The Effects of Airspace Closures on Trade in the Aftermath of Eyjafjallajökull

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Abstract

Over one half of the world's GDP is transported across international borders. Given these extraordinary levels of trade integration, we might conjecture that shocks to transportation networks could pose significant risks to economies. However, assessing the effects of these shocks on trade volumes is difficult, because measures of the size of the transportation network are correlated with innovations in the trade equation. This paper attempts to quantify the effects of a temporary disruption to the air transportation network on trade volumes using the natural experiment provided by the eruption of Iceland's Eyjafjallajökull volcano in 2010. Ash from that eruption forced cancellations to roughly one half of all flights originating and/or terminating in Europe between April 15 and April 22. The immediate effect of this was to lower the volume of US-bound air freight by between 10.9% and 21.8%. Data on Japanese imports reveal similarly sized reductions (between 11.9% and 27.5%) in air freight bound for the Japanese market. By contrast, sea freight was not impacted either positively or negatively by the volcano. The implied elasticities of imports with respect to flight cancellations are between -0.218 and -0.436 for U.S. imports, while that of Japanese imports is slightly larger, ranging between -0.238 and -0.550.

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1. Introduction

If the metric is the volume of trade, the world is more globalized today than at any other time in history (Taylor, 2002). In 2012, the value of merchandise trade was roughly $18 trillion (WTO, 2013)—just under a third of the world's GDP. This compares to a ratio closer to 20 percent during the last era of globalization prior to the outbreak of World War I (Taylor, 2002). Although there are a number factors that can account for the extraordinary level of trade integration today, the rapid growth of transportation networks facilitated by technological advances and declining costs, is certainly amongst the more pertinent explanations. The expansion of the worldwide air transportation network in particular, has been linked to the sharp growth in trade volumes in the post World War II era (Hummels, 2007). While causality from transportation to trade may be suspected, identifying this relationship is difficult, as it is feasible that the direction of causality runs the other way: from higher trade volumes to increased investment in transportation.

One identification strategy is to exploit the variation within data that accompanies occasional disruptions to the transportation network. Some of these disruptions stem from naturally occurring events, as such their occurrences are purely random. This provides opportunities for assessing the effects of disruptions to transportation on trade. For instance, Volpe Martincus and Blyde (2013) used the Chilean earthquake in 2010 to identify the effect of a rise in domestic transportation costs on export volumes, and Ye and Abe (2012) considered the impact on global supply chains of the Great Tohoku earthquake and tsunami off the coast of Tohoku in 2011 and the flooding along the Mekong and Chao Phraya basin in Thailand also in 2011.

Although the randomness of natural disasters provides a "handle" for facilitating structural inferences within data, there may be a number of confounding effects, for which we cannot adequately control. In particular, natural disasters are often accompanied by widespread damage and dislocation which can affect trade through other channels. Hurricane Katrina is a case in point. Although the storm provided an exogenous shock to the transportation network, the physical damage was not so confined. As a result production (and trade) fell independently of any effects that were a direct consequence of the shock to transportation, making it difficult to isolate that structural link.[1]

[1] The devastation caused to the Port of New Orleans, which was closed for seven months, as well as bridges, roads, and other transportation undoubtedly impacted the flow of trade through the Gulf states. However, the post-Katrina decline in trade was not wholly, or even necessarily primarily, the result of the diminished transportation infrastructure. Output losses, stemming from the

This paper attempts to identify the impact on trade of a disruption to transportation, specifically one that affects civil aviation, using a natural experiment that is relatively free of these confounding influences. Our analysis centers on the eruption of the Eyjafjallajökull volcano in Iceland in 2010, which caused intermittent disruptions to air traffic for a two month period. This event is interesting in that the disruption, though extensive, was confined to the air transportation network, and was not associated with physical infrastructure damage and therefore less susceptible to the types of confounding influences evident in many disaster-centric studies.

A mitigation of confounding factors, facilitated through an absence of physical damage, is rare, though admittedly, not unique, to the eruption of Eyjafjallajökull. There have been other volcanic eruptions that have disrupted air travel, with minor or negligible consequence for physical capital and infrastructure. At the same time, non-natural disruptions, such as those caused by strikes and labor disputes, have also impacted transportation networks, without any associated physical damage. However, what makes Eyjafjallajökull unique, is that the disruption was both unexpected *and* extensive in its impact. Thus while the shock to air traffic caused by the eruption of Grímsvötn in 2011, another Icelandic volcano, which erupted just a year after Eyjafjallajökull, was certainly unexpected, it's impact was relatively small--in total 900 scheduled flights were canceled. The size of the shock was certainly too small to have a meaningful impact on trade flows. A far more significant shock to the air transportation network, occurred during the Professional Air traffic Controllers (PATCO) strike in August 1981--all together 26,000 flights were cancelled between August 3 and August 8.[2] However, since the PATCO strike was not unexpected, exporters and importers had some scope to adjust the scheduling of shipments, which in turn complicates the exercise of identifying the impact of that disruption to air traffic on trade.

By contrast the eruption of Eyjafjallajökull, like most volcanoes, was largely unpredictable leaving little time for advanced planning.[3] Moreover, the magnitude of the shock was significant. During its most disruptive phase, from April 15 to April 22, Eyjafjallajökull forced closures of much of European airspace, resulting in 107,000 flight-cancellations affecting 10 million passengers. The unpredictability of the eruption, combined with the magnitude of

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temporary stops in the production and refinement of petroleum, as well as other disruptions, affected the volume of exports and imports of oil and other internationally-traded commodities and goods and services.

[2] FLRA decision: Case no 3-CO-105.

[3] A search of the *New York Times* archive reveals that the first about the volcano were published on April 15, 2010 after closures of European airspace were already in effect.

the shock, and the lack of physical damage, are the bases for a "clean" natural experiment from which we can identify the effect of the disruption to the air transportation network on trade.[4]

To this end, we use product-level data, observed at a monthly frequency, disaggregated by mode of transportation. In particular, we use data on imports entering the US, which are available at the 10-digit HS level, as well as data on imports entering Japan, which are available at the 9-digit HS level. In both cases, data on whether merchandize entered by air or sea are available. Our focus on US and Japanese data is natural, since both countries shared strong trade links with Europe, and any decline in trade volumes triggered by the volcanic eruption would be concentrated with trading partners from that region. In March 2010 the U.S. was the top destination for the EU's non-European exports, accounting for 24% of all EU exports. Although the Japanese market for European exports was significantly smaller (4% of EU exports were imported by Japan), it was still the third largest importer of EU merchandize.[5] Moreover, the choice of Japanese data offers a number of additional advantages that follow on account of its geographic location. First, the use of Japanese data help illustrate that the closure of European airspace was complete, in the sense that it affected virtually all air routes originating in Europe, not just those routes passing close to Iceland, as all transatlantic routes between Europe and North America do. Second, since Europe is a hub for global air traffic, the disruption caused by Eyjafjallajökull reduced not only trade between the U.S. and Europe, but also between the U.S. and all countries which use Europe as a transit point for their exports to the U.S. We can observe the former effect, but not the latter one as we have no information on which U.S. imports transited through Europe. Japanese imports, on the other hand, are much less likely to be affected by such indirect transport connections. Japanese imports from the Americas are unlikely to transit through Europe as are imports from much of Asia. It is only imports from Africa which more than likely transit through Europe and those account for less than 2% of all Japanese imports. Thus, our estimates of the effect of Eyjafjallajökull's eruption on trade using Japanese import data are much less likely to be polluted by our inability to observe the indirect effect of the airspace closure.

[4] Another "natural" experiment, which was large in its impact and unexpected, but where the damage to physical capital was on a *relatively* small scale, is the terrorist attacks on September 11, 2001. However, in the aftermath of those attacks, increased uncertainty, as well as higher oil prices, were the primary influences on world output and trade rather than the disruption caused by a temporary halt of US air traffic.

[5] The second largest trading partner of the European Union is China, however high frequency product-level data for China, disaggregated by mode of transportation were not available.

We employ a difference-in-differences estimation strategy to estimate the effect of airspace closure on trade. Although it is likely that U.S. and Japanese exports (that is, European imports) were impacted by the disruption to air traffic as well, we confine our analysis to U.S and Japanese imports data only, because our identification strategy is predicated on the assumption that after controlling for time-, country-, and product-level fixed effects, the treatment group is essentially comparable to the control group. This assumption seems defensible for U.S and Japanese imports, i.e., we might expect the import of a specific product to exhibit similar trends whether that product originates in Europe (the treatment group) or elsewhere (the control group), because these trends are influenced, in large part, by the same sets of determinants, such as the level of U.S. and Japanese economic activity and prices. By contrast, the level of U.S. and Japanese exports depends on economic activity in their destination countries, which may not be similar to those in Europe, the treatment group, thus creating an identification problem when using the difference-in-differences estimator.

Our results suggest that the disruption to air travel had a significant, if uneven, effect on international trade. A 50% decline in airline traffic--roughly the number of flights cancelled between April 15 and April 22--reduced U.S. imports from affected countries by 10.9%–21.8% and Japanese imports by 11.9%–27.5%. These results suggest that the elasticity of U.S. imports with respect to cancelled flights is between -0.218 and -0.436, while that of Japanese imports is similar, between -0.238 and -0.550. Using imports from Europe shipped by sea as the control group, the effect was as large as a 51.9% reduction in U.S. imports and 47.3% reduction in Japanese imports, implying elasticities of imports with respect to cancelled flights as high as 1.038 and 0.946.

The effect of the disruption was unevenly distributed across industries as only 6 of 21 HS 2 sections show significant reductions in imports. Textiles and textile articles and Machinery and mechanical appliances, electrical equipment, television image and sound recorders and reproducers were the two import-categories showing the consistent reductions in both U.S. and Japanese data across the various subsamples we use. Additionally US imports of Base metals and Miscellaneous manufactured articles as well as Japanese imports of Pulp of wood and recovered paper were consistently negative in our various regressions. In a methodological contribution, we show that the effect of the disruption was sufficiently large to be detectable in data aggregated from thousands of products codes to just 97 chapters of the 2-digit HS classification system. The implied reduction in U.S. imports in aggregated data is between 15.4% and 17.2% and between 8.5% and 14.2% for Japanese imports. Thus, aggregated data reveal an elasticity of imports with respect to flight cancellations ranging between -0.308 and -0.350 for U.S. imports and between -0.170 and -0.284 for Japanese imports.

This paper is related to a number of recent contributions to the trade literature that rely on natural experiments to isolate the exogenous component of trade (see for instance, Feyrer, 2009 and Martincus and Blyde, 2013). However, unlike these earlier contributions to the literature, our analysis focuses on short-term disruptions that impact trade only through its effects on transportation rather than through other channels, such as declines in production levels. In addition, our paper illuminates the ability or lack thereof of the international transportation network to deal with unexpected short term disruptions. Given the short run nature of the interruption and the lack of infrastructural damage, our results could be interpreted as establishing the lower bound on the effect of disruption caused by natural disasters in the short run.[6]

The remainder of this paper is organized as follows. Section 2 describes the impact of Eyjafjallajökull's eruption on European airspace, while section 3 describes our monthly trade data. In section 4 we describe our empirical approach and present our findings. The last section offers some concluding remarks.

