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Prices and Supply Disruptions during Natural Disasters
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ABSTRACT

We study the daily behavior of supermarket prices and product availability following two recent natural disasters: the 2010 earthquake in Chile and the 2011 earthquake in Japan. In both cases there was an immediate and persistent effect on product availability. The number of goods available for sale fell 32% in Chile and 17% in Japan from the day of the disaster to its lowest point, which occurred 61 and 18 days after the earthquakes, respectively. Product availability recovered slowly, and a significant share of goods remained out of stock after six months. By contrast, prices were stable for months, even for goods that were experiencing severe shortages. These trends are present at all levels of aggregation, but there is heterogeneity across categories. We further look at the frequency and magnitudes of price changes in both countries and find that the results in Chile are consistent with pricing models where retailers have fear of "customer anger". In Japan the evidence suggests a bigger role for supply disruptions that restricted the ability of retailers to re-stock goods after the earthquake.

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1 Introduction

Natural disasters compel governments to act quickly to save lives and ensure that their citizens have access to basic goods and services during the emergency. International organizations typically step in quickly to provide aid. Yet these efforts are often stunted by a lack of timely and accurate information about the most pressing needs of the affected population. Data on the type of goods that are unavailable at the stores, as well as information on which of them are experiencing price increases, could be vital for some of those efforts. Furthermore, Central Banks and other government agencies need to forecast the effects of the disaster on inflation and economic activity, yet data on industrial production, GDP, and prices may not be collected and published for months.

In this paper we propose using online data to measure two key economic factors in the aftermath of a natural disaster: supply disruptions and pricing behaviors. We use data from the Billion Prices Project (BPP) at MIT, a large and continuing effort to collect online information from large retailers around the world on a daily basis. We construct daily price indices across various goods and categories and measure the degree of supply disruption with an index of product availability, which tracks the number of goods that are available for purchase over time.

We focus on the earthquakes in Chile (2010) and Japan (2011), two major catastrophic natural disasters that occurred in countries where the BPP was collecting data before the events. We also limit our analysis to products sold in supermarkets, such as food, beverages, and other basic necessities which are more likely to experience shocks after a natural disaster and for which we have more comprehensive data coverage.

We show that these natural disasters had an immediate impact on product availability. A large share of goods went out of stock within days. The fall was gradual but larger in Chile, where the number of products available fell by 32% in the first two months after the earthquake, recovering slowly after that. In Japan, the fall was faster but smaller, with product availability dropping by 17% within 18 days after the earthquake, and recovering gradually after that.

Prices, by contrast, remained surprisingly stable for several months after the earthquakes. The inflation rate started to rise only after 4 months in Japan, and 6 months in Chile.

Nearly all categories of goods experienced a drop in product availability in both countries during the first months. The recovery and price-change behaviors differed significantly across categories. Many goods that could be considered indispensable after an earthquake, such as powdered milk, diapers, and baby food, disappeared quickly from the stores and maintained stable prices for a long time. Others, such as batteries, had drops in availability but they recovered quicker with rising prices.

In Chile, the data is consistent with the predictions of a growing body of theoretical literature that in recent years has emphasized how fear of "consumer anger" may affect firms' pricing decisions by delaying price adjustments.[1] In particular, the frequency of price changes falls dramatically for several months after the earthquake. In Japan, the evidence is more consistent with a supply shock that affected the retailer's ability to re-stock items. We show that the product availability index has a surprisingly close co-movement with the official estimates of industrial production.

At the goods-level, we show that the stockout hazard rate (the probability of a good going out of stock conditional on the days since the natural disaster), was highest in the week after the earthquakes and fell gradually over time. By contrast, the price-change hazard increases slowly over time. These effects are stronger for "emergency" goods, which are in high demand after an earthquake, and milder in perishable goods, which tend to be less affected by customer anger concerns.

2 The Earthquakes in Chile and Japan

On February 27, 2010, a strong earthquake (8.8 on the moment magnitude scale) struck off the coast of central Chile. The earthquake was felt strongly in six Chilean regions (from

[1] See, for example, Rotemberg (2011)

Valparaiso in the north to Araucania in the south) that include approximately 80% of the country's population. The earthquake also triggered a tsunami which caused widespread destruction in coastal towns of south-central Chile, prompting President Michelle Bachelet to immediately declare a "state of catastrophe" and to deploy emergency workers to the affected areas.

Concerns about possible food scarcity and price increases, even in areas that were not directly impacted, quickly surfaced on the news. The bakery's association complained about unjustified increases to the price of flour, and there were multiple consumer complaints about substantial price increases of basic staples.[2] On February 28, President Bachelet announced the government had reached an agreement with the major supermarkets which would require them to give away basic foodstuffs in stock to people affected by the earthquake.[3] In newspaper interviews, government officials also threatened to enforce a law enacted in the 1970's to penalize anyone who in the aftermath of a natural disaster sells basic staples at excessive prices.[4]

Chile's earthquake ranks as one of the most destructive in recent years in terms of economic damages, as Table 1 shows. The total economic damages caused by the earthquake were estimated at $30 billion, or 19% of GDP, according to the CRED International Disaster Database (EM-DAT).

Table 1: Top Natural Disasters by Total Damages (2008-2012)

Country	Date	Type	Killed	Damages (US$ millions)	Damages (% of GDP)
Japan	11-Mar-11	Earthquake (9.0 M_w)	19,846	210,000.00	3.85
China	12-May-08	Earthquake (8.0 M_w)	87,476	91,285.30	2.43
Thailand	5-Aug-11	Flood	813	40,000.00	12.56
United States	12-Sep-08	Storm	82	32,218.34	0.21
Chile	27-Feb-10	Earthquake (8.8 M_w)	562	30,900.90	18.65

Source: Authors' calculation based on EM-DAT and WDI databases.

