# Global Animal Protein Trade Impacts of Largescale Human Health Events

*By Mary Lynn Marks[1], Jada M. Thompson[2]\*, Sreedhar Upendram[3], and T. Edward Yu[4]*

**Abstract**

The emergence of largescale global human health events is expected to increase with evolving zoonotic and transboundary diseases, climate change, agricultural consolidation, increased globalization, and reliance on trade. The government and market response to a disease is dependent on the size of the outbreak, pathogenicity and virulence of the disease, and the perceived risks of its introduction and spread. The impact of largescale human disease events and their respective institutional response can lead to financial and market disruptions and effect nearly every industrial sector and market, including animal protein trade. The latest human disease event, the COVID-19 (SARS-CoV-2) pandemic, continues to be the largest, most expansive disease event in the last century. The COVID-19 pandemic has had sizeable implications domestically and internationally. Labor shortages and supply chain disruptions coupled with demand changes and disease eradication policies substantially impacted global markets. Despite the emergent literature on COVID-19, little has been done to collectively identify and analyze the effects of largescale human health events on animal protein trade. Using export trade data from 2010-2020 for animal protein exporters, this analysis estimates the effects human health events (i.e., MERS-Cov, COVID-19, Ebola, and Zika virus) on global animal protein trade for 23 individual commodities (6-digit HS level). Results show heterogeneity between diseases, products, and exporters. This heterogeneity indicates differences in response between events, dependent on event size, scope, and impacts. The study results can help improve preemptive business continuity planning and deepen the understanding of the implications of future emerging largescale health events on the meat industry.

**Introduction**

The incidence of largescale global human health events is expected to increase with emergent zoonotic and transboundary diseases, climate change, agricultural consolidation, increased globalization, and reliance on trade. Government and market response to a disease is dependent on the size of the outbreak, pathogenicity and virulence of the disease, and the perceived risks of its introduction and spread. The impact of largescale human disease events and their respective institutional response can lead to financial and market disruptions and affect nearly every industrial sector and market, including animal protein trade. The latest human disease event, the COVID-19

[1] Department of Agricultural and Resource Economics, University of Tennessee-Knoxville

[2] Department of Agricultural Economics and Agribusiness, University of Arkansas, Fayetteville, AR, USA;

\*Corresponding Author: University of Arkansas, 479-575-2323, jt074@uark.edu

[3] Assistant Professor, Department of Agricultural and Resource Economics, University of Tennessee-Knoxville

[4] Professor, Department of Agricultural and Resource Economics, University of Tennessee-Knoxville

(SARS-CoV-2) pandemic, continues to be the largest and most expansive disease event of the last century with sizeable implications domestically and internationally. Labor shortages and supply chain disruptions coupled with demand changes and disease eradication policies triggered by the pandemic substantially impacted global markets.

Despite the considerable consequences of the largescale human disease events, little has been done to collectively identify and analyze the effects of largescale human health events on animal protein trade. Using export trade data for the last decade for animal protein exporters, this analysis estimates the effects recent human health events (i.e., MERS-Cov, COVID-19, Ebola, and Zika virus) had on global animal protein trade for 47 individual commodities (6-digit Harmonized System (HS) level). The results provide animal protein and allied industries a better understanding of the economic implications of supply chain disruptions related to human health events. This study seeks to expand this existing knowledge by evaluating recent human health events to support a more comprehensive understanding of the risks to supply chains arising from disruptive disease events.

**Background**

Increased globalization, zoonotic diseases affecting specific regions, and diversity in protein demand have created expansive and competitive global animal protein commerce. The value of total world protein exports in 2019 were approximately $134 billion, led by the United States, Brazil, and Australia (United Nations 2021). Beef, pork, and poultry represented the majority of protein traded with a combined $111 billion value (United Nations 2021). The interconnectedness of these markets creates value risks in the supply chain, where disruptions have multinational and multidimensional effects.