2. Eyjafjallajökull: It's Impact on European Airspace

On March 20, 2010, the Eyjafjallajökull volcano, located on the southern tip of Iceland's eastern volcanic zone, erupted. Over a period of roughly six months, the eruption would progress through a number of stages. The first stage, between March 20 and April 13 was characterized by a gentle outpouring of lava and the relative absence of explosive activity (Sigmundsson, 2013).[7] Lava reached the surface via a number of fissures on the flanks of the volcano, in the relatively ice-free Fimmvörðuháls pass. This absence of ice and water and the effusive nature of the eruption, ensured that the fallout from the volcano was confined to a relatively small area—about 1.3 km^2 (British

[6] Note that this is true even in the case of events such as hurricanes and earthquakes which usually have longer lasting effects combined with infrastructural damage. It is precisely the infrastructural damage that creates the longer lived effect, but in the short run our estimates may provide the lower bound since in the long run it is quite likely that both importers and exporters adjust how they conduct trade. For example, while the Port of New Orleans was closed for months in the wake of Hurricane Katrina it is unlikely that all international trade which used to go through the port was completely halted while the port recovered. It is more likely that some or all of that trade was diverted to other ports of entry or exit.

[7] On the volcanic explosivity index (VEI), the Eyjafjallajökull eruption on March 20 was estimated to be no more than 1 (Jenkins, 2010). The VEI is logarithmic, varies between 0 and 8, and assesses the explosivity by the volume of tephra ejected.

Geological Survey, 2010). In fact, during this stage of its eruption, Eyjafjallajökull's footprint was so small, it was known locally as the tourist volcano (Jenkins, 2010).[8]

Following a brief hiatus, the eruption entered its second stage on April 14, with sustained activity until May 22 (Sigmundsson, 2013). This time the eruption occurred at the center of the Eyjafjallajökull glacier, at the caldera. The presence of water vapor in the magma provided the impetus for an explosion that was roughly 20 to 30 times more powerful than its predecessor three weeks earlier. The eruption generated an ash cloud that reached heights of 10 km (Gudmundsson et.al., 2012; Sigmundsson, 2013). Although half of the tephra, fragmental material ejected by a volcano during an eruption, fell over Iceland, the remainder was distributed over a 7 million km^2 area spanning much of Europe and the North Atlantic (Gudmundsson et.al., 2012), resulting in the closure of much of Europe's airspace for a period of eight days and a cancellation of some 107,000 flights.

The eruption of Eyjafjallajökull was certainly not the only incident of volcanic activity to disrupt air traffic. The eruption of Grímsvötn on Iceland on May 21, 2011, sent a plume of tephra 20km into the atmosphere, which resulted in the cancellation of 900 flights between May 23 and May 25 (Learmount, 2011). Later that same year, an ash cloud from the Puyehue-Cordón Caulle volcanic complex in Chile, led to airport closures in Argentina and as far afield as Australia and New Zealand (Critchlow and Craymer, 2011). While the ash cloud following each of these events often impacted very large geographic areas, the disruption to air traffic was relatively small. For instance the 900 flights cancelled following the eruption of Grímsvötn represented one percent of total European traffic. By contrast, the interruption of commercial aviation following the eruption of Eyjafjallajökull was orders of magnitude greater. This was not because this eruption was particularly powerful. It was of modest size, as its "explosivity" during phase two measured between 3 and 4 out of 8 on the volcanic explosivity index (Gudmundsson et.al., 2012). However, a number of factors combined to magnify the scope of the disruption to air traffic. These included the fine-grained nature of the ash, which was particularly dangerous to jet engines; the positioning of Eyjafjallajökull directly under an unusually stable south-easterly jet stream, which helped spread the tephra over large areas of North and Central

[8] An April 1, 2010 story in The Times of London described the Eyjafjallajökull volcano as a daredevil tourist attraction (Trippier, Edward (2010), "Freezeframe in Iceland," *The Times*, accessed on May 4, 2014, http://www.thetimes.co.uk/tto/travel/images/article2468977.ece).

Europe; as well as a zero-ash tolerance policy implemented by the International Civil Aviation Organization after multiple incidents when volcanic ash interacted with jet turbines (Guffanti et al., 2010; Dunn, 2012).

The initial interruption to air traffic lasted eight days beginning on April 15, when roughly 27% of flights were cancelled (Eurocontrol, 2010), and the airspace over Norway was completely shut down (Bye, 2011). The next day the number of cancellations had increased to 60% and the day after the number of cancellations reached 78%. On April 18, the disruption to air traffic reached its peak, with over 84% flight cancelled. Between April 17 and April 19, 1.2 million passengers were affected each day (Bye, 2011). Over the eight-day interruption to air traffic, about 107,000 flights were cancelled, impacting over 10 million passengers, which represented about 48% of total air traffic during that period. Restrictions were lifted on April 22 after the introduction of new guidelines that raised the safe level of volcanic ash density to 2000 micrograms of ash per cubic meter.

Besides Iceland, three countries were particularly severely impacted by air traffic disruptions. Finland was the worst affected followed by Ireland and the UK. In each of these countries over 90% of flights were cancelled over five consecutive days (Eurocontrol, 2010). After the initial eight-day shutdown between April 15 and April 22, some intermittent closures of the European airspace followed as the volcanic ash density exceeded new safety thresholds. Between May 4 and 5 and May 16 and 17 some restrictions were imposed on the airspace over the British Isles. Additionally on May 9, there were partial closures of airports in Austria, Germany, Italy, Portugal and Spain. These closures led to flight cancellations, but not on the scale observed during the first week of closures in April. In total there were about 7000 flight cancellations in May (Eurocontrol, 2010), about 15 times fewer than in April.

By May 22 the eruption of Eyjafjallajökull had entered its third and final phase, which was marked by a steady decline in eruption intensity, interrupted by only a minor explosive event between June 4 and 8 (Sigmundsson et. al., 2011). No more flight cancellations resulted from this eruption.

3. Data Description

By affecting the extensive product margin of trade, the disruption to air traffic caused by the eruption of Eyjafjallajökull, may have had some long-lasting effects. However the event itself was short-lived, as much of the fallout stemming from it was concentrated over a relatively short window of time. Although annual trade statistics are usually the basis for empirical work, in the current context higher frequency data are necessary in order to precisely estimate the impact of the airspace closures on U.S. and Japanese imports. Monthly data on U.S. merchandize imports are readily available from the US Census Bureau, while those on Japanese imports are available through the Japanese Ministry of Finance.[9] These data provide a record of U.S. imports at the 10-digit HS level and Japanese imports at the 9-digit HS level, the most disaggregated available data for either country. Crucially, for our purposes, both data sets specify how much of any particular good, from any country, is transported by air, sea, or other modes of transportation. We omit observations for which the mode of transportation is unspecified. In addition, we omit the “other” mode of transportation classification, as this likely refers to trade carried by trains and trucks between Canada and Mexico and the U.S. Japanese import data unsurprisingly provide data on air and sea modes only given that Japan is an island nation.

Our data span a 36-month window, starting in January 2009, 15 months prior to the primary eruption of Eyjafjallajökull, and extend to December 2011, 18 months after the primary eruption. While most of our analysis is conducted using 10- or 9-digit product-level data, our results are robust to aggregating the data to the industry level, defined as the 2-digit HS level. Such aggregation offers computational advantages as it limits the proliferation of fixed effects in our regressions and speaks to the size of the effect of the disruption on trade as the effects are still identifiable when data are aggregated from more than 17,000 10-digit product codes (almost 8,200 9-digit codes in the case of Japanese import data) to just 98 2-digit industry codes. However, such aggregation makes it difficult to examine the cross-industry variation of the effect of the eruption.

Data on flight cancellations on a country-by-country basis were obtained from Eurocontrol (2010), the European Organization responsible for air traffic management. “Flight cancellations” actually refers to the change in the number of flights from the week before. The interested reader should consult Eurocontrol (2010) for more detail on how the cancellation figures were obtained by Eurocontrol. These data are available on a daily frequency during the disruption. However, for our purposes we use the average number of flight cancellations during the 8-day interruption in April to measure the intensity of the disruption on a country-by-country basis.

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[9] U.S. data are available either online or on monthly CDs/DVDs the Census Bureau makes available (U.S. Imports of Merchandize). We used data provided on CDs/DVDs as the online data are not conducive to downloading large amounts. Japanese data are available for convenient download at http://www.customs.go.jp/toukei/info/index_e.htm.

3.1. *An Overview of Trends and Cycles in Imports: January 2009 to December 2011*

Figure 1 provides an overview of the main trends in aggregate and seasonally unadjusted US merchandize imports broken down by mode of transportation. During our sample period, which begins in January 2009, the volume of merchandize imports into the US increased by almost 50%. This dramatic expansion in trade followed a similarly dramatic collapse brought on by the onset of the great recession. The rebound (in early 2009), driven by the recovery in OECD economic activity (Francois and Woerz, 2009), did not appear to have a differential impact across modes of transportation. Thus, the growth in US imports transported by air mirrored the expansion in shipments by sea. Juxtaposed on the pronounced upward trend, are large month-to-month fluctuations in import volumes. Cycles at seasonal frequencies are clearly evident within these data. For instance, sharp declines in imports, bottoming-out in February, are evident in 2010 and 2011. The relative decline in import volumes in April is small in relation to the last-to-first quarter decline in imports in 2010 and 2011.