[2]See `http://bit.ly/12zcQDg`
[3]See `http://bit.ly/18dqv8L`
[4]See `http://bit.ly/17bXVTPI`

On March 11, 2011, an even stronger earthquake (9.0 on the moment magnitude scale) struck off the Pacific coast of Japan, triggering a powerful tsunami with severe human and economic consequences. Initial disruptions in Japan were larger than in Chile, particularly because the tsunami caused a nuclear accident in a power-generating plant (the Fukushima Daiichi Nuclear Power Plant complex), forcing the evacuation of thousands of residents in the vicinity of the plant. According to press reports, approximately 4.4 million households in northeastern Japan were left without electricity and 1.5 million without water for days. Nearly 16,000 people were killed as a direct result of the disaster.

Within days after the earthquake the press reported shortages of food and gasoline in regions of Japan as people hoarded basic items out of fear that supplies would soon dry up.[5] According to some reports, shoppers in the Tokyo metro area (150 miles from most affected areas) had cleaned supermarket shelves of items such as rice, bread, and yogurt. Moreover, many retailers claimed to have run out of emergency items such as blankets, sanitary pads, diapers, toilet paper, instant noodles, and flashlights.[6] Although reports and rumors in the media multiplied, there was very little reliable information on the magnitudes of the shortages.

Japan's total economic costs were estimated to be US$ 210 billion, making this event the costliest natural disaster in recent years in nominal terms. However, this represented only 4% of GDP, less than a third of the estimated cost in Chile. [7].

3 Data: The Billion Prices Project

Our data were collected as part of the *Billion Prices Project* (BPP), an academic initiative at MIT that has been "scraping" daily prices from the largest online retailers around the world since 2008. In this paper we use prices from the largest supermarket in Chile and one

[5]See `http://bit.ly/14Qatjw`

[6]See `http://bit.ly/1bascHs`

[7]There is a growing body of economic literature that tries to estimate the direct and indirect costs of natural disasters at different time horizons. See Cavallo and Noy (2011) for a recent survey

of the leading supermarkets in Japan. Database details are shown in Table 2. We focus on a 9-month window around the day of the natural disaster: 3 months before and 6 months after the event.

Table 2: Data Description

	Chile	Japan
Initial Date	December 2009	December 2010
End Date	August 2010	September 2011
Products	17141	3982
Categories	265	26
Days with no data*	42	6

Notes: * These are days where the scraping software failed.

The data collection method is based on the use of software that monitors the public web pages where retailers list product and price information, scans the underlying code to identify the relevant information (such as prices and availability), then stores everything in a structured database.[8]

An example of a good in our data is "Whole Milk, Brand Name, 1 liter". The scraping software automatically collects data on every single product on display on the retailer's website each day. Goods are listed on the website only if they are in stock and available for sale. Out of stock items therefore immediately disappear from our database, and only reappear on the day that they are offered for sale again (if ever). We can therefore build statistics to study how the set of goods available for purchase changes over time after a natural disaster. [9]

In terms of data treatment, our prices include taxes and sale discounts, to account for the final amount payed by the consumer. We do not include shipping costs, which vary

[8]See Cavallo (2012) for more technical details on the scraping methodology.

[9]Our results on product availability are only a lower bound on the degree of supply-chain disruptions because we only know if a good is completely out of stock (the extensive margin), but not how many units are available over time if it is still offered for sale (the intensive margin).

according to the location of the purchaser and are an exclusive feature of the online purchasing experience. In addition, missing prices in the data were often caused by scraping errors on days when the software fails to automatically start. For those dates, no data was collected. These failures are rare, and reported in Table 2. Finally, missing prices also occur when a good goes temporarily out of stock. For the price index calculations, if a good disappears and later reappears in our sample, we fill missing prices with the previously available values until a new price is observed.

Although online transactions are still a small share of retail sales in most countries, we are confident that the data collected online also provides information about offline prices and product availability. In the case of Chile, Cavallo (2012) presents the results of an online-offline validation with a randomly chosen sample of 100 goods for the same Chilean retailer used in this paper. Prices were sampled at an offline store in 15-day intervals between December 2008 and January 2009, then compared to the online prices for the same goods on the same day. Over 90% of goods in the offline store where also available online on the same date. Furthermore, for those available in both locations, price levels were identical in 89% of the cases. The 12 goods which had different prices were for raw food items that were sold online in packages with pre-defined sizes. These items were sold by weight in the offline stores, which could lead to small unit-price differences across the samples. While we do not have direct evidence of the difference between online and offline prices in the case of Japan, we note that Cavallo (2012) found that online retailers tend to have stable markups in percentage terms in many countries. If this is also the case in Japan, then it would imply similar online and offline inflation rates. An indirect way to test this for the case of Japan is to compare a supermarket price index with the CPI, as we do in the Section 4.

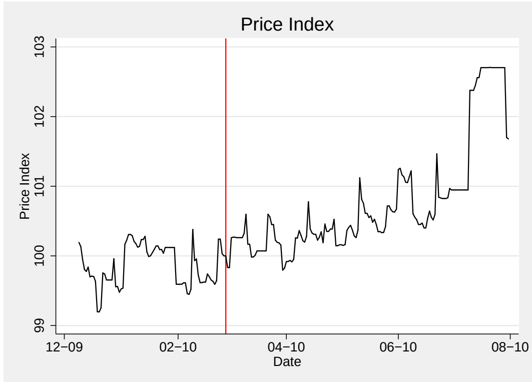
4 The Aggregate Impact: Prices and Product Availability

Natural disasters can create both supply and demand shocks that affect prices and product availability. Supply shocks originate in the destruction of production capacity and the disruption of supply chains. Demand shocks are linked to the panic that consumers may experience after natural disasters, with people rushing to the stores to purchase basic necessities and hoard goods that they fear could become unavailable in the days to come.

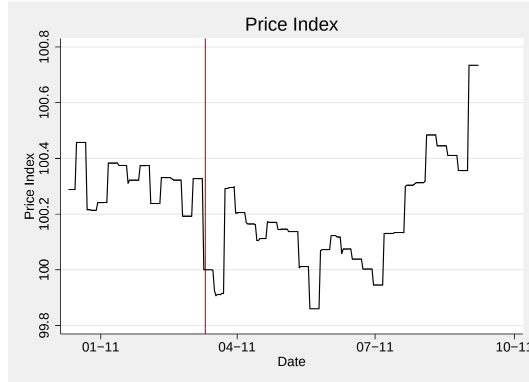
In this section, we look at aggregate prices and product availability in both Chile and Japan, and compare it to the predictions of recent pricing models.