The effects on the supply chain from disruptions in production, transportation, and logistics related to human disease events in a country may be exacerbated by the global trade effect. Trade partners could suspend trade until the exporter is declared disease-free using the World Organization for Animal Health (OIE) standards or by other trade governing bodies. Even when a disease is not generally transmitting to humans. For example, the U.S. outbreak of highly pathogenic avian influenza (HPAI) from 2014 to 2015 led to 45 trading partners imposing import restrictions on U.S. poultry but had very few zoonotic cases in the US (Thompson et al. 2020). These bans stem from the risk of disease spread and are compounded when the disease is transboundary and zoonotic (spread between animals and humans, or vice versa). Emergence of a degenerative cattle disease Bovine Spongiform Encephalopathy (BSE) and its human equivalent Creutzfeldt-Jacob disease led to mass animal depopulation, supply disruptions, and trade restrictions for the United Kingdom in 1996 (Henson and Mazzocchi 2002). Similarly, the U.S. reported a single BSE-confirmed case in bovine in 2003, 53 countries banned U.S. cattle and beef exports with estimated losses over $3 billion despite no zoonotic spread (Pendell et al. 2010). BSE's severe effects identify the risk-averse policies importing countries adopt to preserve their domestic animal health and consumer food safety based on perceptions of disease spread, zoonosis, and acceptable risks.

Largescale communicable human health events also cause changes in risk perception and can lead to rapid response to reduce disease transmission. Specifically pandemics, as defined by high human morbidity and mortality rates over large geographical areas, have substantial impacts on public health and markets (Madhav et al. 2017). Emerging diseases with the potential for widespread

transmission and losses have historically been zoonotic, furthering the impacts of disease livestock on international trade (Madhav et al. 2017). The 2009 H1N1 event, commonly referred to as Swine Flu, had widespread transmission and affected commodity markets (Gatherer 2009; Attavanich, McCarl, and Bessler 2011). While several studies have analyzed animal diseases' effects on protein trade and mass human health events respectively, few have analyzed human health events' impacts on international meat exports. Those that have focused predominantly on the meat industry and trade in relation to the COVID-19 global pandemic due to its size and sprawling effects. Some of these studies have focused on COVID-19's supply chain disruptions (Weersink et al. 2021; Maples et al. 2021) and trade impacts (Zhang 2020; Mallory 2021).

Some of the supply chain effects are related to the multidimensional impacts of a disease event related to changes in demand preferences, labor supply, storage, transportation, and the effects of these disruptions in production, processing, and marketing. Hayes et al. (2021) analyzed the COVID-19 outbreak's effects on the U.S. pork, turkey, and egg markets and determined both supply and demand were highly impacted. However, the effects were not homogeneous. For example, prices associated with restaurant and school consumption (e.g. turkey and breaker eggs) decreased resulting from COVID-19, while products associated with at-home use price surged (e.g. pork and shell eggs) (Hayes et al. 2021). Similarly, McEwan et al. (2020) similarly found volatile initial outbreak demand led to surging hog prices, but were expected to fall after market stabilization and production disruptions were addressed.

Supply chains at risk, lead to a need to address the effect of a realized event and build resilience. In this case, resilience as understanding of not only identifying the effects of an event and the weak points in the system but also in the adaptability of the supply chain in an evolving situation (Stone and Rahimifard 2018; Scholten, Stevenson, and van Donk 2020). Identification of the effects and resiliency have emerged in the literature for select events (Hobbs 2021a; 2021b; Chenarides, Manfredo, and Richards 2021) but more is needed to fully understand the impacts of a disease event across the meat supply chain and help provide information to help adapt in the event of a disease outbreak.

**Methodology**

International trade depends on economic and political factors. In addition to relative comparative production efficiencies, international trade is dependent on trust related to outcomes of the transactions as well as acknowledging potential trade disruptions. These trade disruptions may not be captured fully by price and may include supply chain issues, geopolitical impacts, and risk perceptions. Risk exists on both the importer and exporter side of international trade, whether in political, financial, or unforeseen risk (Bhogal and Trivedi 2008). This risk is especially present in agricultural products when considering disease spread possibilities. Threats exist at both the importer and exporter level, with countries considered to be disease-free due to biosecurity practices and standards affecting international trade levels (Shanafelt and Perrings 2017). This concept includes the threat and perception of spread as well as the event.

To conceptualize the incorporation of perceived trade disruptions (including disease risk) in trade, a formal definition of trade can be described by Equation 1:

$$U_t^R(P, X_i, Z_j, d) > U_t^A(P, X_i, Z_j, d) \qquad (1)$$

where trade will only occur when the utility of trade to an importer ($R$) in time $t$, dependent on price ($P$), importer characteristics ($X_i$), exporter characteristic ($Z_j$), and any market disruptions ($d$) are greater than the utility derived from autarky ($A$). In this analysis, the disruptions captured would be associated with potential disease spread during a global pandemic and their supply chain impacts.

