a medical disaster movie, it is a realistic account of the first recorded case of H5N1 in the European Union (Van Borm et al., 2005). Luckily, a screening performed in human and avian contacts indicated no dissemination occurred. While this particular episode did not lead to any further contagion, it nonetheless suggests that illegal movements of live animals, in this case wild birds, are a major threat for the introduction of infectious diseases such as highly pathogenic avian influenza.

This paper has shown that illicit trade in live animals plays a significant role in spreading infectious diseases in animals. Using a dataset covering about 130 countries over a sixteen year period, we have shown that discrepancy in mirror trade statistics – used in the extant literature to uncover evidence of smuggling across various items – is systematically linked to spread of infectious diseases in the associated animal species. We have provided additional evidence that this relationship is likely to be driven by evasionary practices such as mis-classification or under-pricing of the imported species.

Much of the public concern about animal diseases, of course, is about the associated risks for human health. We have provided some preliminary evidence that illicit imports, in addition to threatening animal health, could also pose a risk to human health through spreading zoonotic diseases. However, currently available data used in this study cover only few of those zoonoses that are responsible for most human illness and human cases. More research is needed to quantify the impact of illicit animal trade on human health, especially in light of the COVID-19 pandemic.

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Supplement to "Illicit Trade and Infectious Diseases"

Table of Contents

A Matching animal diseases to trade data

The left column of Table A-1 lists the thirty-one animal-related diseases with confirmed cases for which we have collected data from the FAO's EMPRES-i database. The right column shows the World Organization for Animal Health (OIE)'s classification of these diseases by species affected.

The OIE classifies fifteen diseases as affecting a single class of species, fourteen diseases as affecting multiple species and two as 'other diseases'. It is straightforward to match diseases that affect a single species to an HS4 live animal category. To precisely assign diseases that affect multiple species to an animal category k (four-digit HS heading), we use the description on the species affected by each outbreak that is included in the raw FAO's EMPRES-i data.

Table A-1: Animal diseases in FAO EMPRES-i and animal species affected in OIE classification

Disease	Animal species affected (OIE classification)
African horse sickness	Equine
African swine fever	Swine
Anthrax	Multiple
Bluetongue	Multiple
Bovine spongiform encephalopathy	Cattle
Bovine tuberculosis	Multiple
Brucellosis	Multiple
Brucellosis (Brucella abortus)	Multiple
Brucellosis (Brucella melitensis)	Multiple
Brucellosis (Brucella suis)	Multiple
Classical swine fever	Swine
Contagious bovine pleuropneumonia	Cattle
Equine infectious anaemia	Equine
Foot and mouth disease	Multiple
Glanders	Equine
Hendra Virus Disease	Multiple

Continued on next page

Table A-1: Animal diseases in FAO EMPRES-i and animal species affected in OIE classification – *Continued from previous page*

Disease	Animal species affected (OIE classification)
Influenza - Avian	Avian
Influenza - Equine	Equine
Influenza - Swine	Swine
Japanese encephalitis	Multiple
Leptospirosis	Multiple
Lumpy skin disease	Cattle
MERS-CoV	*Other diseases*
Newcastle disease	Avian
Peste des petits ruminants	Sheep and goat
Porcine reproductive and respiratory syndrome	Swine
Rabies	Multiple
Rift Valley fever	Multiple
Schmallenberg	*Other diseases*
Sheep pox and goat pox	Sheep and goat
West Nile Fever	Multiple

Notes: Left column: list of diseases with confirmed cases in the FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Right column: World Organization of Animal Health (OIE)'s classification of animal diseases by species affected, sourced from OIE's 'Information on aquatic and terrestrial animal diseases'. See tab 'Type of animal' at `https://www.oie.int/en/animal-health-in-the-world/information-on-aquatic-and-terrestrial-animal-diseases/`. MERS-CoV stands for Middle East Respiratory Syndrome Coronavirus.

To provide an example, consider the case of the outbreak of Foot and mouth disease (FMD), which OIE classifies as affecting multiple species, in the Republic of Korea. According to FAO's EMPRES-i, in 2015 there were 159 reported outbreaks of FMD in the country. Out of these, Table A-2 presents the descriptions of animals affected from the 120 outbreaks (out of 159), with non-missing information on the number of animals infected. In this example, the dependent variable ($Infections_{jkt}$) in the observation in which j is the Republic of Korea, k is HS heading 0102, and t is 2015, is equal to the sum of recorded infections across the five outbreaks where the HS assigned is 0102, i.e. six (see row "Dom. cattle" in Table A-2).[37] The dependent variable ($Infections_{jkt}$) in the observation in which j is the Republic of Korea, k is HS heading 0103, and t is 2015, is equal to the

[37]For "Dom. cattle", which is concorded to HS heading 0102, recorded infections were equal to one in four instances, and two in one instance. Therefore, $Infections_{jkt}$ is equal to six, as reported in the last column of Table A-2.