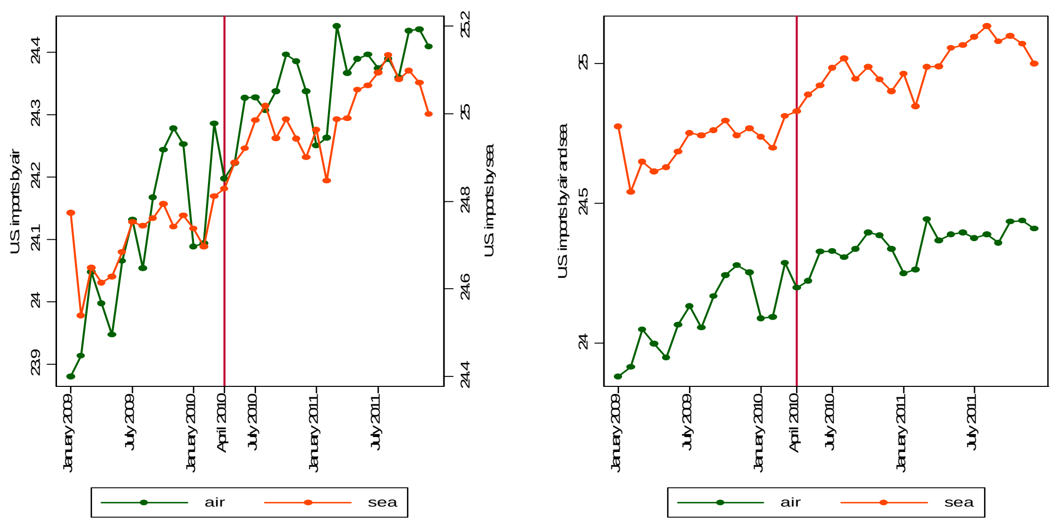

Figure 1- Seasonally Unadjusted U.S. Imports by Mode of Transportation

The trajectory of Japanese imports, shown in Figure 2, is quite the opposite having been declining since 2008. During our period of analysis, between January 2009 and December 2011, Japanese imports decreased by 43%, almost exactly the opposite of the growth of U.S. imports. While a good portion of this decrease is attributable to the consequences of the Great Tohoku earthquake of March 2011, the Japanese imports were on the decline prior to the earthquake. There are similar cyclical patterns in Japanese data to those in the U.S. data in that imports by either mode decrease at the start of both 2010 and 2011. But unlike the case of U.S. imports, Japanese imports only partially recover during the remainder of either year. But similar to U.S. imports, and important for our empirical strategy, Japanese imports by air and sea follow similar trends except during April 2010 when air imports decrease, while sea imports are increasing.

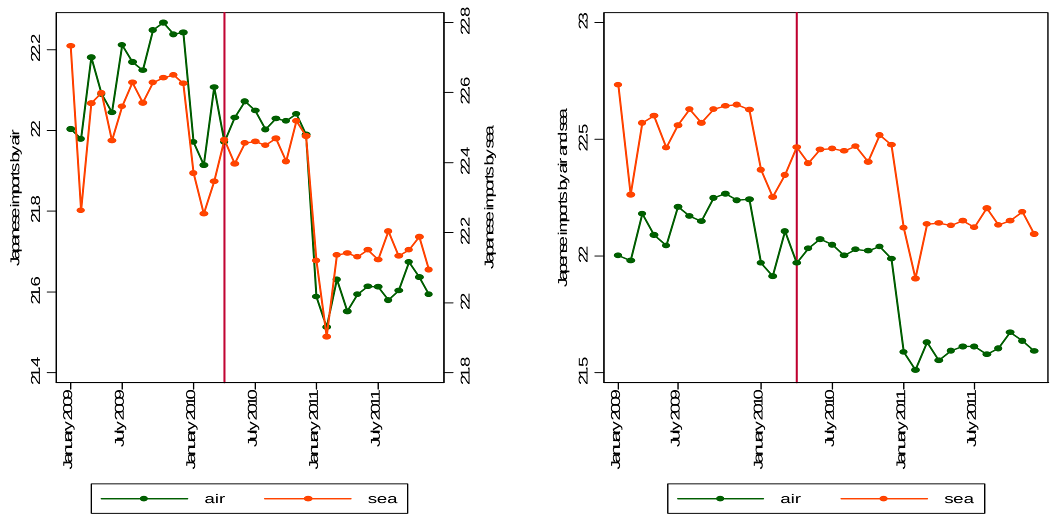

Figure 2 - Seasonally Unadjusted Japanese Imports by Mode of Transportation

These aggregate figures, even when broken into air and sea categories, however mask the variation in the data across countries of origin. Although, by affecting European hubs, the volcanic disruption had global implications its impact was most concentrated on the 32 European countries directly affected by the airspace closure. When we disaggregate imports by country of origin and differentiate between countries directly impacted by the volcano (the treatment group) and countries whose airspace was not affected (the control group), the Eyjafjallajökull footprint is clearly evident in our data as illustrated by Figures 3 and 4 which plot only air imports.

There are a number of observations regarding these time series that are worth noting. First, over the sample period, imports recovered from their recessionary lows at a faster rate in the control group (approximately 2.4% per month in U.S. imports and 3% per month in Japanese imports). The treatment group, which is composed of European countries, experienced slower export-growth to both the US market (averaging 1.5% per month) and the Japanese market (averaging 1.7% per month). Second, the cyclical variation in imports across the two groups exhibited a very similar pattern prior to April 2010. In particular, prior to the airspace closures, the correlation between the two groups, in month-to-month import volumes, was 0.80 for U.S. imports and 0.89 for Japanese imports. After the disruption, this figure declined to 0.66 for U.S. imports and 0.65 for Japanese imports.

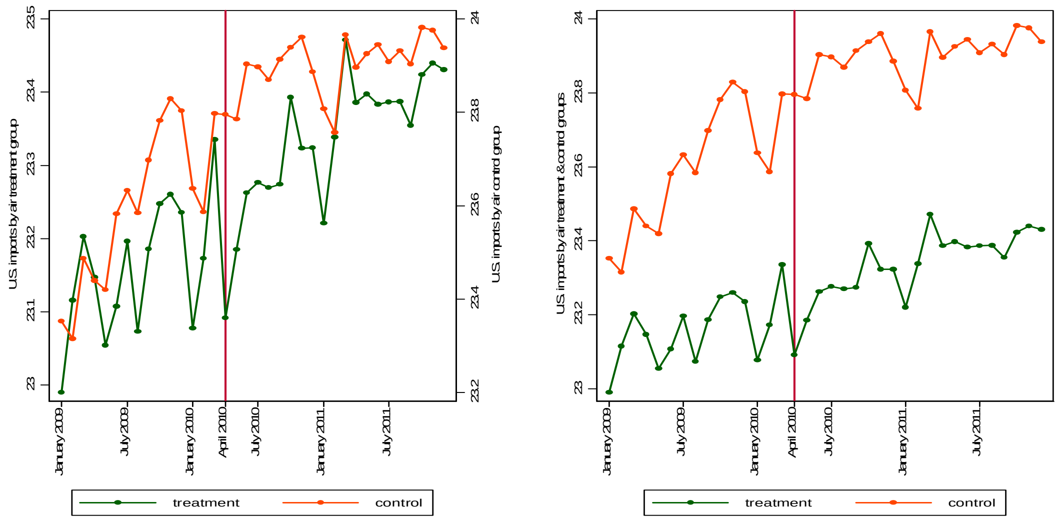

Figure 3 - U.S. Imports for Treatment and Control Groups

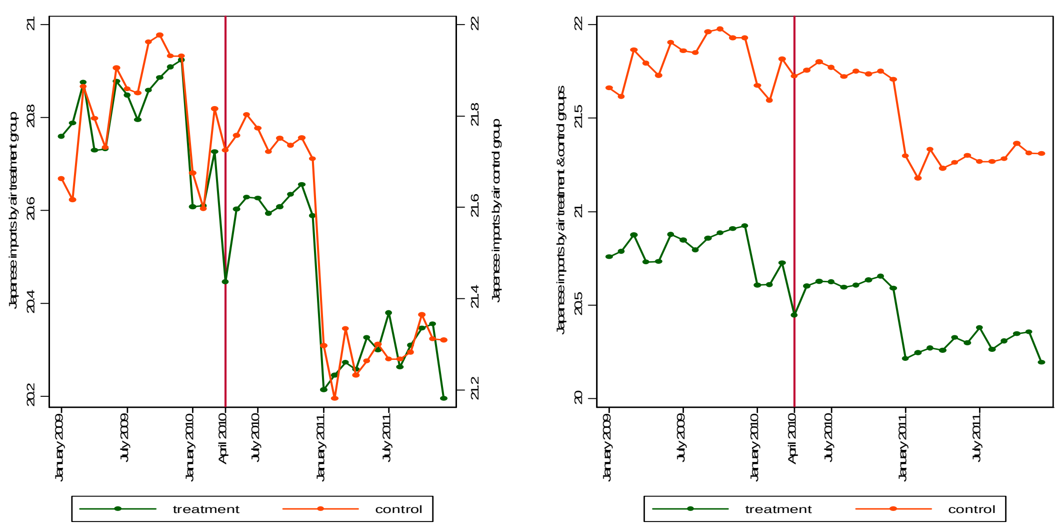

Figure 4 - Japanese Imports for Treatment and Control Groups

Third, the lower association between the two time-series in the aftermath of the volcanic eruption can be explained in large part by the divergence between the two time-series in April 2010. In that month, U.S. imports from the treatment group declined by 21% but remained unchanged in the control group. Japanese imports from the treatment group decreased by 25% in April 2010 and by 9% from the control group.

4. Results

4.1. Methodology

The central objective of this paper is to quantify the impact of a short-term disruption to the air transportation network on trade volumes. To this end, we use the eruption of Eyjafjallajökull, to calculate the difference-in-differences in import volumes between two groups – a treatment and a control – prior to and in the immediate aftermath of the volcanic disruption. Accordingly, our empirical strategy is organized around variations of the following two-way fixed-effects model:

$$m_{i,j,t} = \mu_{i,j} + \tau_{i,t} + \beta_{air\ frieght} T_{j,t} f_j + \varepsilon_{i,j,t} \qquad (1)$$

Here $m_{i,j,t}$ is the log of the volume of imports of products in HS category i, from country j at time t; $\mu_{i,j}$ is a country i-HS code j pair fixed effect; $\tau_{i,t}$ is a time/month t-HS code j pair fixed effect; $T_{j,t}$ is a dummy variable that identifies the treatment group, i.e., $T_{j,t}$ assumes the value one if t is equal to April 2010 and j is a country that experienced an airspace closure due to the volcano; finally f_j is the average fraction of flights cancelled between April 15 and April 22 in country j. $\beta_{air\ frieght}$ is the estimated effect of flight cancellations on trade and reflects a semi-elasticity of the volume of imports with respect to flight cancellations.

Although in theory estimating equation (1) is straightforward, in practice its estimation can pose a computational challenge, when the number of panel units is large. For instance, with imports measured at the 10-digit HS product level, there are over 336 thousand fixed effects, $\mu_{i,j}$, in our data--one for each country-product pair. This number essentially doubles when we further differentiate between modes of transportation by which products were shipped. The number of time effects, $\tau_{i,t}$, is similarly large. In the full sample, the number of dummies needed to incorporate a *product-specific* time effect is over 625 thousand, if we differentiate between modes of transportation and consider a *country-product-specific* time effect in a matched-pairs design, this number increases to over 8 million. Although a simple transformation can purge the $\mu_{i,j}$'s (or $\tau_{i,t}$'s) from the data, the memory requirements necessary to handle the other time- (or fixed-) effect dummies can be daunting.