4.1 Prices

Figure 1 shows a price index constructed with the online data. The index is normalized to a value of 100 on the day of the natural disaster in order to more easily track changes after the event, as well as better compare across countries. The vertical line marks the day of the natural disaster. The index is a simple Jevons geometric-average price index that uses all the products sold by these supermarkets and implicitly assigns equal importance to all goods. Details of the methodology and motivation for this index formula are provided in the Appendix.



(a) Chile



(b) Japan

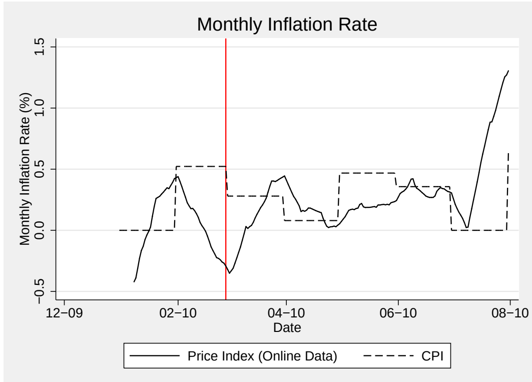
Figure 1: Price Index (Online Data)

Notes: Unweighed geometric-average price index. All the products available for sale each day are used.

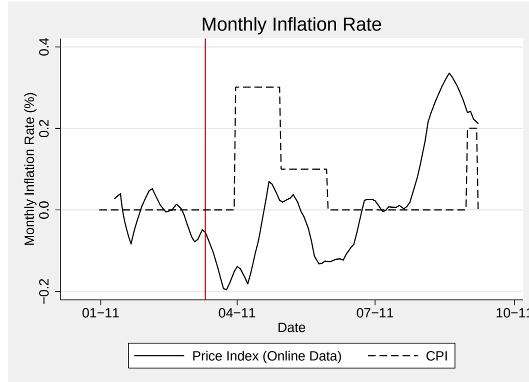
In both cases prices did not increase significantly during the first few months after the events. In Chile, the trend of the index remained remarkably stable after the earthquake. Prices only rose in mid-July 2010, almost 6 months after the earthquake.[10] In Japan, a similar pattern emerges. Before the earthquake, prices had a negative trend, which did not change during the first 4 months after the earthquake. Only in mid-August did the inflation trend change and prices start to rise.

The pricing trends in the supermarket data is consistent to those later reflected in official CPI data. This can be seen in Figure 2, where we plot a daily measure of "monthly inflation" at time t by taking the average in the index from t to $t-29$ and calculating the percentage change with respect to the same average a month before, from $t-30$ to $t-59$, and compare it to the monthly official CPI (all items, non-seasonally adjusted).

[10]Note that there is a relatively big spike in the Chilean index in late July. The scraping software failed for 10 days before this date, so this spike reflects accumulated price changes during this period. A similar thing happened at the end of August, with a large drop in the index.



(a) Chile



(b) Japan

Figure 2: Price Index (Online Data) vs. the CPI

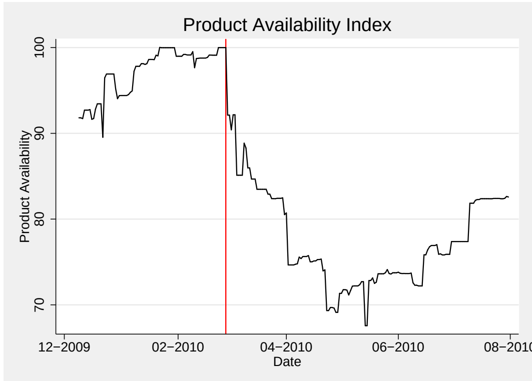
Notes: For our daily measure of "monthly inflation" at time t, we are taking the average in the index from t to $t-29$ and calculating the percentage change with respect to the same average a month before, from $t-30$ to $t-59$.

There is significant co-movement and even some anticipation in the online supermarket data, particularly in the case of Chile. Overall, CPI estimates were stable in both countries for several months, just as in our data. The only exception was a temporary spike in Japan's CPI in April 2011. This was driven by a 0.2% increase in fuel and transportation, categories of goods not covered in our sample.

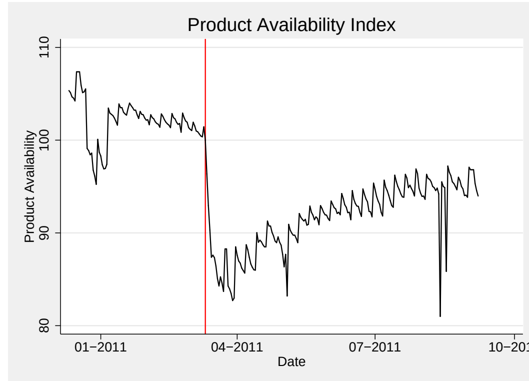
4.2 Product Availability

The rigidity of prices contrasts sharply with the behavior of goods availability in the aftermath of the earthquakes. Figure 3 shows indices of *product availability* for both countries.

We measure product availability with a simple index that captures how many items are for sale in the supermarket on a given day. We normalize the index to a value of 100 on the day of the natural disaster in order to be able to easily compute the change in product availability over time, as well as to facilitate comparisons across categories and countries. All goods sold by these retailers are included in each case, with every good having equal weight in the index. As such, these metrics are meant to show retailer-level effects. In the next section we compare results across categories.



(a) Chile



(b) Japan

Figure 3: Product Availability

In the case of Chile, overall product availability fell by almost 8% the day after the earthquake and decreased a further 25% from peak to trough (61 days after the earthquake). Product availability did not fully recover to pre-event levels during the sample window. Six months after the earthquake, the number of goods sold was still 15% lower than before the earthquake. Note that the index incorporates new goods, even if they were not sold before the earthquake. Therefore, if the pre-earthquake goods were being replaced with new varieties, these already have been counted in our availability index.