Table A-2: Example of matching: 2015 FMD outbreak in the Republic of Korea

Species description	Frequency	Percent	HS assigned	Infections
"Dom. cattle"	5	4.17	0102	6
"Domestic (dom.) swine"	114	95.00	0103	85,442
"Dom. swine, dom. cattle"	1	0.83	N.A.	382
Total	120	100		

Notes: FMD stands for Foot and Mouth Disease. N.A. stands for non-assignable. Species description as reported in the FAO's EMPRES-i database.

sum of recorded infections across the 114 outbreaks where the HS assigned is 0103, i.e. 85,442 (see row "Domestic (dom.) swine" in Table A-2).[38] Notice that one event of FMD is reported to have affected both swine and cattle species (see row "Dom. swine, dom. cattle" in the table), and therefore we could not assign it to any HS heading.[39]

Table A-3 summarizes the assignment of the 94,711 disease outbreaks recorded in the FAO's EMPRES-i database to the HS4 product live animal classification. A total of 1,602 outbreaks across eight different diseases affect HS heading 0101 (horses, asses, mules and hinnies); 13,119 outbreaks across 16 diseases affect HS heading 0102 (bovine animals); 24,254 outbreaks across 13 diseases affect HS heading 0103 (swine); 11,607 outbreaks across 12 diseases affect HS heading 0104 (sheep and goats); 30,804 outbreaks across seven diseases affect HS heading 0105 (poultry, fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea fowls); and 6,980 outbreaks across 17 diseases affect HS heading 0106 (live animals not elsewhere classified). Finally, 6,345 outbreaks across 24 diseases could not be assigned to any HS heading in live animals, and therefore are excluded.[40]

Among the fifteen diseases that the OIE classifies as affecting single species (Table A-1), 94% of outbreaks are on average concentrated in only one HS4 heading according to our assignment in Table A-3 (the leading HS4 heading also aligns with the OIE classifica-

[38]For "Domestic (dom.) swine", which is concorded to HS heading 0103, recorded infections range from one to 8,639 (mean = 749.5, median = 361.5). Their sum across the 114 observations is 85,442, as reported in the last column of Table A-2.

[39]FAO's EMPRES-i only provides the total number of infection cases for each outbreak. In case when multiple species are infected, such as in the third row of Table A-2, we can not identify how many infection cases are attributable to different species. Hence, we leave out these outbreaks from our final sample.

[40]Cases in which it was not possible to assign observations from FAO's EMPRES-i to an HS heading typically involve descriptions that include two or more distinct live animal categories, as in row "Dom. swine, dom. cattle" in Table A-2.

tion of species affected). In contrast, only 59% of outbreaks, on average, are concentrated in one HS4 heading for diseases that are listed as affecting multiple species in the OIE classification in Table A-1. For these diseases, a precise matching is essential to avoid potentially large mis-classification errors.

The twin results that the majority of disease outbreaks for 'single species' diseases are concentrated in an HS4 category that aligns with the prior OIE classification, combined with a significant dispersion of disease outbreaks across HS4 categories for OIE's 'multiple species' diseases, validate our matching exercise.

Table A-3: Correspondence between animal diseases in FAO EMPRES-i and HS headings

	HS heading						
Disease	0101	0102	0103	0104	0105	0106	N.A.
African horse sickness	199	0	0	0	0	1	0
African swine fever	0	0	20,785	0	0	1	76
Anthrax	11	211	32	34	1	31	103
Bluetongue	0	4,238	1	4,108	0	15	4,283
Bovine spongiform encephalopathy	0	37	0	0	0	1	1
Bovine tuberculosis	0	9	1	0	0	0	2
Brucellosis	0	99	7	252	4	0	96
Brucellosis (Brucella abortus)	0	23	0	2	0	0	0
Brucellosis (Brucella melitensis)	0	5	0	25	0	0	10
Brucellosis (Brucella suis)	0	3	14	0	0	0	2
Classical swine fever	0	0	2,246	0	0	0	4
Contagious bovine pleuropneumonia	0	202	0	1	0	0	0
Equine infectious anaemia	142	0	0	0	0	0	45
Foot and mouth disease	0	3,118	605	382	0	23	508
Glanders	45	0	0	0	0	0	9
Hendra Virus Disease	42	0	0	0	0	0	5
Influenza - Avian	0	0	0	0	29,296	2,940	41
Influenza - Equine	682	0	0	0	0	0	4
Influenza - Swine	0	0	141	0	10	45	9
Japanese encephalitis	0	0	6	0	0	0	110
Leptospirosis	0	1	0	0	0	0	312
Lumpy skin disease	0	2,954	0	0	0	0	0
MERS-CoV	0	0	0	0	0	2,407	0
Newcastle disease	0	0	0	0	1,486	21	24
Peste des petits ruminants	0	0	0	3,100	0	6	7
Porcine reproductive and respiratory syndrome	0	0	384	0	0	0	0
Rabies	38	911	11	28	1	1,402	200
Rift Valley fever	0	171	0	372	0	21	459
Schmallenberg	0	1,136	0	2,190	0	3	8
Sheep pox and goat pox	0	0	21	1,113	0	0	0
West Nile Fever	443	1	0	0	6	63	27
Total	1,602	13,119	24,254	11,607	30,804	6,980	6,345