To determine the effect of a human health event on the value exported, a time series panel regression is estimated on the logged value of trade using Equation 2:

$$lnTrade_{i,t}^k = \beta_1 + \beta_{n|n \neq 1}(Disease_{i,t} \times Type_{i,t}) + \lambda lnShare_{k,i,t-1} + \theta Reporter_{i,t} + \delta Type_{i,t} + \psi Months_t + \gamma Year_t + \varepsilon_{i,t} \qquad (2)$$

where the transformed value of trade exported from exporter $i$ in time $t$ for commodity $k$ is a function of the individual human health events (*Disease*) and meat product state (*Type*), the logged natural logarithm of exporters' share (*Share*) of the total commodity trade of protein $k$ at time *t-1*, and fixed effects for the animal protein exporter (*Exporter*) and time (*Month* and *Year*). $\varepsilon_{i,t}$ represents the error term, $\beta$, $\lambda$, $\theta$, $\gamma$, $\psi$, and $\delta$ represent estimated coefficients. *Share* represent the exporters importance in that protein market and may capture some effects related to trade persistence based on habit formation that may influence trade restriction decisions. *Share* variables are lagged to address endogeneity. The *Type* variable characterizes the commodity's export state (*Fresh*, *Frozen*, *Other*[5]). The regression will be estimated for each $k$ protein– *Beef*, *Poultry*, *Swine*, *Other*[6]. The time series panel regression models are estimated in Stata (StataCorp 2019) accounting for serial correlation and estimated with robust standard errors to account for heterogeneity.

**Data**
Monthly value of trade was collected from the UN Comtrade database from 2010 to 2020. The data include monthly countries' export values (in US dollars) of six-digit UN Harmonized System (HS) commodity codes for all products in the 0201, 0202, 0203, 0204, and 0207 commodities to provide the most granular data, while remaining consistent across trading partners (United Nations 2017). In total 47 codes were analyzed.

While there are many countries that export, given excess supply or high international demand, this analysis primarily focused on consistent meat exporting countries. To limit this study to countries that consistently export meat products, exporters were limited to those that accounted for more than 1% of global protein trade at the two-digit HS level for the study period (Table 1). There are 23 exporters included in the analysis based on the trading criteria.

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[5] The type *Other* indicates the six-digit HS code not specifying fresh or frozen. This only occurs in the *Other* protein model and is characterized as *Other Other.*

[6] The protein commodity *Other* represents the animal proteins analyzed not including beef, swine, or poultry. In this study, this is sheep and goat meat products.

Non-endemic diseases[7] were studied based on criteria that 1) the event covered multiple months and 2) cases reported on at least two continents (Table 2). The pandemics include Ebola, MERS-Cov, Zika, and COVID-19. While the H1N1 event was an important global disease, data from the pandemic period are not available for the selected exporters. Expanded data would solve this omission and improve future studies. Rather than use the official event dates as reported by the World Health Organization (WHO) or Center for Disease Control (CDC) which list from detection until full control, the pandemic periods where trade may be impacted were recorded based on a measure of the global importance of the disease. These event periods were estimated using Google Trend data to account for news and searches for the disease. This allows a refinement of the recorded, affected months where the disease had its highest relevance in the general population globally. Using WHO and CDC dates as general guidelines to inform date parameters, diseases were recorded as a binary variable if the Google Trend index was higher than 40[8], which indicated the global importance of the disease in that period (Equation 3).

$$Disease_{j,t} = \begin{cases} 1 \ if \ GTrend_t > 40 \\ \quad 0 \ otherwise \end{cases} \tag{3}$$

To maintain contiguous disease periods where appropriate, an exception to this rule was created where a low index rate occurring between months that meet the criteria was recorded as a one. In other words, index rates below 40 but between event-level months were considered a low segment of a disease event and therefore recorded as a disease period. For example, the index for MERS-Cov was 65 in July 2013, 29 in August, 19 in September, and 42 in October. All months were recorded as a MERS-Cov disease period and part of the same event.