Fortunately, in recent years a number of advances in the estimation of high-dimensional two-way fixed-effects models have reduced these memory requirements considerably (see McCaffrey et. al., 2012, for a review). One simple, but elegant, approach to this problem (which can be extended to three-way fixed effect models), proposed in Carneiro et al. (2012), entails initially sweeping away one of the fixed-effects (by removing the group means) from the data and then iteratively refining estimates of the model parameters (both the fixed-effects as well as the β's). This latter step is accomplished by regressing import volumes, $m_{i,j,t}$, (as well as a certain transformation of these data) on the slope variable, $T_{j,t}f_j$, and as result is not impacted by the dimensionality of the matrix of dummies. This approach, while computationally intensive, imposes minimal memory requirements.

Prior to discussing our results a note on how our two data sets are constructed. We examine the monthly imports at the 10-digit HS level for the U.S. and 9-digit HS level for Japan. Since we use the difference-in-differences estimator we construct a complete monthly time series of imports for every product and every country observed to have exported to either the U.S. or Japan giving us a balanced panel. Given the level of product detail our data sets are large by construction. U.S. imports arriving by air for the 36-month period account for 9,830,952 monthly observations. A vast majority of these are zeros as not every exporter ships its product to the U.S. in every month. More precisely, some 73% of these observations are zeros, underscoring what the duration of trade literature has shown – that a vast majority of trade relationships are short. For example, using quarterly U.S. imports Besedeš and Prusa (2013) show that the median duration of a U.S. import relationship is one quarter. In the case of Japanese imports, we have 5,811,156 observations, of which some 67% are zeros.

Both data sets reflect exports to the U.S. where shipments take place in every of the 36 months as well as those where a single shipment occurs in precisely one out of the 36 months with no other shipments during the period. Some 30% of our observations on U.S. imports in fact are instances of shipments in just one out of the 36 months in the period and another 12% are instances of shipments in only two months. On the other side of the spectrum, some 650,000 observations or 6% belong to exports with a shipment in every single month. Similar patterns are seen in Japanese imports with 24% of observations on instances of just a single positive shipment in the 36 month period, 11% with two months of positive shipments, and 600,000 or some 10% with positive shipments in every single month.

For many country-industry or country-product groups characterized by intermittent trading relationships, there was no change in the volume of imports between March and April 2010, not because the volcanic eruption had zero-effects on shipments, but because there were no shipments scheduled during those months. These data points are not informative about the extent to which the airspace disruptions impact trading relationships. Moreover, since each of these data points shows no effect, including them in our data, likely biases estimates of the difference in import volumes during the month of the eruption toward zero. Since this bias operates in both treatment and control groups, the overall direction of the bias in β is unclear. However, if zeros are distributed uniformly across the treatment and control, and if the volcano impacted trade form Europe more so than it affected trade from countries not impacted by its ash cloud, there is a case to be made that $|\beta_{air\ freight}|$ will be downward biased.

Given the likely downward bias due to the presence of a large number of zero observations in our data, we will use four different samples throughout the paper. Our basic sample is the balanced panel on all imports of U.S. and Japan during the 36 months between January 2009 and December 2011. Given that many zeros in April 2010, when the eruption took place, would have been zeros even in the absence of the eruption, we will employ three different subsamples. The first subsample is composed of imports with a positive volume in January, February, and March 2010, but not necessarily April 2010. The second subsample extends the continuously-positive-shipment window back to October, November, and December 2009, focusing only on imports which have been continuously shipped for six consecutive months before April 2010, but not necessarily April 2010 itself. The former, 3-month window, reduces our U.S. sample by some 85% of observations and the Japanese sample by 83%, while the latter, 6-month window, reduces the U.S. sample by 89% and the Japanese sample by 87% of observations. As our results below illustrate, the large number of zeros in the fully balanced panel does bias the estimated effect down towards zero, though they do not eliminate it.

Despite such large reductions in the number of observations, it is possible we still have some zeros in April 2010 which are not caused by the eruption, but would have been zeros regardless. The 6-month continuously-positive-shipment window is twice as long as the median duration of U.S. imports at the 10-digit HS level (Besedeš and Prusa, 2013), so it stands to reason at least some of the zeros we observe are unrelated to the volcanic disruption. Short of observing detailed shipment plans, it is difficult to ascertain which of these zeros are directly related to the disruption. The next best alternative is to focus on the most robust shipments or trade relationships – those which are positive in every single month during the 36 month period we focus on, including April 2010. This reduces our U.S. sample by some 93% and the Japanese sample by some 92%, relative to the full sample. While this sample will exclude all zeros directly caused by the disruption, it will establish what we could refer to as the lower bound of the effect of the disruption as it will allow us to identify the reduction in most robust trade relationships, which due to their longevity likely involve most frequent shipments as well.

4.2. Initial Findings

Table 1 collects our findings from an initial set of regressions using U.S. imports data. Our starting point is the first column where we estimate equation (1) on all observations on U.S. imports arriving by air between January 2009 and December 2011 controlling for country-product fixed effects as well as product-specific time-dummies.[10] The control group is composed of all countries that were not directly impacted by air-space closures, and the treatment group are countries with airspace closures. Since we are regressing the log of volume on the fraction of cancelled flights, all our estimated coefficients are semi-elasticities. Our results suggest that the volcanic eruption did cause a decline in air freight from the treatment group during the month of airspace closures with an estimated coefficient of -0.217, both statistically and economically significant effect, as we show below. Our estimated coefficient indicates that if 100% of flights were cancelled, the volume of trade decreased by 0.217 log points, which translates to almost a 19.5% reduction. The average number of cancelled flights between April 15 and April 22, 2010,

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[10] Similar to Manova and Chor (2012), the product-time dummies are used to address the monthly seasonality in the data. We have also experimented using monthly seasonal adjustment factors provided by the Census Bureau's Foreign Trade Division (we thank Andreana Able and Ryan Fescina for making these available to us). The Census Bureau calculates these adjustment factors for the most detailed level of the end-use classification, a total of 149 categories. None of our results are appreciably affected by the use of monthly adjustment factors. These results are available on request.

was 50% across all affected countries. Our estimate then indicates that the average reduction in the volume of trade was almost 10%. To put it in other terms, the elasticity of trade with respect to flight cancellations is -0.195. The high point in cancellations was reached on April 17 and 18 when 85% of all flights were cancelled, resulting in a 16.8% reduction in the volume of trade. On April 17 the least affected European country had 39% of its flights cancelled, while the most affected country had 99% of its flights cancelled. The corresponding range for the reduction in the volume of trade was 8%-19.3%. On April 18, the range of cancelled flights was 28% to 100%, reducing the volume of trade by almost 6% to 19.5%.

Table 1 - Basic results with air freight data only				
	(1)	(2)	(3)	(4)
	U.S. Imports, 10-digit HS data			
$\beta_{air\ freight}$	-0.217***	-0.568***	-0.426***	-0.247***
	(0.0187)	(0.0480)	(0.0441)	(0.0216)
N	9,830,952	1,434,780	1,103,976	650,016
R^2	0.655	0.690	0.703	0.881
	Japanese Imports, 9-digit HS data			
$\beta_{air\ freight}$	-0.305***	-0.660***	-0.495***	-0.349***
	(0.0311)	(0.0754)	(0.0696)	(0.0352)
N	3,118,752	531,396	406,368	242,172
R^2	0.677	0.700	0.719	0.893
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

The estimated effect of the disruption was larger for Japan with an estimated semi-elasticity of -0.305. This translates to a 26.3% reduction in the volume of trade when 100 percent of flights are cancelled, or a 13.1% reduction corresponding to 50% of flights cancelled, the average level of cancellations during the April 15-April 22, 2010, period. Thus, Japanese data reveal a larger elasticity of trade with respect to cancelled flights of -0.263. Japanese imports from Europe were reduced by between 11.2% and 26% on April 17 and 8.2% and 26.1% on April 18, the two most affected days.

Our point estimate in column (1) suggests that effects on air freight were non-negligible. Even so, there is reason to believe that these estimates are biased downward in an absolute sense. As we discussed above, the issue has to do with the large number of zero-observations in our data. As we documented above, almost a half of our U.S.

data set is made up of U.S. imports active in only one or two out of the 36 months of our sample. For these imports, the remaining months are all zeros. For many of these import relationships the volcanic eruption did not cause a reduction in volume simply because nothing was supposed to be traded to begin with in April 2010. Since each of these data points shows no effect, including them in our data, biases estimates of the difference in import volumes during the month of the eruption toward zero.

In column (2) we restrict our sample to just those relationships with positive shipments in each of the three months prior to April 2010, but not necessarily April itself. These relationships were affected more significantly as indicated by the estimated coefficient of -0.568 for U.S. imports and -0.660 for Japanese imports, confirming our suspicion of the downward bias embodied in the full sample. These estimates entail a much larger reduction in the volume of trade, with 50% of cancelled flights reducing U.S. imports by 24.7% and Japanese imports by 28.1%, implying elasticities of -0.494 and -0.562. In column (3) we further restrict the sample to continuously positive shipments in each of the six months prior to April 2010. This subsample again reveal the existence of a downward bias in the balanced panel, though somewhat smaller than in the three-month continuous-positive-shipments sample. The estimated semi-elasticities are -.426 for U.S. imports and -0.495 for Japanese imports, translating to a reduction of 19.2% in U.S. imports and 22% in Japanese imports in response to a cancellation of 50% of flights, implying elasticities of -0.384 and -0.440.

In column (4) we present our most conservative estimates based on a sample of most robust import relationships which have positive shipments in each of the 36 months we examine. The estimated semi-elasticities are now much closer to those of the full sample, though there is still some evidence of the downward bias due to the zeros present in the full sample. The estimated semi-elasticity for U.S. imports is -0.247, while that for Japanese imports is -0.349. These figures translate to a reduction of 11.6% in U.S. imports and 16% in Japanese imports in response to 50% of cancelled flights, or elasticities of -0.232 and -0.320. Note that the estimated reductions in the volume of imports are significant as they are estimated reductions in *monthly* imports in response to just an eight-day closure of airspace, roughly a quarter of the month.