Notes: Left column: list of diseases with confirmed cases in the FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Other columns: authors' classification of animal diseases by live animal category (HS heading) affected, based on information from FAO's EMPRES-i and from USA Trade Online (`https://uscensus.prod.3ceonline.com/`). Each row assigns all the observations on each disease available in the FAO's EMPRES-i database to Harmonized System (HS) headings 0101-0106, or to the non-assignable (N.A.) category if there is not sufficient information to make a precise assignment. HS heading 0101 includes horses, asses, mules and hinnies; HS heading 0102 includes bovine animals; HS heading 0103 includes swine; HS heading 0104 includes sheep and goats; HS heading 0105 includes poultry, fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea fowls; HS heading 0106 includes live animals not elsewhere classified. MERS-CoV stands for Middle East Respiratory Syndrome Coronavirus.

B Variables' description and summary statistics

Table A-4: Variables' description

Variable	Description	Data source
Border precautions	Number of precautions at the border issued by importing country j on live animal category (HS heading) k in year t.	OIE WAHIS
Confiscated (qty.)	Number of imported units of live wildlife specimen which were confiscated by the customs authority in importing country j in year t.	CITES Trade Database
Declared imports	Log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t.	UN COMTRADE
Differentiated HS heading	Dummy equal to one if live animal category (HS heading) k is differentiated, based on the Rauch (1999)'s conservative classification. See Section J for details.	Rauch (1999)
Emergency import ban	Dummy equal to one if importing country j imposed an emergency Sanitary and Phytosanitary (SPS) measure to stop importing in live animal category (HS heading) k in year t.	WTO I-TIP
Exposure	Missing imports in HS heading 0106 vis-à-vis 'Golden Triangle' (the sum of Laos, Myanmar, and Thailand), averaged in the 'pre-treatment' period (2004-2006), by importing country j. Missing imports are the difference between the log value of exports (augmented by one) reported by 'Golden Triangle' countries (the sum of Laos, Myanmar, and Thailand) to importing country j in HS heading 0106 in year t, and the log value of imports (augmented by one) reported by importing country j from 'Golden Triangle' in HS heading 0106 in year t.	UN COMTRADE
GDP per capita	GDP per capita (in logs) of importing country j in year t.	IMF WEO
Health expenditure	Importing country j's health expenditure as percentage of GDP in year t.	WHO's Global Health Expenditure database
High MFN tariff w.r.t. HS 01	Dummy equal to one if the MFN tariff applied by importing country j in live animal category (HS heading) k in year t is larger than the average tariff on live animals (HS chapter 01) applied by importing country j in year t, computed excluding HS heading k.	UNCTAD TRAINS and WTO IDB
High MFN tariff w.r.t. HS 0106	Dummy equal to one if the MFN tariff applied by importing country j in year t on HS heading $k \in [0101, 0102, 0103, 0104, 0105]$ is larger than the MFN tariff applied by importing country j in year t on HS heading 0106 (Animals; live, n.e.c. in chapter 01).	– "–

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Table A-4: Variables' description – *Continued from previous page*