In Japan, product availability fell even faster and, initially, by a larger margin. It dropped approximately 17% from peak to trough (18 days after the earthquake). Japan's product availability started to recover quickly, although it remained below the pre-earthquake level during our sample window. After 6 months, the number of goods sold was still 5% lower than before the earthquake.

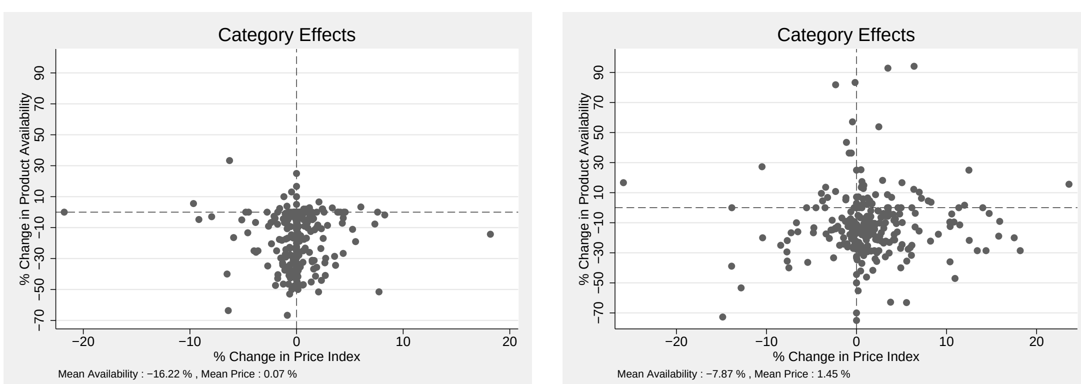
The Japanese index has two additional characteristics. First, there is a weekly pattern of ups and downs, which appears to be driven by re-stocking occurring on a weekly basis. This coincides with days in which most price changes take place, as we show later on. Second, there was a significant drop on December 22 (the day before the "Emperor's Birthday" holiday) that lasted until January 2 (the day after the "New Year's" holiday). We take this as evidence of how spikes in demand can affect availability.[11]

5 Category-Level Impacts

We now focus on category-level metrics to see if compositional effects play a role in the previous results. We also focus on the price and product availability behaviors of basic necessities.

An important advantage of online data is that products are automatically categorized by the retailers inside individual category pages. The names that identify the product categories are typically displayed on top of each page, in an area called the "breadcrumb." For example, the page where every whole milk product is shown would typically have this breadcrumb: "Home >> Groceries >> Diary >> Milk >> Whole Milk." We scraped the data at the most disaggregated level available in each retailer. We have 26 different categories in Japan, and 256 in Chile.

For each category we compute a product availability and price level index. We then calculate the percentage change in the first 30 and 180 days after the earthquake, and plot results for all categories in Figures 4 and 5. [12]

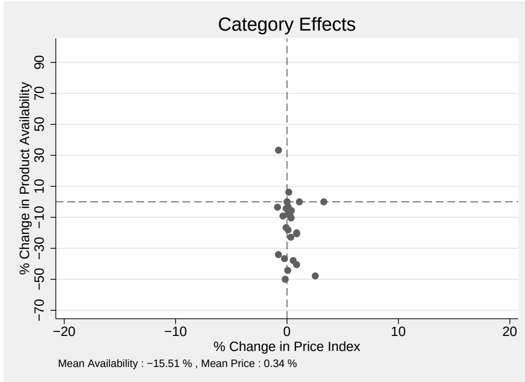


(a) 30-days (b) 180-days

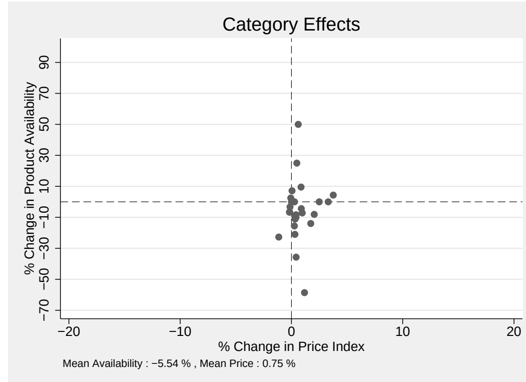
Figure 4: Chile: Changes in Availability and Prices

[11] There are also two single-day drops in September 2011 which were caused by scraping errors.

[12] Time series of availability and prices for a selected number of categories are shown in the Appendix.



(a) 30-days



(b) 180-days

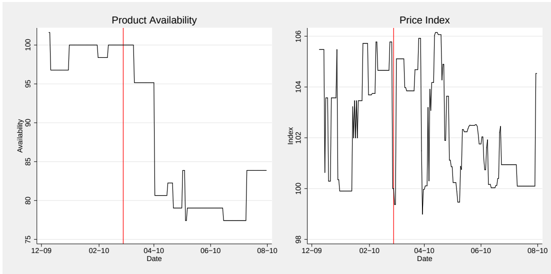
Figure 5: Japan: Changes in Availability and Prices

The y-axis shows the accumulated drop in product availability across categories. In both countries we see that most categories experienced significant availability drops in the first 30 days of the disaster and returned closer to their pre-disaster levels after 180 days. The aggregate results are therefore not driven by just a few categories. Instead, both of these earthquakes had an impact on the availability of nearly all categories of goods sold at the stores.

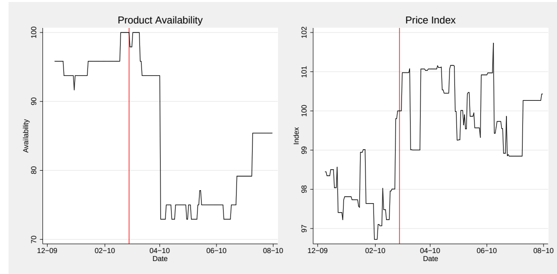
The x-axis, where the accumulated price changes in each category are plotted, shows a very different pattern. There are roughly the same number of categories with price increases and decreases, both at the 30 and 180-day horizons. While the aggregate price index is stable, there is clearly significant dispersion in pricing behaviors across categories.