To account for heterogeneity between animal proteins, individual binary variables were created for the four overarching protein commodity categories. These allow for trade impacts to be protein specific. To account for an exporter's contribution to the global market in a specified period, indicators for exporters share of the market is calculated for each commodity annually at the 4-digit HS level and expressed in Equation 4 as:

$$lnShareP_{i,year} = ln(\frac{Trade_{i,year}^P}{\sum_i^n Trade_{i,year}^P}) \tag{4}$$

where $P$ represents the 4-digit HS commodity codes: 0201 and 0202 for *Beef Shares*, 0203 for *Swine Shares*, 0204 for *Other Shares*, and 0207 for *Poultry Shares*. Variables accounting for general seasonal effects and time (month and year) are included in the model. Select data are summarized in Table 3.

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[7] This study will not include *endemic* diseases—those already present, common, and reoccurring in the area, as the effects of an endemic disease would already be absorbed into the market.
[8] The 40 threshold was used as it was a natural break in the Google Trend index during known disease dates. Other values were used to test the sensitivity to this analysis and the results were robust.

**Results**

Results for all four protein trade models are presented in Table 4. The effects represent the average trade response between exporters and include any market substitutionary effects in destination markets. Fixed effects for exporters are not included in this table for brevity, but full results are available upon request.

*COVID-19 Results*

The COVID-19 pandemic emerged globally with the highest global infection count impacting labor supply, transportation, production, and consumption at an unprecedented level. Animal protein trade was impacted by these disruptions both as direct effects of trade restrictions imposed to reduce disease spread but also in indirect effects on trade related to reduced production and supply chain blockages. These effects are evident in the significant changes in trade during the COVID-19 period compared to non-disease event periods. There was an estimated average 28.82% reduction in the value of *Fresh Beef* trade, 26.66% in *Fresh Poultry*, 38.12% in *Frozen Poultry*, and 14.79% in *Frozen Other* products. These impacts are consistent with the nascent literature on COVID-19 and the *a priori* expectations and that the disease led to reductions in the value of trade across meat exporters.

Contrarily there was an exception to the substantial decline in trade value across exporters. *Frozen Swine* trade which increased in trade value during the period (by an estimated 44.77%). This could be driven by several factors. Frozen products have longer shelf lives, are able to travel further distances, and may have better food safety for long distance trade than fresh products. Exporting countries that increased trade may not have been affected or perceived as affected by the respective importers, and therefore may have been thought of as safer to import, thus increasing trade. Additionally, the concurrent African Swine Fever animal health event in key importing countries (e.g., China) may, in part, have led to increased demand despite COVID-19. Assuming this strong demand, these results may reflect the changing global price for the products, such that an exporter able to move product would have done so at a premium price.

*Zika Results*

Similar to COVID-19, the Zika virus pandemic led to a reduction in trade value for animal protein products compared to non-disease periods. *Fresh Beef* decreased by 5.82%, *Fresh Poultry* 12.19%, and *Frozen Other* 20.55%. These trade disruptions had a stronger exporter-specific effect than COVID-19's impacts, with the Zika outbreak affecting Brazil and the US, two large poultry, bovine, sheep, and goat exporters (Waggoner and Pinsky 2016; United Nations 2021). Zika may have more subdued impacts on the supply chain directly, not driven by bottlenecks in transportation but rather impacts on human health. The emergence of Zika which is less relatively virulent than other pandemics may have affected trade market perceptions. It had the second highest infection counts, but many products were not significantly impacted, which may reflect the difference between a pandemic with mass mortalities compared to morbidities. The trading partners that limited movements of products related to Zika may have done so as a precaution to mitigate the risk of moving infected mosquitos, the primary transmission agent.

*MERS-Cov and Ebola Results*

Both the MERS-Cov and Ebola outbreaks, the first two in the dataset, had minimal impact on trade values compared to the other events. These events were also limited in infection cases and typically were found in notable animal protein exporters. *Frozen Poultry* and *Frozen Other* products were significantly impacted during the Ebola pandemic (13.88% and 23.37%, respectively), with increased value of trade compared to non-disease trade. There were no significant differences in disease to non-disease trade periods for the MERS-Cov pandemic. These results likely indicate that the countries impacted did not substantially affect the movement of products or any changes in imports was compensated in destination switching. In terms of the supply chain, the lack of outbreaks in notable exporters may have contributed to the limited effects of these events.