Variable	Description	Data source
Humans infected dummy	Dummy equal to one if there is at least one observed human infection case in importing country *j*, live animal category (HS heading) *k*, and year *t*.	FAO's EMPRES-i
Human infections	Number of observed human infection cases by importing country *j*, live animal category (HS heading) *k*, and year *t*.	– "–
Infections	Number of animals in HS heading $k \in [0101, 0102, 0103, 0104, 0105, 0106]$ infected by diseases affecting live animal category (HS heading) *k* in importing country *j* in year *t*.	– "–
$Infections^{GT}_{jt}$	Number of observed animal infections in live animals (HS 01) in importing country *j* in year *t*.	– "–
Live animal stock	Log of one plus the stock (in units) of live animals in importing country *j* in live animal category (HS heading) *k* in year *t*.	FAOSTAT
MFN tariff	Most-Favoured-Nation tariff imposed by importing country *j* on live animal category (HS heading) *k* in year *t*.	UNCTAD TRAINS and WTO IDB
Missing imports	Difference between the log value of exports (augmented by one) reported by all exporting countries to importing country *j* in live animal category (HS heading) *k* in year *t* and the log value of imports (augmented by one) reported by importing country *j* from all countries in live animal category (HS heading) *k* in year *t*.	UN COMTRADE
Missing imports in chapter 02	Constructed as missing imports, with *k* being HS chapter 02 (Meat and edible meat offal).	– "–
Missing imports in heading 0504	Constructed as Missing imports, with *k* being HS heading 0504 (Guts, bladders and stomachs of animals other than fish).	– "–
Missing imports (qty.)	Difference between the log quantity of exports (augmented by one) reported by all exporting countries to importing country *j*, summed across all live animal HS headings (0101, 0102, 0103, 0104, 0105, and 0106), in year *t* and the log quantity of imports (augmented by one) reported by importing country *j* from all countries, summed across all live animal HS headings (0101, 0102, 0103, 0104, 0105, and 0106), in year *t*.	UN COMTRADE
Post	Dummy equal to one from 2008 onward, i.e. in the 'post-treatment' period following the establishment of the Golden Triangle Special Economic Zone in 2007.	
Quality of port infrastructure	Importing country *j*'s quality of port infrastructure in year *t* (1-7 scale from extremely underdeveloped to well developed and efficient by international standards).	WEF's Global Competitiveness Report

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Table A-4: Variables' description – *Continued from previous page*

Variable	Description	Data source
Remoteness	Weighted sum of bilateral distances between importing country j and exporting country e, with weights given by e's share of world GDP in year t: $\sum_i (GDP_{it} / \sum_i GDP_{it}) Dist_{ij}$.	CEPII's *GeoDist* and IMF WEO
Screening measures	Number of 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 in all or part of the national territory, by importing country j, live animal category (HS heading) k, and year t.	OIE WAHIS
Surveillance measures	Number of measures of continuous investigation of a given population to detect the occurrence of disease for control purposes, which may involve testing a part of the population, by importing country j, live animal category (HS heading) k, and year t.	– "–
Time to import	Importing country j's time associated with importing a standardized cargo of goods by sea transport, calculated in calendar days, in year t.	WB' Doing Business Indicators

Notes: Data from the World Organisation for Animal Health's World Animal Health Information System (OIE WAHIS) database, available since 2005, were downloaded from https://wahis.oie.int. The CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Trade Database is available at https://trade.cites.org. The Rauch (1999)'s classification is available at https://econweb.ucsd.edu/~jrauch/rauch_classification.html. UN (United Nations) COMTRADE data are sourced from the World Bank's World Integrated Trade Solution (WITS): https://wits.worldbank.org/. WTO Integrated Trade Intelligence Portal (I-TIP) data for goods are available at http://i-tip.wto.org/goods. IMF WEO (International Monetary Fund's World Economic Outlook) data are sourced from the April 2021 edition, available at https://www.imf.org/en/Publications/WEO/weo-database/2021/April. The WHO (World Health Organization)'s Global Health Expenditure database, with data available until 2018, was downloaded from https://apps.who.int/nha/database/Select/Indicators/en. Integrated Database (IDB) tariff data are used in all instances of missing Trade Analysis Information System (TRAINS) tariff data. Tariff data are sourced from WITS. The FAO (Food and Agriculture Organization)'s EMPRES-i database is available at http://empres-i.fao.org/eipws3g. FAOSTAT data were downloaded from http://www.fao.org/faostat/en. Data from the WEF (World Economic Forum)'s Global Competitiveness Report, available since 2006, were downloaded from https://www.theglobaleconomy.com. The Centre d'Etudes Prospectives et d'Informations Internationales (CEPII)'s *GeoDist* database (Mayer and Zignago, 2011) is available at http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=6. The WB (World Bank)'s Doing Business Indicators, 2006-2015 methodology, were downloaded from https://www.doingbusiness.org/content/dam/doingBusiness/excel/db2020/Historical-data---COMPLETE-dataset-with-scores.xlsx.