We can further look at how the product availability and prices for each one of these categories changes over time.

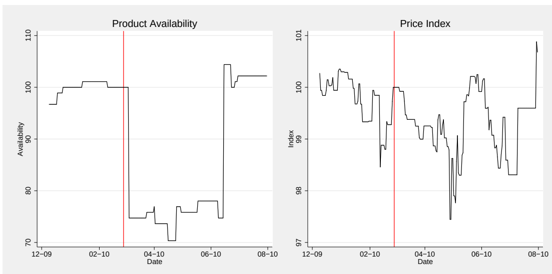
In Chile there was a set of goods whose product availability decreased significantly, by more than 50% within weeks. In some cases product availability fell within days of the earthquake. Examples include: pasta, powdered milk, and basic staples like baby diapers. In other cases the drop was more gradual. For example: baby foods, soups, and unflavored cookies. Note that all these are nonperishable goods that people are likely to stock up on if they are fearful of future scarcity. Notwithstanding the fall in product availability, in all these cases prices did not increase significantly for several months.



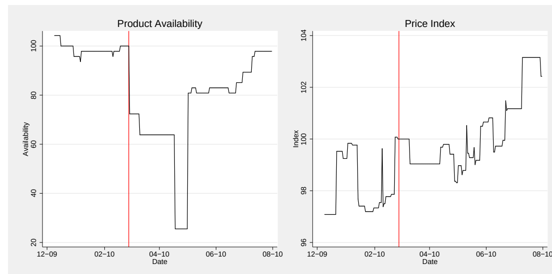
(a) Pasta



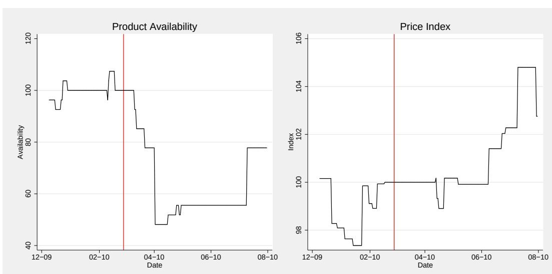
(b) Powdered Milk



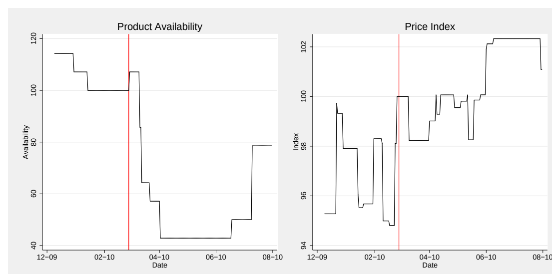
(c) Baby Diapers



(d) Baby Food



(e) Soup

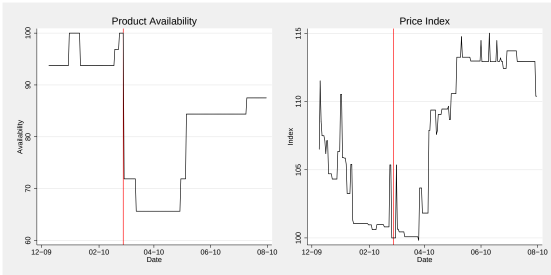


(f) Unflavored Cookies

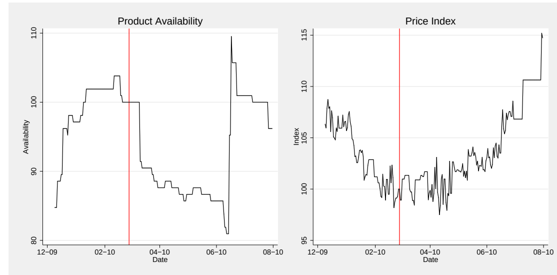
Figure 6: Chile - Drops in Product Availability and Stable Prices

Notes: In all cases the left graph is Availability, and the right graph is Price Index

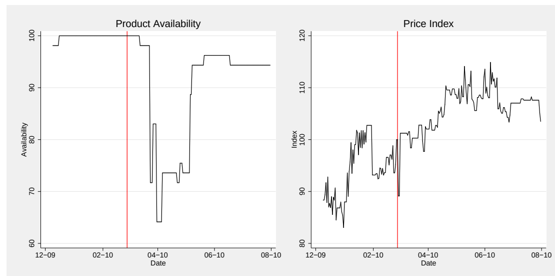
A second set of goods also had lower product availability; however, unlike the previous set, these goods experienced price increases after the earthquake. These included perishable goods like eggs, fresh vegetables, and meat.



(a) Eggs



(b) Vegetables



(c) Meat

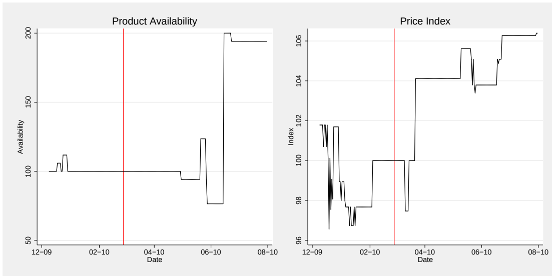
Figure 7: Chile - Drops in Product Availability and Higher Prices

Note: In all cases the graph on the left is Product Availability, and the graph on the right is the Price Index

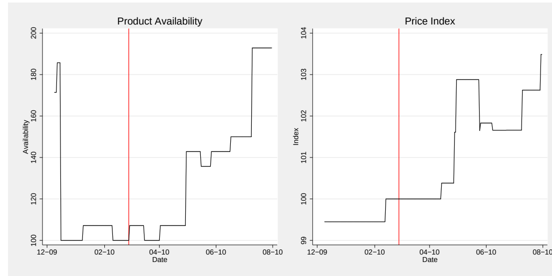
Goods that experienced no fall in product availability include fish and batteries. This is surprising, given that coastal towns were affected by the tsunami following the earthquake and also that demand for batteries might have increased in the aftermath of the event for fear of blackouts. It is likely, however, that the large price increases for these products may have helped to reduce demand and prevent stockouts.