*Additional Factors*

Additional factors were accounted for to capture trade creation and restriction parameters. Briefly, these include exporter-specific effects, temporal effects, and product effects. Product shares (along with *Exporter* fixed effects) are exporter-specific effects which help explain heterogeneity in trade values across exporters. These behave in expected ways, with increases in own product lagged shares lead to increase in trade value, e.g., an increase in global beef exports (*Beef Shares*) by 1% leads to a 58% change in trade value. The only significant cross share impact was *Poultry Shares* positive effect on *Other* products, which likely relates to the nature of animal protein mixes by exporters. Temporal effects were also significant showing seasonal effects in protein trade.

**Conclusion**

Future large-scale human health events are inevitable. Research indicates the emergence and reemergence of transboundary and zoonotic diseases will continue to intensify. This intensification compounded with increased global food supply dependence will continue to create risks in the value of food production and marketing and for costs to consumers stemming from supply chain disruptions, lost sales revenues, and possible reduced access to inputs and transportation. In terms of trade, there are additional layers of geopolitics and varying importer risk perceptions which can also impact the value of food trade.

The effects of largescale human health events are significant on animal protein trade. However, results indicate that these effects are heterogenous across proteins and product type, which is important to understand how to adapt during an event, such as shifting focus to alternative export products or markets more quickly. The relative intensity of trade disruption relates to the severity of the disease and its impacts on human and animal health, labor, production, processing, transportation, and markets. The literature on agricultural impacts of pandemics have focused on COVID-19 but are consistent with the outcomes from this study. Preparing for these events in building multilateral trade relationships and addressing supply chain pressure points may help exporters face the challenges in evolving international trade during an event. This may help reduce bottlenecks in moving products to markets, allow for expedited reviews between partners, or reduce the geographic scope of trade restrictions related to agreed biosecurity protocols, aiding business continuity in the supply chain. Future work could expand on the scope of disease and countries studied and address limitations of available data.

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**Table 1: Global Meat Exporters With More Than 1% of Trade Shares from 2010-2020**

| Country | Total Trade Value (US $) | % of World Trade |
|---|---|---|
| USA | $231,913,177,113 | 14.60% |
| Brazil | $200,208,608,857 | 12.60% |
| Netherlands | $149,058,295,926 | 9.38% |
| Germany | $140,325,552,043 | 8.83% |
| Australia | $132,367,722,962 | 8.33% |
| Denmark | $82,362,079,322 | 5.19% |
| Canada | $81,564,368,024 | 5.14% |
| Spain | $79,526,910,644 | 5.01% |
| France | $74,160,817,259 | 4.67% |
| New Zealand | $74,041,685,052 | 4.66% |
| Belgium | $68,314,870,874 | 4.30% |
| Poland | $56,286,544,108 | 3.54% |
| Ireland | $52,220,003,080 | 3.29% |
| India | $43,313,138,310 | 2.73% |
| Italy | $38,196,052,609 | 2.40% |
| United Kingdom | $32,530,448,511 | 2.05% |
| Argentina | $31,510,773,054 | 1.98% |
| Uruguay | $23,424,429,775 | 1.47% |
| Austria | $20,948,711,089 | 1.32% |
| Hungary | $19,033,579,887 | 1.20% |
| Mexico | $17,595,666,547 | 1.11% |
| China | $17,199,552,600 | 1.08% |

*Source: (UN Comtrade 2021)*

**Table 2: Summary of Global Human Health Pandemics Studied, 2010-2020**

| Pandemic | Continents Affected | Estimated Infections[1] | Event Periods in Data |
|---|---|---|---|
| COVID-19 | Asia, Africa, North America, South America, Europe, Australia | 460,280,168[2] | Mar-Dec 2020 |
| Zika | North America, South America | 707,133 | Feb-Sept 2016 |
| Ebola | Africa, North America, Europe | 28,652 | Aug-Oct 2014 |
| MERS-Cov | Asia, Africa, North America, Europe | 2,519 | Jun-Oct 2013 |

[1] *Infection rates are provided for context. The data are not available by period and are not included in the analysis.*

[2] *COVID-19 infection counts as of March 2022.*

*Source: (WHO 2021; da Costa, Moreli, and Saivish 2020; Ikejezie 2017; CDC 2020)*