Table A-5: In-sample descriptive statistics

Variable	Mean	Median	Std Dev	Min	Max
Border precautions	14.07	9.50	14.13	0	148
Confiscated (qty.)	5,117.07	0	75,195.57	0	2,277,120
Declared imports*	7.65	7.95	2.93	0.01	14.75
Exposure*	0.10	0	0.87	-3.17	5.09
GDP per capita*	9.26	9.35	1.32	5.50	11.70
Health expenditure	7.01	6.98	2.31	1.60	16.84
Human infections	5.59	0	41.51	0	687
Infections	5,399.32	0	117,444.60	0	7,763,979
$Infections_{jt}^{GT}$	21,260.93	0	294,372.90	0	7,763,979
Live animal stock*	14.70	14.76	2.88	0	22.57
MFN tariff	13.00	6.67	34.27	0	480.76
Missing imports*	0.13	-0.03	1.30	-8.28	9.72
Missing imports in chapter 02*	0.12	0	0.68	-2.77	8.54
Missing imports in heading 0504*	0.27	-0.01	1.08	-4.36	7.77
Missing imports (qty.)*	-0.35	0	2.30	-15.46	15.12
Quality of port infrastructure	4.38	4.30	1.09	1.20	6.80
Remoteness	7,662.98	7,021.04	1,758.67	5,471.55	13,305.44
Screening measures	4.22	2	6.12	0	48
Surveillance measures	4.48	2	6.95	0	84
Time to import	19.44	16.00	13.25	5	76
Variable	Zeros	Ones	Std Dev	Min	Max
Differentiated HS heading	2,773	3,248	0.50	0	1
Emergency import ban	4,842	260	0.22	0	1
High MFN tariff w.r.t. HS 01	3,146	1,956	0.49	0	1
High MFN tariff w.r.t. HS 0106	2,787	2,027	0.49	0	1
Humans infected dummy	662	151	0.39	0	1
Post	456	342	0.50	0	1

Notes: Variables marked with * are in logs. Descriptive statistics for Border precautions, MFN tariff, Screening Measures, Surveillance measures, and Emergency import ban computed from the sample of column (6) of Table A-10. Descriptive statistics for Confiscated (qty.) and Missing imports (qty.) computed from the sample of column (2) of Table A-7. Descriptive statistics for Declared imports computed from the sample of Table A-6. Descriptive statistics for Exposure, $Infections_{jt}^{GT}$, and Post computed from the sample of column (1) of Table 3. Descriptive statistics for GDP per capita, Health expenditure, Quality of port infrastructure, and Time to import computed from the sample of column (5) of Table A-9. Descriptive statistics for Human infections computed from the sample of column (1) of Table 5. Descriptive statistics for Infections and Missing imports computed from the sample of column (1) of Table 1. Descriptive statistics for Live animal stock and Remoteness computed from the sample of column (3) of Table 2. Descriptive statistics for Missing imports in chapter 02 and for Missing imports in heading 0504 computed from the sample of column (3) of Table A-8. Descriptive statistics for Differentiated HS heading computed from the sample of column (3) of Table 4. Descriptive statistics for High MFN tariff w.r.t. HS 01 computed from the sample of column (1) of Table 4. Descriptive statistics for High MFN tariff w.r.t. HS 0106 computed from the sample of column (2) of Table 4. Descriptive statistics for Humans infected dummy computed from the sample of column (2) of Table 5. See Section 3 and Table A-4 for variables' description.

C Licit imports and infection cases

In this section we consider the relationship between licit trade and infection cases in animals. We regress the count of infection cases on the measure of licit imports, which is the log value of imports (augmented by one) reported by importer j from all countries (M_{jkt}). Results presented in Table A-6 show a negative association between licit imports and infection cases, which is consistent with our interpretation of reverse causality, i.e., the occurrence of infection cases dampens the local demand for the associated animal species.[41]

Table A-6: Licit trade

	(1)
Declared imports	-0.361***
	(0.136)
No. of importers	136
Years included	2004-2019
Observations	6,254

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regression. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Declared imports: log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in all specifications. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

[41] We also regress infection cases on declared exports. The resulting estimate is still negative, however the effect is smaller in magnitude and it is statistically not different from zero.

D Missing imports as a proxy for illicit live animals trade

We use two empirical tests to assess whether missing imports are a suitable proxy for illicit trade. We use the intuition from the tariff evasion literature, which shows that missing imports are increasing in import tariffs. Further, we hypothesize that illicit imports should be positively correlated with the number of confiscated live animal species at the customs. Therefore, we should find a positive association between missing imports and the number of confiscated species.

Results presented in column (1) of Table A-7 shows a positive association between MFN tariff and missing imports. In column (2) of Table A-7 we find that missing imports (in number of units) are positively correlated with the number of species that are confiscated by the customs. These results justify the use of missing imports as a proxy for illicit imports of live animals.