As we focus on progressively longer relationships with uninterrupted shipments, the estimated effect decreases. At first blush this may be surprising. However the longer a relationship is active, the less likely it is to cease, ceteris paribus, as indicated by the duration of trade literature (see Besedeš and Prusa, 2006, 2013, for example). Such relationships tend to be larger on average and likely involve more frequent shipments. It stands to reason that relationships with more frequent shipments will display a smaller reaction to the disruption caused by the eruption. This is reinforced by our results in column (4) in which we use the most restrictive subsample. Two observations are in order. First, note that the amount of bias in column (1) estimates is relatively small, roughly equal to 14% of the column (1) estimate for both the U.S. and Japanese data. Second, the column (4) coefficient eliminates a possible confounding element built into column (2) and (3) results. Both of the latter subsamples are predicated on continuous positive shipments leading up to April 2010, but in April they may have had no recorded shipment. This may have happened for two reasons: the only shipments intended for April were supposed to take place between April 15 and 22 and were prevented from being carried out or no shipment was intended to be made in April 2010. The latter cause confounds the disruption effect. Our estimates in column (4) are free of this confounding effect and the entire estimated decrease in the volume can attributed to the volcanic disruption.[11]

Thus far our analysis has been conducted using air freight data only. Since our treatment variable affects air traffic only, at first blush, restricting our analysis to air freight seems sensible. However, on April 15, the first day of widespread disruption to European airspace, it was difficult to predict how long this disruption was going to last. As a result, it is possible that European suppliers chose alternative modes of transportation to ship their goods. If this was the case, we might expect a "blip" in the volume of goods shipped by alternative modes, which in this case are necessarily shipments by sea.

$$m_{i,j,t} = \mu_{i,j} + \tau_{i,t} + \beta_{sea\ freight} T_{j,t} f_{j,t-1} + \varepsilon_{i,j,t} \quad (2)$$

In Table 2 we examine the evidence on possible substitution effects. We examine the exact same four samples of data as in Table1 but use the volume of trade shipped as sea freight rather than air freight as in Table 1. We now estimate a slightly modified equation (1), given by equation (2), where we regress the volume of trade shipped as sea freight on the same variables as air freight volume except that the average fraction of cancelled flights is lagged by one month. Such an approach allows for time lags in transportation by sea—it is certainly not

[11] We can clearly estimate a number of other similarly defined subsamples with a number of consecutive positive shipments leading up to April 2010 and including April 2010 itself.

uncommon for ocean freight leaving Europe to take two weeks or more to reach its destination in the US and a month to reach Japan.[12] There is considerable anecdotal evidence to suggest that when the disruption to European airspace was at its peak, European travelers were quick to switch to alternative modes of transport. However, it is not immediately obvious that the shock to air freight was similarly mitigated by an increase in the volume of sea freight. Aside from the logistics of re-booking shipments on such a large scale, transportation by ship is not viable for fresh produce, perishables and pharmaceuticals, as well as for sectors that carry minimal inventory and rely on just-in-time supply chains. The results in Table 2 are consistent with this perspective. If there were any substitution between the air and sea freight shipping in the wake of the disruption, the estimate of $\beta_{sea\ freight}$ would be positive and significant. The point estimates for the semi-elasticity of sea freight to the disruption are an order of magnitude smaller than those for air freight and are never statistically significantly different from zero. Since we cannot detect any effect in sea freight, the remainder of the paper will focus on air freight data only.

Table 2 - Basic results with air freight data only				
	(1)	(2)	(3)	(4)
	U.S. Imports, 10-digit HS data			
$\beta_{sea\ freight}$	0.0200	0.0128	0.0903	0.0154
	(0.0246)	(0.0603)	(0.0551)	(0.0257)
N	7,962,080	1,487,605	1,193,605	709,695
R^2	0.678	0.701	0.726	0.907
	Japanese Imports, 9-digit HS data			
$\beta_{sea\ freight}$	-0.0552	-0.0306	-0.0104	-0.0630
	(0.0380)	(0.0881)	(0.0814)	(0.0392)
N	2,617,615	647,885	534,030	345,870
R^2	0.730	0.719	0.743	0.925
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

Estimates in Table 1, which allow for no dynamics whatsoever, are simplifications of the underlying data generating process which ignore persistent as well as seasonal variations in the trade flow data. In the absence of lagged variables to incorporate feedback over time, estimates of the long-run impact of the volcano could be

[12] According to the website searates.com it takes about 10 days for a container ship to sail from Rotterdam, the Netherlands, to the Port of New York, U.S., the two busiest ports in Europe and the eastern seaboard of the U.S. It takes 34 days for a ship originating in Rotterdam to reach Tokyo, the busiest Japanese port.

Table 3 - Air freight with autoregressive terms								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	U.S. Imports, 10-digit HS data				Japanese Imports, 9-digit HS data			
$\beta_{air\ freight}$	-0.256***	-0.492***	-0.368***	-0.231***	-0.253***	-0.644***	-0.455***	-0.307***
	(0.0192)	(0.0487)	(0.0447)	(0.0216)	(0.0318)	(0.0770)	(0.0707)	(0.0359)
ar1	0.0632***	0.134***	0.150***	0.197***	0.0593***	0.122***	0.145***	0.213***
	(0.000743)	(0.00223)	(0.00303)	(0.00322)	(0.00133)	(0.00361)	(0.00514)	(0.00698)
ar2	0.0301***	0.0646***	0.0893***	0.0881***	0.0205***	0.0546***	0.0824***	0.0884***
	(0.000664)	(0.00199)	(0.00281)	(0.00277)	(0.00117)	(0.00320)	(0.00468)	(0.00530)
ar3	0.00897***	0.0230***	0.0561***	0.0388***	0.000621	0.00615**	0.0425***	0.0385***
	(0.000631)	(0.00187)	(0.00271)	(0.00266)	(0.00112)	(0.00301)	(0.00455)	(0.00526)
ar4	-0.00237***	0.00385**	0.0248***	0.0118***	-0.0121***	-0.00372	0.0124***	0.00581
	(0.000614)	(0.00184)	(0.00261)	(0.00265)	(0.00109)	(0.00291)	(0.00417)	(0.00461)
ar5	-0.00681***	0.00292	0.0152***	0.00308	-0.0173***	-0.0123***	0.00271	-0.00726
	(0.000604)	(0.00180)	(0.00253)	(0.00256)	(0.00107)	(0.00291)	(0.00407)	(0.00450)
ar6	-0.0121***	0.00337*	0.00414*	-0.000760	-0.0172***	-0.00301	-0.00215	0.0100**
	(0.000598)	(0.00180)	(0.00245)	(0.00264)	(0.00106)	(0.00286)	(0.00398)	(0.00495)
ar7	-0.0177***	-0.00678***	-0.00482**	-0.00795***	-0.0242***	-0.0207***	-0.0160***	-0.0132***
	(0.000577)	(0.00171)	(0.00232)	(0.00245)	(0.00101)	(0.00271)	(0.00382)	(0.00473)
ar8	-0.0205***	-0.0190***	-0.0140***	-0.0171***	-0.0249***	-0.0248***	-0.0248***	-0.0276***
	(0.000576)	(0.00170)	(0.00231)	(0.00242)	(0.000990)	(0.00268)	(0.00367)	(0.00468)
ar9	-0.0202***	-0.0133***	-0.00902***	-0.00772***	-0.0230***	-0.0277***	-0.0141***	-0.0150***
	(0.000572)	(0.00166)	(0.00223)	(0.00255)	(0.000982)	(0.00262)	(0.00371)	(0.00464)
ar10	-0.0177***	-0.0134***	-0.00926***	-0.0120***	-0.0177***	-0.0133***	-0.0113***	-0.0277***
	(0.000574)	(0.00166)	(0.00215)	(0.00246)	(0.000981)	(0.00267)	(0.00371)	(0.00446)
ar11	-0.0128***	-0.00694***	-0.00752***	0.000962	-0.00276***	0.00522**	0.00395	0.0134***
	(0.000584)	(0.00166)	(0.00218)	(0.00241)	(0.00102)	(0.00265)	(0.00363)	(0.00480)
ar12	-0.00440***	0.00915***	0.00950***	0.0343***	0.0119***	0.0224***	0.0234***	0.0557***
	(0.000602)	(0.00168)	(0.00218)	(0.00252)	(0.00109)	(0.00278)	(0.00374)	(0.00501)
N	6,553,968	956,520	735,984	433,344	2,079,168	354,264	270,912	161,448
R^2	0.675	0.727	0.75	0.902	0.696	0.737	0.762	0.912
Robust standard errors in parentheses								
*** p<0.01, ** p<0.05, * p<0.1								

mismeasured. In Table 3, we estimate an autoregressive model given by equation (3), with 12 lags in the dependent variable, the volume of trade shipped as air freight. This specification allows for autoregressive dynamics in the trade-flow data, including seasonal variations. We again use four different samples, all observations in columns (1) and (5), and import relationships with positive flows in: each of the first three months of 2010 (columns 2 and 6), each of the last three months of 2009 and first three months of 2010 (columns 3 and 7), and every month in the sample (columns 4 and 8).

$$m_{i,j,t} = \mu_{i,j} + \tau_{i,t} + \beta_{air\ frieght} T_{j,t} f_j + \sum_{k=1}^{12} \gamma_{t-k} m_{i,j,t-k} + \varepsilon_{i,j,t} \tag{3}$$

Incorporating lags in the dependent variable does not significantly impact our estimate of the direct impact of the volcano, which remain in the same range as our earlier estimates. Relative to Table 1, the estimated semi-elasticities tend to be somewhat smaller, the only exceptions being column (1) which uses all observations on U.S. imports.[13] This is because the misspecification built-in to static models does not translate into biases in $\hat{\beta}$, since the timing of the eruption is orthogonal to innovations in the trade equation. The immediate effect of the disruption is a reduction in imports ranging between 10.9% (column 4) and 21.8% (column 4) for the U.S. and between 11.9% (column 5) and 27.5% (column 8) in the aftermath of a cancellation of 50% of flights.

One important assumption in the estimation of Table 3 regressions is that the lag structure is unaffected by the disruption to airspace. In particular, we assume that coefficients on the autoregressive parameters are unaffected in the period following the airspace shutdown. In Table 4, we test this assumption, by allowing the autoregressive coefficients in the treatment group to change in the post-eruption period. Though not a formal test of parameter stability, the individual t-statistics do not provide any evidence to suggest that the dynamics of import flows changed in the aftermath of the volcanic eruption.

4.3. Treatment and Control Group

Since the disruption to air traffic was exogenous, the eruption of Eyjafjallajökull created a basis for assessing how access to air transportation can impact trade. However, like most natural experiments, there was a lack of researcher-control. In the current context this lack of researcher control means not only that the assignment of countries into treatment and control groups is non-random, but also that the definition of treated versus untreated is somewhat fuzzy. “Fuzziness” derives from the difficulty in precisely measuring treatment levels in countries not imposing restrictions on their airspace. Our assumption has been that these countries are a control for the 32 that did impose such restrictions. However, this definition of treatment and control does not take into consideration the central role played by European airports in providing inter-regional connectivity. Hubs such as Heathrow and Charles de

[13] While we do not show them to save space, equivalent regressions on sea freight reveal results similar to those in Table 2 – even after taking into account dynamic considerations, the volcanic disruption had no appreciable effect on sea freight.