**Table 3: Summary Statistics for Animal Protein Trade Analysis 2010-2020**

| Variable | Unit | Obs. | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| Trade Value | Millions USD | 75,724 | 13.28 | 39.73 | 0.00 | 680.52 |
| Beef Share | Trade Share | 75,724 | 0.04 | 0.04 | 0.00 | 0.16 |
| Swine Share | Trade Share | 75,161 | 0.05 | 0.05 | 0.00 | 0.18 |
| Other Share | Trade Share | 74,915 | 0.05 | 0.10 | 0.00 | 0.43 |
| Poultry Share | Trade Share | 75,485 | 0.04 | 0.05 | 0.00 | 0.28 |
| COVID-19 | 1 if Disease Present; 0 Otherwise | 75,724 | 0.07 | 0.25 | 0 | 1 |
| MERS-Cov | 1 if Disease Present; 0 Otherwise | 75,724 | 0.05 | 0.21 | 0 | 1 |
| Ebola | 1 if Disease Present; 0 Otherwise | 75,724 | 0.02 | 0.15 | 0 | 1 |
| Zika | 1 if Disease Present; 0 Otherwise | 75,724 | 0.06 | 0.24 | 0 | 1 |
| Fresh | 1 if Product Fresh; 0 Otherwise | 75,852 | 0.48 | 0.50 | 0 | 1 |
| Frozen | 1 if Product Frozen; 0 Otherwise | 75,852 | 0.50 | 0.50 | 0 | 1 |
| Other | 1 if Product Other; 0 Otherwise | 75,852 | 0.02 | 0.15 | 0 | 1 |

**Table 4: Select Estimated and Transformed Elasticities for the Effects of Human Health Events on Meat Trade by Protein, 2010-2020**

| | Beef | Swine | Poultry | Other |
|---|---|---|---|---|
| *COVID-19* | | | | |
| Fresh | -28.82***(0.07) | -5.82 (0.09) | -26.66***(0.08) | -12.19 (0.12) |
| Frozen | -2.96 (0.13) | 44.77**(0.15) | -38.12***(0.07) | -22.12*(0.13) |
| Other | | | | -14.79 (0.32) |
| *Zika* | | | | |
| Fresh | -5.82*(0.03) | 1.01 (0.07) | -12.19* (0.07) | -10.42(0.10) |
| Frozen | -6.76 (0.10) | -2.96 (0.08) | -6.76 (0.05) | -20.55***(0.08) |
| Other | | | | -11.31(0.12) |
| *MERS-Cov* | | | | |
| Fresh | 0.00 (0.03) | 2.02 (0.06) | -4.88 (0.06) | 4.08 (0.08) |
| Frozen | 4.08 (0.07) | -10.42 (0.08) | 3.05 (0.06) | 1.01 (0.09) |
| Other | | | | -25.17 (0.27) |
| *Ebola* | | | | |
| Fresh | 2.02 (0.06) | 2.02 (0.06) | -3.92 (0.07) | 5.13 (0.10) |
| Frozen | 7.25 (0.11) | -1.00 (0.08) | 13.88*(0.07) | 23.37**(0.10) |
| Other | | | | 11.63 (0.20) |
| *Protein Commodity Shares* | | | | |
| Beef Share | 58.00***(0.18) | 18.00 (0.15) | -4.00 (.08) | 6.00 (0.11) |
| Swine Share | 13.00 (0.07) | 58.00***(0.11) | 4.00 (.08) | 0.00 (0.05) |
| Other Share | 3.00 (0.04) | -7.00(0.04) | -2.00 (.03) | 37.00***(0.13) |
| Poultry Share | 12.00 (0.09) | -4.00 (0.09) | 77.00***(0.16) | 32.00*(0.18) |
| *Product Type* | | | | |
| Frozen | -83.80***(0.51) | -53.70*(0.40) | 716.62***(0.40) | 8.33 (0.32) |
| Other | | | | -58.52**(0.40) |
| Observations | 13,453 | 13,236 | 30,563 | 17,016 |

*Standard errors in parentheses; * p<0.1; ** p<0.05; *** p<0.01; Exporter and time (Year and Month) fixed effects are excluded for brevity, for full results contact corresponding author.*