Table A-7: Missing imports as a proxy for illicit trade

Dependent variable	Missing imports	Confiscated (qty.)
	(1)	(2)
MFN tariff	0.001**	
	(0.001)	
Missing imports (qty.)		1.578**
		(0.753)
Model	OLS	PPML
R-squared	0.206	
Years included	2004-2018	2004-2018
Observations	8,719	1,080

Notes: *p<0.10, **p<0.05,***p<0.01. Dependent variable in column (1): difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Dependent variable in column (2): number of imported units of live wildlife specimen confiscated by the customs authority in importing country j in year t, sourced from the CITES Trade Database. MFN tariff is the most favoured nation tariff imposed by importing country j on live animal category (HS heading) k in year t, sourced from UNCTAD TRAINS. Missing imports (qty.) is the difference between the log quantity of exports (augmented by one) reported by all exporting countries to importing country j, summed across all live animal HS headings (0101, 0102, 0103, 0104, 0105, and 0106), in year t, and the log quantity of imports (augmented by one) reported by importing country j from all countries, summed across all live animal HS headings (0101, 0102, 0103, 0104, 0105, and 0106), in year t, sourced from UN COMTRADE. Standard errors clustered at the country and year level in parentheses. Importer (j), HS heading (k), and year (t) fixed effects included in column (1). Importer (j) and year (t) fixed effects included in column (2). HS headings included in column (1): 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

E Including additional controls

We replicate the baseline estimation after controlling for potential confounders. In Table A-8 we control for missing imports in meat products and animals fodder, which can potentially transmit communicable diseases. In Table A-9 we control for the level of economic development and other institutional characteristics such as the quality of health services, and customs infrastructure and services. Finally, in Table A-10 we control for the stock of live animals in HS product category k, as well as the remoteness of a country. The association between missing imports and infection cases is robust to inclusion of these potential confounders.

Table A-8: Additional controls (1)

	(1)	(2)	(3)
Missing imports	0.341***	0.402***	0.335**
	(0.126)	(0.150)	(0.167)
Missing imports in HS chapter 02	0.610		1.113
	(0.544)		(1.011)
Missing imports in HS heading 0504		-0.986	-0.930*
		(0.612)	(0.513)
No. of importers	134	121	121
Years included	2004-2019	2004-2019	2004-2019
Observations	5,856	5,239	5,238

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Missing imports in HS chapter 02 are constructed as missing imports, with k being HS chapter 02 (Meat and edible meat offal). Missing imports in HS heading 0504 are constructed as missing imports, with k being HS heading 0504 (Guts, bladders and stomachs of animals other than fish). Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in all specifications. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

Table A-9: Additional controls (2)

	(1)	(2)	(3)	(4)	(5)
Missing imports	0.406***	0.470***	0.394***	0.414***	0.363**
	(0.138)	(0.149)	(0.145)	(0.072)	(0.162)
GDP per capita	-1.355				0.562
	(1.080)				(1.179)
Health expenditure		0.373**			0.807*
		(0.151)			(0.489)
Quality of port infrastructure			0.564		-0.210
			(0.541)		(0.763)
Time to import				0.151***	0.169***
				(0.051)	(0.054)
No. of importers	135	128	124	125	114
Years included	2004-2019	2004-2017	2006-2019	2006-2015	2006-2015
Observations	6,006	4,877	4,994	2,869	2,581

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. GDP per capita is the log of country j's GDP per capita in year t, sourced from IMF's World Economic Outlook data. Health expenditure is country j's health expenditure as percentage of GDP in year t, sourced from the World Health Organization's Global Health Expenditure database. Quality of port infrastructure is country j's quality of port infrastructure in year t, sourced from the World Economic Forum's Global Competitiveness Report. Time to import is country j's time associated with importing a standardized cargo of goods by sea transport, calculated in calendar days, in year t, sourced from the World Bank's Doing Business Indicators, 2006-2015 methodology. Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in all specifications. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

Table A-10: Additional controls (3)

	(1)	(2)	(3)
Missing imports	0.373**	0.390***	0.369**
	(0.147)	(0.144)	(0.153)
Live animal stock	-1.046		-1.485
	(1.262)		(1.364)
Remoteness		0.002*	0.003*
		(0.001)	(0.001)
No. of importers	134	136	134
Years included	2004-2019	2004-2019	2004-2019
Observations	5,787	6,021	5,787

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Live animal stock is the log of one plus the stock of live animals in importing country j in live animal category (HS heading) k in year t, sourced from FAOSTAT. Remoteness is the weighted sum of bilateral distances between importing country j and exporting country e (sourced from CEPII's *GeoDist* database – see Mayer and Zignago, 2011), with weights given by e's share of world GDP in year t (sourced from IMF WEO): $Remoteness_{jt} \equiv \sum_i (GDP_{it} / \sum_i GDP_{it}) Dist_{ij}$. Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in all specifications. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