Table 4 - Air freight with autoregressive terms and affected country-specific autoregressive terms									
	(1)	(2)	(3)	(4)		(5)	(6)	(7)	(8)
	U.S. Imports, 10-digit HS data					Japanese Imports, 9-digit HS data			
$\beta_{\text{air freight}}$	-0.254***	-0.497***	-0.377***	-0.230***		-0.252***	-0.610***	-0.448***	-0.309***
ar1	0.0224***	0.0758***	0.167***	0.137***		0.0276***	0.0852***	0.158***	0.163***
ar2	0.00917***	0.00378	0.0965***	0.0657***		0.000769	0.00117	0.115***	0.0776***
ar3	0.00633***	-0.0183***	0.0986***	0.0511***		0.00472*	-0.0256***	0.0901***	0.0449***
ar4	-0.00181	-0.0244***	-0.00188	0.0215***		-0.00409	-0.0268***	-0.00420	0.0203
ar5	-0.00591***	-0.0237***	-0.0135***	0.0135**		-0.0170***	-0.0269***	-0.0188***	-0.00144
ar6	-0.00634***	-0.0215***	-0.0184***	0.00808		-0.00898***	-0.0256***	-0.0218***	0.0317**
ar7	-0.00795***	-0.0204***	-0.0207***	0.00701		-0.0166***	-0.0299***	-0.0294***	-0.00734
ar8	-0.00776***	-0.0172***	-0.0194***	-0.0103		-0.0110***	-0.0307***	-0.0257***	-0.0265**
ar9	-0.0102***	-0.0169***	-0.0181***	0.00356		-0.0116***	-0.0316***	-0.0300***	-0.0102
ar10	-0.00684***	-0.0186***	-0.0219***	-0.000665		-0.0112***	-0.0221***	-0.0241***	-0.0431***
ar11	-6.97E-05	-0.0189***	-0.0224***	-0.00113		0.0101***	-0.0108***	-0.0223***	0.0282***
ar12	0.0127***	-0.0170***	-0.0216***	0.0406***		0.0313***	-0.0128***	-0.0186***	0.0694***
erupt_ar1	0.0455***	0.0486***	-0.0222***	0.0681***		0.0352***	0.0259***	-0.0182	0.0565***
erupt_ar2	0.0229***	0.0649***	-0.0119*	0.0245***		0.0214***	0.0565***	-0.0382***	0.0112
erupt_ar3	0.00214	0.0541***	-0.0488***	-0.0155**		-0.00612**	0.0442***	-0.0543***	-0.00849
erupt_ar4	-0.00153	0.0378***	0.0262***	-0.0123*		-0.0105***	0.0332***	0.0157**	-0.0176
erupt_ar5	-0.00189	0.0356***	0.0332***	-0.0130*		-0.00147	0.0235***	0.0252***	-0.00746
erupt_ar6	-0.00730***	0.0336***	0.0308***	-0.0111		-0.0106***	0.0324***	0.0280***	-0.0259*
erupt_ar7	-0.0118***	0.0207***	0.0226***	-0.0182***		-0.00964***	0.0167***	0.0203***	-0.00743
erupt_ar8	-0.0151***	0.00275	0.00976**	-0.00875		-0.0167***	0.0133***	0.00549	-0.00238
erupt_ar9	-0.0120***	0.00905***	0.0145***	-0.0139**		-0.0135***	0.0112**	0.0242***	-0.00670
erupt_ar10	-0.0129***	0.0101***	0.0184***	-0.0138**		-0.00778***	0.0152***	0.0192***	0.0175
erupt_ar11	-0.0150***	0.0169***	0.0206***	0.00198		-0.0151***	0.0226***	0.0353***	-0.0178
erupt_ar12	-0.0200***	0.0344***	0.0416***	-0.00806		-0.0225***	0.0446***	0.0545***	-0.0162
N	6,553,968	956,520	735,984	433,344		2,079,168	354,264	270,912	161,448
R^2	0.675	0.732	0.751	0.902		0.696	0.742	0.763	0.912
Robust standard errors in parentheses									
*** p<0.01, ** p<0.05, * p<0.1									

Gaulle serve as major international gateways for both European and non-European traffic. For instance, Heathrow is Mumbai's primary gateway to the world. When it closed, the effective distance between Mumbai and airports located all over the world increased. Distances to North America increased by about 40% (Woolley-Meza et. al., 2013), possibly affecting the cost of airfreight between India and the US.

It is also worth remarking that the 32 countries that were directly impacted by the ash from Eyjafjallajökull are very different from those unaffected by it. Notably, they are richer with a greater concentration of exports in manufacturing and high-value products that can better absorb the high-cost of air freight. Whether this imparts a bias in our estimates of the effect of airport closures is unclear, since the identifying assumption does not preclude systematic differences between treatment and control, but rather imposes an equivalence in the average response of the treated group in the absence of the treatment and the average response of the untreated group. By definition this is an assumption that we cannot test. However, near parallel trends in air freight volumes in the treatment and control groups in the 15-month period prior to the eruption of Eyjafjallajökull would be certainly consistent with it. As we have seen in Figures 3 and 4, there are no discernible differences in trends between the two groups for the three-year sample period. However, in the 15 months prior to the eruption of Eyjafjallajökull, the average monthly growth rate in import volumes in the control group was about 1.5 times that of the average monthly growth rate in import volumes in the treatment. These slightly divergent trends are less than ideal, given our research design. Moreover, the lack of random assignment means that there is no way to rule out unequal (in a probabilistic sense) influences of extraneous factors across the two groups.

In this sub-section, we consider a number of variations on the control sample. Our aims are first, to limit the contamination of the control by removing countries indirectly impacted by airport closures, and second, to better match the treated and untreated samples in order to limit the effects of extraneous influences.

We begin in Table 5 by re-defining the control group so that it is composed of countries from North, South and Central America. In these regions, the disruption to the European airports did not, substantially, increase effective distances to US airports, if at all (Woolley-Meza et. al., 2013). Accordingly air freight to the US should have been unaffected by the loss in connectivity following the European closures. The America's therefore provide a better control sample for the 32 European countries which were directly impacted by Eyjafjallajökull, but importantly this is not simply because countries in the American control sample were more likely to remain untreated during the disruption. It also has to do with the correspondence in trends in airfreight with the treatment group prior to the April eruption, which is much tighter within this subsample of the data.[14] In the case of Japanese imports the alternative control group is composed of the Americas as well as all of Asia and Pacific.

[14] The ratio of the trend in import volumes in the treatment group to the trend in import volumes in the new control group is 1:1.12. This compares to the earlier figure of 1:2.7 when using non-European countries as a control.

Table 5 - Control group is the Americas for U.S. data, Americas and Asia for Japanese data								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	U.S. Imports, 10-digit HS data				Japanese Imports, 9-digit HS data			
$\beta_{air\ freight}$	-0.277***	-0.481***	-0.326***	-0.185***	-0.371***	-0.655***	-0.421***	-0.321***
	(0.0263)	(0.0818)	(0.0770)	(0.0378)	(0.0417)	(0.0726)	(0.0665)	(0.0363)
ar1	0.0585***	0.125***	0.145***	0.177***	0.0494***	0.101***	0.122***	0.214***
	(0.000971)	(0.00303)	(0.00418)	(0.00461)	(0.00147)	(0.00357)	(0.00486)	(0.00713)
ar2	0.0296***	0.0632***	0.0848***	0.0859***	0.0150***	0.0450***	0.0684***	0.0896***
	(0.000871)	(0.00272)	(0.00386)	(0.00395)	(0.00133)	(0.00325)	(0.00468)	(0.00547)
ar3	0.00864***	0.0193***	0.0533***	0.0409***	-0.00189	0.00417	0.0330***	0.0373***
	(0.000833)	(0.00260)	(0.00376)	(0.00379)	(0.00128)	(0.00300)	(0.00438)	(0.00539)
ar4	-0.000645	0.00738***	0.0270***	0.0162***	-0.0123***	-0.00272	0.00739*	0.00577
	(0.000809)	(0.00257)	(0.00362)	(0.00374)	(0.00124)	(0.00293)	(0.00401)	(0.00476)
ar5	-0.00520***	0.00139	0.0135***	0.00797**	-0.0170***	-0.0107***	0.00140	-0.00683
	(0.000794)	(0.00244)	(0.00345)	(0.00352)	(0.00123)	(0.00288)	(0.00400)	(0.00463)
ar6	-0.0105***	0.00564**	0.00542	0.00488	-0.0161***	-0.00133	-0.000188	0.0122**
	(0.000785)	(0.00247)	(0.00337)	(0.00368)	(0.00122)	(0.00291)	(0.00392)	(0.00498)
ar7	-0.0170***	-0.00414*	-0.00197	-0.00235	-0.0229***	-0.0180***	-0.0124***	-0.0143***
	(0.000759)	(0.00237)	(0.00321)	(0.00335)	(0.00116)	(0.00270)	(0.00370)	(0.00474)
ar8	-0.0203***	-0.0194***	-0.0169***	-0.0155***	-0.0238***	-0.0205***	-0.0200***	-0.0276***
	(0.000759)	(0.00234)	(0.00315)	(0.00344)	(0.00116)	(0.00271)	(0.00358)	(0.00468)
ar9	-0.0205***	-0.0162***	-0.0102***	-0.0102***	-0.0240***	-0.0241***	-0.0114***	-0.0160***
	(0.000753)	(0.00229)	(0.00304)	(0.00351)	(0.00114)	(0.00264)	(0.00348)	(0.00477)
ar10	-0.0176***	-0.0120***	-0.00952***	-0.0120***	-0.0208***	-0.0151***	-0.0152***	-0.0276***
	(0.000756)	(0.00227)	(0.00299)	(0.00343)	(0.00114)	(0.00268)	(0.00362)	(0.00454)
ar11	-0.0132***	-0.00606***	-0.00657**	-0.00247	-0.00669***	0.00292	0.00129	0.0138***
	(0.000767)	(0.00229)	(0.00302)	(0.00334)	(0.00117)	(0.00263)	(0.00348)	(0.00491)
ar12	-0.00363***	0.0101***	0.0102***	0.0290***	0.00832***	0.0208***	0.0224***	0.0536***
	(0.000794)	(0.00233)	(0.00303)	(0.00351)	(0.00123)	(0.00282)	(0.00361)	(0.00512)
N	3,889,512	564,816	432,312	253,704	1,413,243	325,585	254,511	155,448
R^2	0.678	0.753	0.775	0.911	0.745	0.751	0.778	0.913
Robust standard errors in parentheses								
*** p<0.01, ** p<0.05, * p<0.1								

In Table 5 we report results from estimating equation (3) with redefined control samples. Since our original control sample included countries that experienced some loss in connectivity, we may expect (in an absolute sense) a slight downward bias in our estimates of β reported in Table 3. However, results we report in Table 5 are virtually identical to those in Table 3, with the immediate effect of a 50% reduction in flights reducing U.S. imports by 8.8% to 21.4% and Japanese imports by 14.8% to 27.9%, depending on which subsample we use. At first blush, we might infer that the loss in connectivity experienced by countries outside the geographic footprint of Eyjafjallajökull had negligible impacts on US bound airfreight originating from those countries. However, the downward bias that we were expecting in Table 1 may have been offset by a positive bias on account of the differential pre-eruption trends between control and treatment groups. Importantly, the trend in the average volume of airfreight in our original control sample is more than twice that in the treatment, which would, all else equal, overstate the impact of the eruption.