Another case for which there was no product availability shortage was milk. In addition, milk had stable prices in the aftermath of the earthquake. This may be related to the efforts of the Chilean government, which specifically announced that basic products would be available to victims of the earthquake and used "milk" as an example. [13]

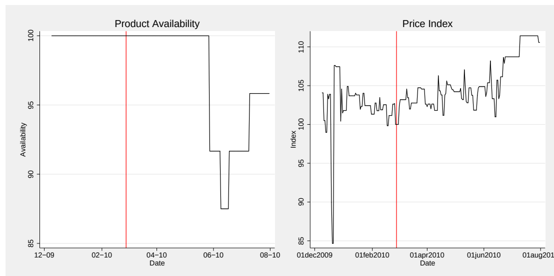
[13] See `http://bit.ly/13HyNY4`



(a) Fish



(b) Batteries

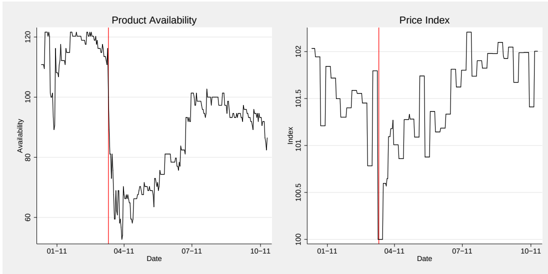


(c) Milk

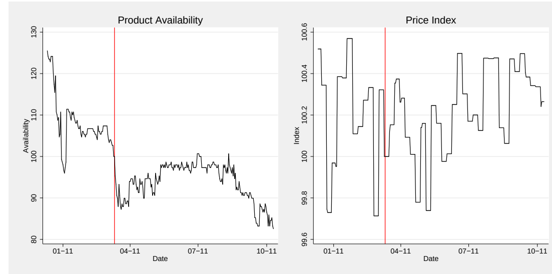
Figure 8: Chile - Stable Product Availability

Note: In all cases the graph on the left is Product Availability, and the graph on the right is the Price Index

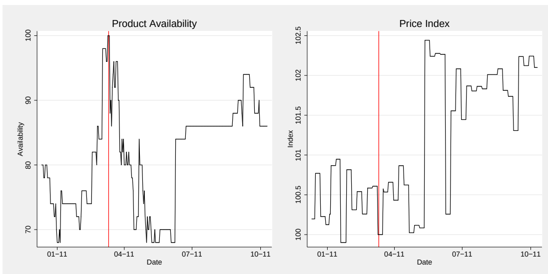
In Japan the product categories are much more broadly defined, due to the way the retailer chooses to group products in its website. Still, some interesting patterns emerge. First, we find fresh fish among the categories where stocks fell sharply after the earthquake. This is not surprising because many fishing ports in Japan were washed out by the tsunami, and health concerns arose due to the nuclear accident in Fukushima. Also, the stock of meat fell after the earthquake. Perishable items like meat cannot be stocked in large quantities. Notwithstanding the fall in product availability, in both cases prices did not change much after the earthquake. Another category where product availability fell was baby food. However, in this case, the price increased sharply (for Japanese standards) about a month after the earthquake, and product availability began to recover at the same time. Some categories, such as tea, suffered only mild decreases in availability, while prices increasing steadily after the shock.



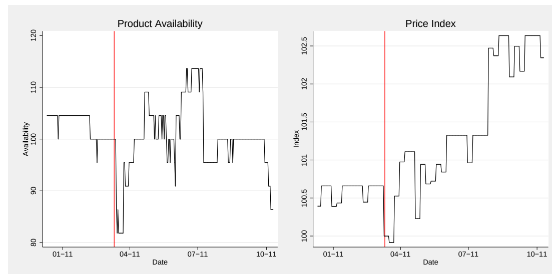
(a) Fresh Fish



(b) Meat



(c) Baby Food



(d) Tea

Figure 9: Japan: Categories

Notes: In all cases the left graph is Availability, and the right graph is Price Index

6 Supply Shocks and Consumer Anger

It is not surprising to see items that go out of stock in the days after an earthquake: people get scared, demand for some basic goods rises suddenly, and retailers have no time to react either with prices or stocks. What is harder to understand is how the combination of large stockouts and stable prices can persist for many months.

One possibility is that retailers are unable to re-stock due to a persistent supply shock disruption and, at the same time, that prices only get updated when a re-stocking takes place. For example, suppose that a retailer sets a simple markup over marginal cost, which becomes known at the time new goods are purchased from a wholesaler. This is often refered to as a“cost-plus” pricing stategy. If the supply chain is broken because of the earthquake, and some goods are not being produced, then the retailer will simply not be updating those prices at all. The prices of available goods (those that still have a positive stock) should also not significantly affected by the lack of availability in related goods that are no longer in stock. The combination of a cost-plus pricing and a persistent supply shock could therefore explain why so many goods remain out of stock and prices do not change for so long. When supply disruptions start to ease, retailers acquire goods at higher costs and both product availability and prices would increase at the same time.