F Sensitivity checks

We assess if the baseline result is sensitive to alternative model and data specifications. The results are summarized in Table A-11. In column (1) we cluster standard errors at the country-level instead of clustering them at the country- and year- level. In column (2) we exclude years 2004 and 2019 from the sample. This is due to the fact that the number of infections in 2004 was unusually large compared to the sample average, which in turn was driven by outbreak of the 'mad cow disease'. We exclude 2019 since in this year the missing imports data was only available for 39 out of approximately 130 countries in the sample. In column (3), we set the dependent variable to missing, instead of zero, if no infection case was recorded for a *jkt* observation. In column (4), we use an alternative construction of missing imports where we take an inverse hyperbolic sine transformation of exports and imports for treating zeroes in the trade data. Finally, in column (5) we exclude HS category 0106, which predominantly includes wild animals. We do this to test if the results are primarily driven by the link between wildlife and infectious diseases. The baseline results are robust to these sensitivity checks.

Table A-11: Sensitivity checks

Sensitivity check	Country-clustered standard errors	Excluding outlier years (2004, 2019)	No zeros' replacement in dep. var.	Inverse hyperbolic sine	Excluding HS 0106
	(1)	(2)	(3)	(4)	(5)
Missing imports	0.395***	0.363***	0.439***	0.383***	0.405***
	(0.137)	(0.132)	(0.107)	(0.134)	(0.135)
No. of importers	136	134	123	136	133
Years included	2004-2019	2005-2018	2004-2019	2004-2019	2004-2019
Observations	6,021	5,249	1,750	6,021	4,814

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports in columns (1)-(3) and (5): difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Missing imports in column (4): difference between the inverse hyperbolic sine transformations of exports and imports: $\ln\left(X + \sqrt{X^2+1}\right) - \ln\left(M + \sqrt{M^2+1}\right)$, sourced from UN COMTRADE. Standard errors clustered at country and year level in parentheses. Country-HS heading and year fixed effects included in all specifications. Years included: 2004-2019 (columns (1), (3)-(5)); 2006-2015 (column (2)). HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106 (columns (1)-(5); 0101, 0102, 0103, 0104, and 0105 (column (5)). See Section 3 and Table A-4 for detailed variables' description.

Another sensitivity test concerns the definition of missing imports. We estimated 1,000 versions of the baseline model of column (1) of Table 1, each with a different parameter $a \in [0.01, ..., 10]$ that is added (instead of adding one) to imports and exports in the definition of missing imports (see equation (1)). Table A-12 reports summary statistics for the vector of estimated coefficients. Both the mean and the median are almost identical to the baseline results, which are therefore unaffected by the choice of the constant that is added to exports and imports in the definition of missing imports.

Table A-12: Alternative definition of missing imports

	Observations	Mean	Median	Std. Dev.	Min	Max
$\widehat{\beta}$	1000	0.42	0.42	0.02	0.37	0.44

Notes: Summary statistics on the vector of coefficients estimated in 1,000 replications of the model of column (1) of Table 1, where missing imports are defined as the difference between the log value of exports (augmented by a constant a) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by a) reported by importing country j from all countries in live animal category (HS heading) k in year t – i.e. $mi_{jkt} \equiv \ln\left(a + X_{jkt}\right) - \ln\left(a + M_{jkt}\right)$ – sourced from UN COMTRADE. The constant a takes values between 0.01 and 10, in steps of 0.01. PPML regressions. The coefficient β is significant in all 1,000 regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

G Additional identification test: sub-sample analysis

We test if we are capturing a spurious relationship between discrepancies in mirror trade statistics, that arise due to imports being recorded inclusive of the cost of insurance and freight (CIF), and infection cases. This would imply that we find an association between missing imports and infection cases when missing imports are smaller than zero (i.e., when recorded imports are systematically larger than corresponding exports). Column (2) of Table A-13 however shows that there is no association between missing imports and infection cases when missing imports are smaller than zero. In fact, column (1) shows that the positive association between missing imports and infection cases is specific to the sub-sample where imports are systematically under-reported compared to the exports, or when missing imports are positive.