Although the near 1:1 correspondence in pre-treatment trends between the treatment and the redefined control groups gives considerable more credence to the parallel paths assumption implicit in our empirical strategy, in the absence of randomization it is impossible to rule out effects from extraneous factors. However, we can certainly attempt to limit the effects of these extraneous factors. In Table 6, we attempt to do precisely that. Our strategy is to better match the treatment and control samples. We do this by restricting our attention to countries directly impacted by the volcanic ash, but use data on shipments of sea freight to the US as our control, also including time-effects for imports that are specific to both HS category and country of origin and the 12 lags of the dependent variable. Accordingly, this specification is essentially a matched pairs design without random assignment of the treatment, since the data are matched by country.

Implicitly we have made two assumptions. First, the effect of airspace closures did not spill over into sea freight. This seems reasonable given the short-lived nature of the disruption, and is also consistent with some of our earlier evidence reported in Table 2. Second, the trend in air freight absent the disruption to air traffic mirrors the trend in sea freight. The pre-eruption data are certainly very consistent with this assumption, both when we examine averages across all countries, but also when we examine averages across HS categories for any given country. Our results yield slightly lower coefficients of $\beta_{air\ freigt}$ when using either all observations or observations on continuously active trade relationships. The other two samples, relationships with positive flows in either the three or six months preceding the disruption, yield significantly higher estimated coefficients, indicating that the effect of the disruption was potentially much higher for some relationships. The estimated reduction in imports from the affected countries is now between 8.2% and 51.9% for the U.S. and 6.8% and 47.3% for Japan, depending on which subsample we use.

Table 6 - European sea freight as control group									
	(1)	(2)	(3)	(4)		(5)	(6)	(7)	(8)
	U.S. Imports, 10-digit HS data					Japanese Imports, 9-digit HS data			
$\beta_{air\ freight}$	-0.209***	-1.462***	-0.767***	-0.172***		-0.358***	-1.282***	-0.803***	-0.140**
	(0.0240)	(0.0572)	(0.0510)	(0.0344)		(0.0399)	(0.104)	(0.1000)	(0.0699)
ar1	0.0634***	0.113***	0.126***	0.161***		0.0253***	0.0724***	0.0815***	0.134***
	(0.000859)	(0.00427)	(0.00596)	(0.00661)		(0.00151)	(0.00749)	(0.00961)	(0.0132)
ar2	0.0424***	0.0693***	0.0900***	0.0894***		0.0160***	0.0645***	0.0881***	0.0853***
	(0.000764)	(0.00378)	(0.00548)	(0.00545)		(0.00135)	(0.00681)	(0.00922)	(0.0122)
ar3	0.0207***	0.0252***	0.0539***	0.0382***		0.00373***	0.0177***	0.0539***	0.0492***
	(0.000730)	(0.00356)	(0.00520)	(0.00505)		(0.00129)	(0.00648)	(0.00922)	(0.0125)
ar4	0.00804***	0.00898***	0.0175***	0.0164***		-0.00601***	0.00319	0.0288***	0.0315***
	(0.000708)	(0.00348)	(0.00505)	(0.00477)		(0.00124)	(0.00613)	(0.00835)	(0.0102)
ar5	0.00157**	0.00505	0.0200***	0.00942**		-0.00943***	-0.0108*	-0.00104	-0.00512
	(0.000691)	(0.00335)	(0.00474)	(0.00477)		(0.00122)	(0.00627)	(0.00754)	(0.0106)
ar6	-0.00569***	-0.00568*	-0.00455	-0.0103**		-0.0121***	-0.00534	-0.00224	0.00225
	(0.000685)	(0.00339)	(0.00471)	(0.00496)		(0.00121)	(0.00624)	(0.00844)	(0.0112)
ar7	-0.0111***	-0.0103***	0.00141	-0.00854*		-0.0185***	-0.0128**	-0.0151*	0.00567
	(0.000666)	(0.00314)	(0.00449)	(0.00482)		(0.00115)	(0.00577)	(0.00789)	(0.00959)
ar8	-0.0157***	-0.00634*	-0.00605	-0.0166***		-0.0207***	-0.0134**	-0.00468	-0.000980
	(0.000659)	(0.00325)	(0.00434)	(0.00458)		(0.00113)	(0.00550)	(0.00751)	(0.00990)
ar9	-0.0164***	-0.0116***	-0.0128***	-0.00967**		-0.0201***	-0.0187***	-0.0123*	-0.0340***
	(0.000656)	(0.00308)	(0.00390)	(0.00454)		(0.00111)	(0.00573)	(0.00743)	(0.00949)
ar10	-0.0149***	-0.0147***	-0.0200***	-0.0241***		-0.0164***	-0.0148***	-0.0192***	-0.0111
	(0.000660)	(0.00311)	(0.00388)	(0.00456)		(0.00112)	(0.00566)	(0.00740)	(0.0107)
ar11	-0.0107***	-0.0104***	-0.0136***	-0.0148***		-0.00455***	0.00410	0.00268	0.0140
	(0.000669)	(0.00308)	(0.00380)	(0.00462)		(0.00114)	(0.00567)	(0.00713)	(0.00998)
ar12	-0.00157**	0.00376	0.00592	0.0142***		0.0155***	0.0126**	0.0145*	0.0502***
	(0.000684)	(0.00310)	(0.00385)	(0.00473)		(0.00120)	(0.00597)	(0.00760)	(0.0114)
N	5,013,144	292,032	206,544	106,176		1,603,032	81,696	58,704	25,536
R^2	0.666	0.741	0.78	0.897		0.665	0.721	0.744	0.885
Robust standard errors in parentheses									
*** p<0.01, ** p<0.05, * p<0.1									

4.4. Industry-Level Analysis by HS 2 Sections

By incorporating fixed effects, our regressions thus far have accounted for industry- and even product-level variation within the data. However, each of these specifications assumes that flight cancellations in affected countries had the same impact across products. In this sub-section we attempt to “unpack” this aggregate coefficient into 21 separate coefficients, by estimating a separate regression for each HS 2 section. Although a variety of sensitivity analyses were conducted using static and dynamic models, as well as combinations of air and sea freight data, our findings were qualitatively similar across these variations. Accordingly, we report only a subset of these broader results, which, in order to facilitate comparisons with earlier findings, are based estimating equation (3) on air freight for each of the 21 HS 2 chapters. For space considerations in Table 7, we do not report the coefficients on the lagged dependent variables, instead reporting only the short term impacts of the disruption.[15] The control sample for our analysis in Table 7 is composed of all countries that did not impose airspace restrictions in the month of April.

Not surprisingly, our results suggest differential impacts following the air traffic disruption across different HS sections. Despite this variation, some broad-stroke conclusions can be drawn. First, for many industries and HS sections, the effect of the disruption on air freight to the US was unclear. Although in most of the 21 HS sections, the coefficient on the treatment factor is negative, we can only estimate this coefficient with reasonable precision for six sections.[16] In every other the case, the variation in import volumes is well within plausible ranges of uncertainty. Second, in some industries the effect was substantial as we document next, indicating a great deal of variation in the effect and susceptibility of different industries to unexpected shocks to the transportation network.

The two industries most consistently affected by the disruption are Section 11, "Textiles and Textile articles," and Section 16, "Machinery and mechanical appliances, electrical equipment, television image and sound recorders and reproducers" for both U.S. and Japanese data, with significant and negative semi-elasticities in every (sub)sample. For textiles, cancellation of 50% of flights reduces U.S. imports by between 15.7% and 46.6% and Japanese imports by between 26.6% and 74.7%. In the case of appliances and electrical equipment the reduction is between 7.3% and 12.1% for U.S. imports and 11.3% and 15.5% for the Japanese imports. In the case of U.S. imports, two additional industries have a consistently negative estimated semi-elasticities, Section 15, "Base metals, and Section 20, "Miscellaneous manufactured articles." For the former the reduction in imports is estimated to have been between 7.3% and 12.1% in response to a cancellation of 50% of flights and for the latter it is between 17.5% and 45.4%. For the remaining industries, the effect on U.S. imports is estimated to be significant in some subsamples. In the case of Japanese imports, Section 10, "Pulp wood, recovered paper," is estimated to have had a

[15] Where the estimate of the effect of the disruption on trade is missing it is because the sample in that HS 2 section was too small.

[16] Depending on the subsample, two HS 2 sections in U.S. data and up to seven HS 2 sections in Japanese data have a positive coefficient, though always imprecisely estimated.

Table 7 - Estimates by HS 2 Sections

HS Sections	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	U.S. Imports, 10-digit HS data				Japanese Imports, 9-digit HS data			
1 - Live animals, animal products	-0.250	-0.421	-0.455	-0.621	-0.134	-0.099	0.249	-0.326
2 - Vegetable products	-0.092	-0.774	-1.172	-0.406	-0.142	0.153	-0.228	-0.596
3 - Animal or vegetable fats and oils	0.072	-1.001		-0.074	0.149			
4 - Prepared foodstuffs, beverages, tobacco	-0.183	-0.337	-2.202		**-0.418****	-0.910	-1.039	**-1.039***
5 - Mineral products	0.086	**-4.396***	-0.410		0.098			
6 - Chemical and allied products	**-0.406*****	**-0.596****	**-0.503****	-0.156	0.075	-0.278	-0.075	0.068
7 - Plastics, Rubber	**-0.216*****	**-0.329****	-0.183	**-0.153***	**-0.250***	-0.578	**-0.726****	-0.200
8 - Raw hides and skins, leather goods	-0.074	-0.184	-0.407	-0.241	-0.242	-0.823	-0.443	**-0.643*****
9 - Wood and articles of wood, wood charcoal, cork, straw	-0.046	-1.921	**-4.118****		-0.194			
10 - Pulp of wood, recovered paper	-0.141	-0.237	0.354	-0.061	-0.027	**-1.703*****	**-1.525*****	**-0.407****
11 - Textiles and textile articles	**-0.324*****	**-1.255*****	**-0.912*****	**-0.645*****	**-0.618*****	**-2.745*****	**-2.344*****	**-1.328*****
12 - Footwear, headgear, umbrellas, prepared feathers, flowers, articles of human hair	**-0.341*****	-0.327	-0.199	**-0.680****	**-0.661*****	-0.810	-0.351	-0.218
13 - Articles of stone, plaster, cement, asbestos, mica, ceramics, glass	-0.170	**-0.994****	-0.367	**-0.305***	0.054	-0.341	-0.404	-0.307
14 - Pearls, precious stones and metals, imitation jewlery, coin	0.113	-0.341	-0.537	**-0.407****	0.165	**-1.135****	**-1.037***	-0.073
15 - Base metals	**-0.220*****	**-0.481****	**-0.335***	**-0.210*****	-0.056	**-0.478***	-0.184	-0.084
16 - Machinery and mechanical appliances, electrical equipment, television image and sound recorders and reproducers	**-0.258*****	**-0.227*****	**-0.197*****	**-0.152*****	**-0.239*****	**-0.246****	**-0.303*****	**-0.336*****
17 - Vehicles, aircraft, vessels	-0.056	-0.140	-0.193	0.003	0.0291	-0.585	**-0.905****	-0.208
18 - Optical, photographic, cinematographic, measuring, checking, precision, and medical instruments, clocks and watches, musical instruments	-0.101	-0.197	**-0.298*****	**-0.204*****	**-0.264****	-0.250	-0.071	**-0.165****
19 - Arms and ammunition	0.074	1.094	0.101	-0.458	-1.025			
20 - Miscellaneous manufactured articles	**-0.443*****	**-1.211*****	**-0.823*****	**-0.384****	-0.103			
21 - Works of art, collectors' pieces, and antiques	-0.621	0.060	-0.073	0.542	0.109	0.020	0.174	0.191

*** p<0.01, ** p<0.05, * p<0.1

significant effect in the three subsamples of the full data set, with the implied reduction after 50% of flights were cancelled of 18%.4 to 57.3%. For other Japanese imports across HS 2 sections, the effect is significant in some subsamples.