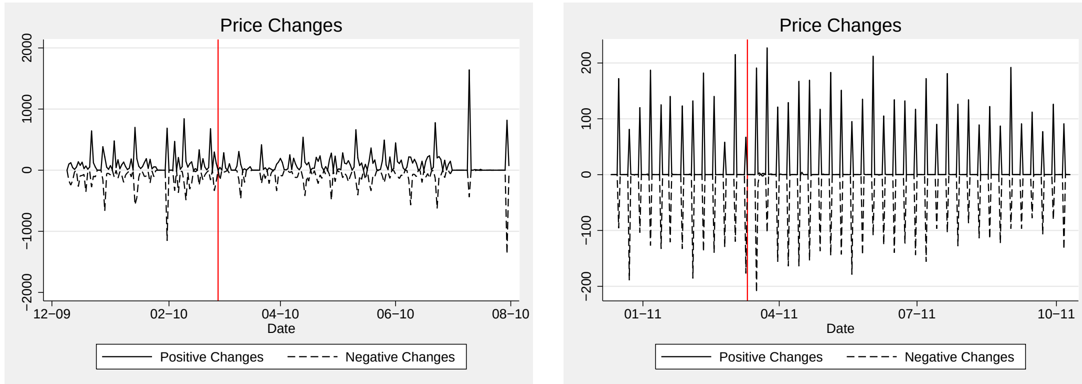
Another possibility is that retailers are able to re-stock at a higher cost, but they are unable to pass on some of those price increases onto retail prices. Retailer may be reluctant to change their prices due to fear of "customer anger". In macroeconomics, the importance of customer relationships and the effect on price changes goes back to the work of Okun (1981). Okun emphasized how firms care about repeated customer relations and therefore may refrain from raising prices when facing increases in demand, even though they may be more responsive to cost changes. The fear of antagonizing customers is also frequently mentioned by retailers in surveys as a reason for not changing prices often (Blinder et al. (1998), Fabiani et al. (2006)). Recent papers such as Rotemberg (2005) and Rotemberg (2011) provide models where consumers experience disappointment with price changes that they consider "unfair" and stop buying after that. In Rotemberg (2005) fairness enters directly into the utility function. Consumers expect producers to have a certain degree of altruism. They form expectations about the size of price change that is acceptable, and consider any increase larger than that to be unfair. This creates a sort of fairness threshold that can change with the amount and quality of information available to consumers. For example, if consumers think that the retailer's costs have increased, then they will tolerate higher price changes. The level of altruism expected from retailers could also change exogenously. In particular, during a natural disasters consumers could simply expect retailers to reduce their margins and be more altruistic. In Rotemberg (2011), fairness is linked to regrets that customers have from not buying the good before a price increase. In the context of an earthquake, for example, consumers may regret not having bought the products needed for an emergency kit, but they would not regret not buying perishable items that could not be stored. Regardless of the specific mechanism behind customer anger, after a natural disaster consumers are likely going to be more susceptible to fairness considerations. And if retailers cannot increase prices, they have no incentive to re-stock goods that have disappeared.[14]

Both of these explanations are plausible and not mutually exclusive. In fact,Okun (1981) emphasizes how worries about customer relationships can explain why so many firms use a cost-plus pricing strategy. Some of the results in the previous section are consistent with theories of customer anger, particularly in Chile. Non-perishable goods such as pasta, powdered milk, and baby food, had large drops in availability and no reaction in prices. These goods are likely in high demand after an earthquake, and since they are easy to stock consumers may not understand why retailers need to raise prices. By contrast, it may be easier for customers to understand that an earthquake will disrupt the supply of perishable goods, such as eggs and meat, raising their costs [15]. In the case of Japan, supply disruptions likely played a larger role, particularly with the power outages that followed the earthquake and the nuclear crisis in Fukushima.

Although the aggregate results are not enough to distinguish between these two theories, we can learn about their relative importance in each country by looking at some price-stickiness statistics. Figures 10 to 12 show the number, frequency, and size of price changes.

[14]In addition, even if retailers are not worried about customer reactions, they may be afraid of government sanctions. For example, in the case of Chile, a few days after the earthquake the government publicly threatened to apply a law from the 1970's that penalizes people who sell goods at "excessive" prices. The wording of the law is ambiguous; it states that it is unlawful to sell during times of emergency at "higher than official prices". Given than in Chile there were no price controls (i.e., no "official" prices), this ambiguity could provide a lot of leeway to authorities.

[15]Perishable goods can also be less affected by regrets for not buying them sooner, as Rotemberg (2011) points out



(a) Chile (b) Japan

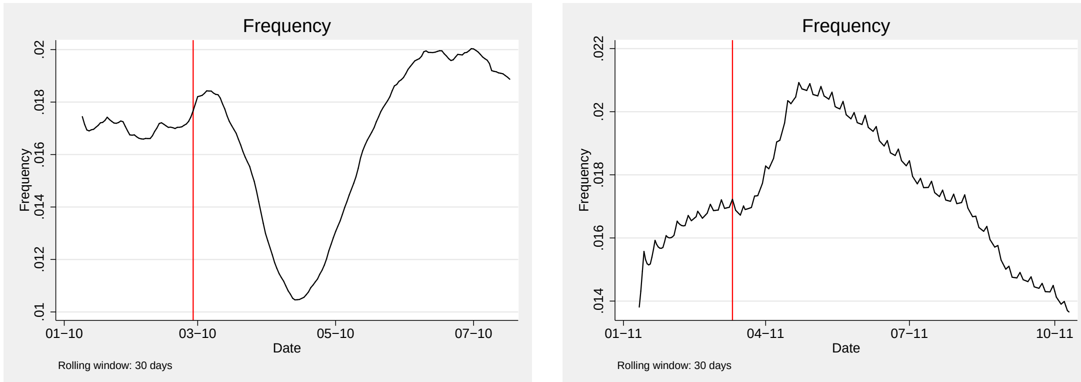
Figure 10: Price Changes

The effects of the earthquakes were noticeably different when we look at the number of price changes over time in each country, shown in Figure 10. In Chile, the number of daily changes fell immediately after the earthquake, consistent with the fear of "consumer anger" or threat of legal prosecution. In Japan, by contrast, there is little change in the number of price changes over time. About 100 prices were changed each week, both before and after the earthquake. There seems to be a lot of inertial behavior in this retailer's pricing decisions. The earthquake did not change the number of prices that changed per week, even though it had a large impact on the number of products available for sale.[16]

In Figure 11, we plot the "frequency of price changes" over time, defined as the number of changes by the total number of prices that can change each day. This is essentially an unconditional probability of daily price change, computed over a rolling window of 30-day averages to smooth out the daily volatility. Our price index is not only affected by the number of changes, but also by the magnitude of those changes, so in Figure 12 we also plot the average size of the absolute value of price changes, conditional on a change (i.e. the daily

[16]Note that, in both countries, pricing decisions are taken periodically, both for price increases and price decreases. This pattern is particularly strong in the case of Japan, where prices are changed only once a week. This is consistent with time-dependent pricing decisions, and they are likely connected to the times when stocks are replenished in the stores. Indeed, the index of product availability for Japan in Figure 3 has a similar pattern of weekly spikes, suggesting that the timing of re-stockings and price changes is closely related.