Table A-13: Sub-sample analysis

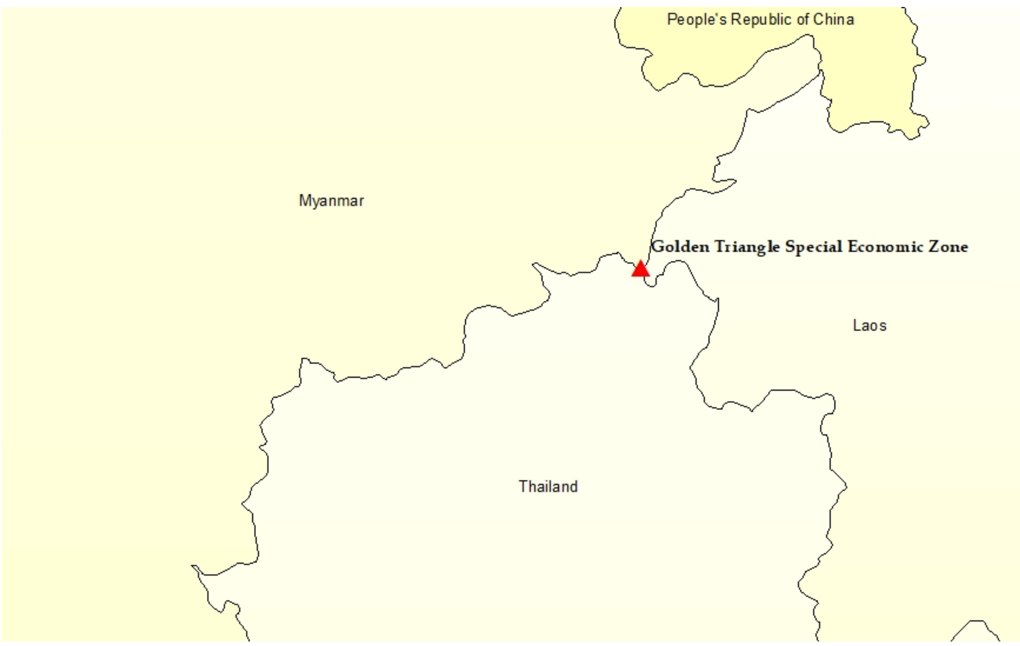
Sub-sample	Missing imports > 0	Missing imports ≤ 0
	(1)	(2)
Missing imports	0.800***	-0.262
	(0.234)	(1.336)
No. of importers	112	117
Years included	2004-2019	2004-2019
Observations	2,313	2,901

Notes: *p<0.10, **p<0.05,***p<0.01. PPML regressions. Dependent variable: number of observed animal infection cases by importing country j, live animal category (HS heading) k and year t ($Infections_{jkt}$), sourced from FAO's EMPRES Global Animal Disease Information System (EMPRES-i). Missing imports is the difference between the log value of exports (augmented by one) reported by all exporting countries to importing country j in live animal category (HS heading) k in year t, and the log value of imports (augmented by one) reported by importing country j from all countries in live animal category (HS heading) k in year t, sourced from UN COMTRADE. Standard errors clustered at the country and year level in parentheses. Importer-HS heading (jk) and year (t) fixed effects included in all specifications. HS headings included: 0101, 0102, 0103, 0104, 0105, and 0106. See Section 3 and Table A-4 for detailed variables' description.

H Golden Triangle Special Economic Zone

Figure A-1 shows the location of the Golden Triangle Special Economic Zone (GT SEZ) along the international boundaries of Laos, Myanmar, and Thailand.

Figure A-1: Spatial map of GT SEZ



I Examples of potential mis-classification

We argue that the mis-classification of a higher taxed animal to a similar-looking lower-taxed variety can enable the spread of infectious diseases. In Figure A-2 we provide two examples of animals that can be mis-classified across product categories. For example, 'wild goat' in Panel (a), which is classified in HS category 0104, can be mis-classified as an antelope, which would be included in HS category 0106. Similarly, 'Guinea fowls' in Panel (b), that are included in HS category 0105, can be mis-classified as 'other live birds' in HS category 0106.

Figure A-2: Examples of potential mis-classification

(a) Wild goat antelope

(b) Guinea fowl

J Rauch classification of live animals

This section details the assignment of the 'differentiated' dummy to HS headings, based on the conservative version of Rauch's (1999) classification.

HS headings 0101 and 0106 are unambiguously 'differentiated' (being coded as such by Rauch). HS headings 0102, 0103, and 0104 are unambiguously 'homogeneous' (being coded as 'goods traded on an organized exchange' by Rauch). Concerning HS heading 0105, six-digit products containing live poultry weighting less than 185 grams (sub-headings 010511, 010512, and 010519 in the 2007 HS classification) are coded as 'differentiated', while six-digit products containing live poultry weighting more than 185 grams (sub-headings 010594 and 010599 in the 2007 HS classification) are coded as 'goods traded on an organized exchange'. The choice to treat HS heading 0105 as 'differentiated' was made based on the trade-weighted average of the ones associated to differentiated live poultry and the zeros associated to homogeneous live poultry (weights were computed using COMTRADE data on world trade in live poultry, averaged between 2007 and 2019).[42] Since the trade-weighted average (0.6) is closer to one than to zero, we treat HS heading 0105 as 'differentiated'.

[42]2007 is the first year in which trade data are reported following the HS 2007 classification.

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