4.5. Data Aggregation

Our analysis so far has focused on 10-digit HS data in the case of U.S. imports and 9-digit HS data in the case of Japanese imports. Such disaggregated data maximizes variations in the data allowing us to identify the effect of Eyjafjallajökull's eruption on trade. Methodologically an interesting question to ask is whether one can identify the effects of the disruption in more aggregated data. Our analysis of effects by HS 2 sections reveals that the overall effect we have identified is driven by a small subset of the 21 HS 2 sections. We now examine whether we can still identify an effect after first aggregating our data to the 2-digit HS level. Our results are presented in Table 8 where we estimate equation (3).

Note first that aggregation significantly reduces the sample size. The 6.5 million observations[17] on all air freight imports of the U.S. are reduced to 215,928, slightly over 3% of the original sample. Depending on which subsample we use, we have 8-13% of U.S. imports observations remaining after aggregation. For Japanese data, aggregation leaves us with just 7% of all observations and 15-23% of observations in the other three samples. Aggregating the data to 2-digit HS level drastically reduces the size of the two data sets and potentially eliminates much of the variation.

However, despite such large reductions in the number of observations, our results indicate we can still identify the effect of the disruption. In fact, in the case of U.S. imports the effect of the disruption is now larger, -0.377 when all observations are used, and more stable across the additional three subsamples we examine. The implied effect of a cancellation of 50% of flights is now a range between 15.4% and 17.2% reduction in imports, roughly in the middle of the range of the estimated effect with 10-digit data which was between 10.0% and 21.8%. The estimated coefficient in the case of Japan is not significant when all observations are used, though it does become significant in the remaining three subsamples and is smaller than with 9-digit data. The implied reduction in imports

[17] This number is based on column (1) of Table 3. It is by some 3 million observations lower than the sample in column (1) of Table 1 on the account of the inclusion of the 12 lags of the dependent variable.

after 50% of flights were cancelled is between 8.5% and 14.2%, at the low end of the range implied by 9-digit data, which was between 11.9% and 27.5%. The fact that we can still identify the effect of the disruption underscores the significance of such disruptions and their ability to reduce trade, even if they are of short duration.

Table 8- Air freight estimates with HS2 aggregated data								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	U.S. Imports, 2-digit HS data				Japanese Imports, 2-digit HS data			
$\beta_{air\ freight}$	-0.377***	-0.350***	-0.360***	-0.335***	-0.106	-0.189*	-0.306***	-0.178***
	(0.113)	(0.116)	(0.101)	(0.0467)	(0.101)	(0.114)	(0.0910)	(0.0571)
ar1	0.0589***	0.140***	0.162***	0.196***	0.0500***	0.136***	0.172***	0.212***
	(0.00470)	(0.0118)	(0.0147)	(0.0105)	(0.00530)	(0.0103)	(0.0122)	(0.0142)
ar2	0.0372***	0.0783***	0.104***	0.0892***	0.0142***	0.0424***	0.0598***	0.0703***
	(0.00413)	(0.00911)	(0.0108)	(0.00901)	(0.00453)	(0.00901)	(0.0107)	(0.00920)
ar3	0.0138***	0.0343***	0.0540***	0.0280***	-0.00475	0.00464	0.0272**	0.0196*
	(0.00380)	(0.00824)	(0.0105)	(0.00886)	(0.00459)	(0.00909)	(0.0114)	(0.0103)
ar4	-0.00109	0.0116	0.0253**	0.00475	-0.0157***	-0.0162*	-0.00863	-0.0241**
	(0.00361)	(0.00788)	(0.0102)	(0.00853)	(0.00444)	(0.00857)	(0.0104)	(0.0101)
ar5	-0.0118***	-0.00867	-0.00163	0.00188	-0.0180***	-0.0106	0.00596	-0.0208*
	(0.00360)	(0.00834)	(0.00965)	(0.00778)	(0.00429)	(0.00893)	(0.0106)	(0.0109)
ar6	-0.0158***	-0.00199	0.000330	-0.00170	-0.0268***	-0.0230***	-0.0189*	0.000747
	(0.00350)	(0.00810)	(0.00931)	(0.00795)	(0.00448)	(0.00886)	(0.0105)	(0.00995)
ar7	-0.0188***	-0.00293	0.00251	-0.00672	-0.0232***	-0.0301***	-0.0275***	-0.0370***
	(0.00343)	(0.00795)	(0.00931)	(0.00818)	(0.00437)	(0.00841)	(0.00968)	(0.00836)
ar8	-0.0185***	-0.0156**	-0.00702	-0.0272***	-0.0312***	-0.0330***	-0.0341***	-0.0228***
	(0.00336)	(0.00784)	(0.00918)	(0.00773)	(0.00408)	(0.00796)	(0.00877)	(0.00848)
ar9	-0.0211***	-0.0164**	-0.0137	-0.0111	-0.0257***	-0.0288***	-0.0269***	-0.0268***
	(0.00331)	(0.00679)	(0.00840)	(0.00724)	(0.00411)	(0.00709)	(0.00897)	(0.00819)
ar10	-0.0130***	-0.00263	0.0111	-0.0151**	-0.0145***	-0.00286	0.00828	-0.0254***
	(0.00333)	(0.00746)	(0.00858)	(0.00737)	(0.00409)	(0.00814)	(0.0106)	(0.00894)
ar11	-0.00699**	0.00793	0.0134	0.0111	0.0133***	0.0274***	0.0392***	0.0515***
	(0.00343)	(0.00760)	(0.00968)	(0.00834)	(0.00428)	(0.00908)	(0.0106)	(0.00908)
ar12	0.0106***	0.0338***	0.0337***	0.0586***	0.0366***	0.0666***	0.0833***	0.108***
	(0.00379)	(0.00875)	(0.0105)	(0.00817)	(0.00482)	(0.00996)	(0.0113)	(0.0109)
N	215,928	78,864	71,208	56,160	145,896	54,048	47,568	37,248
R^2	0.809	0.772	0.802	0.942	0.831	0.809	0.844	0.941
Robust standard errors in parentheses								
*** p<0.01, ** p<0.05, * p<0.1								

5. Conclusion

The international transportation network is susceptible to a range of shocks which reduce its ability to deliver goods across and within borders. The nature of the shocks ranges from man-made, consequences of terrorist attacks or labor stoppages, and caused by nature, be that hurricanes, earthquakes, or volcanos. In this paper we have focused on the ability of the international transportation network to weather an unexpected shock caused by nature. We conduct a natural experiment using the 2010 episode of the eruption of Iceland's Eyjafjallajökull volcano which caused the European airspace to be closed to varying degrees for an eight day period in the second half of April. All told some 107,000 flights were cancelled, averaging to about 50% of all flights over Europe over that period.

Unlike most shocks to the international transportation network, this particular episode offers a clean natural experiment. Volcano eruptions are sufficiently unpredictable that importers and exporters were unable to plan for the interruption and adjust their behavior in advance. Hurricanes potentially offer somewhat more time for adjustment, and man-made shocks such as labor stoppages offer yet more time for adjustment. While terrorist attacks, earthquakes, and hurricanes, provide little opportunity for advance planning and can be considered unexpected in nature, they suffer from another drawback if one wants to analyze the effect of unexpected shocks – they are frequently, if not always, accompanied by significant infrastructural damage making it difficult to decouple the effect of the event itself from the accompanying infrastructural damage. In the case of terrorist attacks there may be accompanying effects due to a change in import or export procedures made in the interest of security, as was done in the U.S. after the attacks of September 11. The advantage of Eyjafjallajökull's eruption is its sudden and unexpected eruption and lack of any infrastructure damage. Thus, all reduction in trade is purely due to the closure of airspace and resulting cancellation of flights.

We use detailed monthly product-level data for U.S. and Japanese imports disaggregated by mode of transportation to examine the effect of the disruption on international trade. Using a difference-in-differences strategy we find that the average rate of cancelled flights of 50% reduced U.S. imports by air from the countries affected by the closure of airspace ranging from 10.9% and 21.8%, while Japanese imports by air were reduced by between 11.9% and 27.5%. We show that the international transportation network did not adjust by allowing for substitution between air and sea freight, as we could not identify an increase in seaborne trade. This may have been due to the shortness of the disruption caused by the volcano, however unexpected its duration was initially, or due to the rigidity and inflexibility of the transportation network associated with quickly relocating freight from air to sea.

Our results are robust to alternative definitions of the control group. We also show that the effect of the disruption was not uniform across the industries, with only a relatively small subset of them showing a significant effect of the disruption. Two industries in particularly were heavily affected for both the U.S. and Japan, Textiles and textile articles and Machinery and mechanical appliances, electrical equipment, television image and sound recorders and reproducers. In the case of the U.S. Base metals and Miscellaneous manufactured articles were also heavily affected as were Pulp of wood and recovered paper for Japan. Finally, we show that the effect of the disruption was sufficiently large to be detectable in data aggregated from thousands of products codes to just 97 categories of the 2-digit HS classification system. The implied reduction in U.S. imports in aggregated data is between 15.4% and 17.2% and between 8.5% and 14.2% for Japanese imports in response to 50% of flights being cancelled.

We consider the estimated effect of the disruption, ranging between 10.9% and 21.8% for U.S. data and between 11.9% and 27.5% for Japanese data, to be large and economically meaningful. Not that these effects quite plausibly could be underestimated despite our best efforts to eliminate all biases we can control for. It is quite likely that once the European airspace reopened that there was a larger than usual number of flights leaving Europe in order to reposition the aircraft and to carry the stranded passengers to their ultimate destinations. Such an increase in air traffic above the average amount could have delivered some of the stalled trade volume that was prevented from being delivered during the disruption. Monthly data do not allow us to decouple the reduction in trade due to cancelled flights and an increase in trade due to increased air traffic. Thus, our results should be thought of as the lower bound of the effect of the disruption, or a net effect.

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