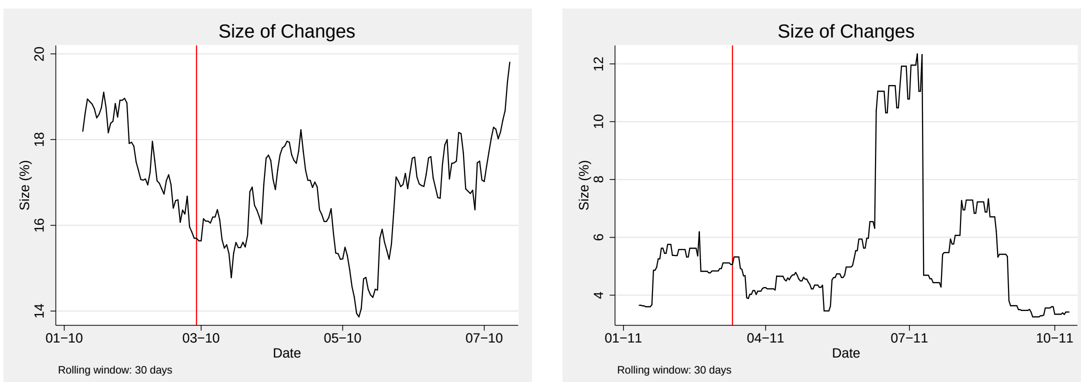
price change is not equal to zero). Here too, the difference between countries is significant and highlights the nature of price rigidities in each country after the earthquakes.



(a) Frequency Chile

(b) Frequency Japan

Figure 11: Price Stickiness: Frequency of Adjustment



(a) Chile

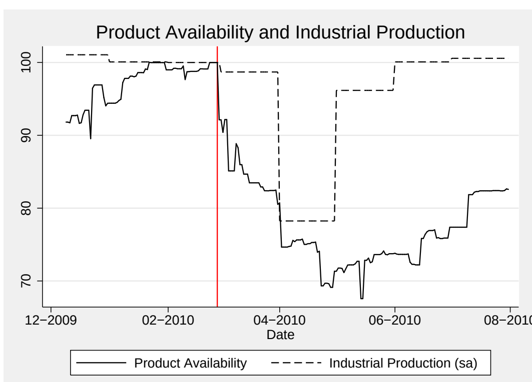
(b) Japan

Figure 12: Size of Changes

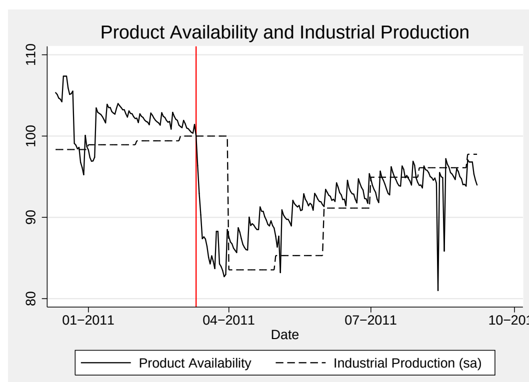
In Chile the frequency of changes fell from 0.018 to 0.01 after the disaster, with an implied duration of the average price spell (measured as 1/frequency) that goes from 55 to 100 days. The effect was both strong and persistent, lasting over 3 months. In addition, the size of price changes remained relatively stable, oscillating between 14% and 18% over this period.

By contrast, the data in Japan appears to be more consistent with a supply shock affecting the capacity of the retailers to replenish their stocks. The retailer continued doing the same number of price changes per week as before. But since product availability was falling, this led to an *increase* in the frequency of price changes. There are also huge swings in the magnitude of price changes, which jumped from 4% to 12% in June 2011, likely reflecting increases in wholesale prices that were being passed-on to consumers. This volatility in the frequency and size of changes is not consistent with pricing decisions that are affected by fears of customer anger.

Furthermore, if product availability remains constrained by a persistent supply shock, we should expect to observe similar trends in other statistics of manufacturing activity. Indeed, as Figure 13 shows, in Japan there is a surprising correlation between our index of product availability and the official index of industrial production published later on. By contrast, industrial production in Chile recovered very quickly after the earthquake, suggesting that the slow recovery of product availability was more related to customer anger and demand factors than to disruptions in the supply chain.



(a) Chile



(b) Japan

Figure 13: Availability and Industrial Production

7 Survival Analysis

In Section 4 we showed that the immediate effects of the natural disaster were mostly in product availability, not in prices. Section 5 shows that this applies to most categories of goods. We now extend the analysis to study good-level effects of price changes and stockouts. Our objective is to estimate the "Hazard Rate" of price changes (or stockouts). This is the probability of a price change (or stockout) conditional on the number of days since the natural disaster. We want to understand if, at the good level, there is evidence that the hazard rate of stockouts decreases with time after the disaster, while the hazard rate of price changes increases. We also want to see if goods that are considered necessities after an earthquake (e.g. those in a typical emergency kit) tend to behave differently in terms of their good-level hazards.

To measure hazard rates, we use standard methods in Survival Analysis, a technique that focuses on the time elapsed from the "onset of risk" until the occurrence of a "failure" event. In our context, the "risk" starts on the day of the natural disaster, and the "failure" is a stockout (or a price change). Formally, if T is a random variable measuring the duration of the price spell, with density function $f(t)$ and cumulative density $F(t)$, the hazard $h(t)$ is the limiting probability that a failure occurs at time t, conditional on the days passed since the natural disaster:

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t < T < t + \Delta t | t < T)}{\Delta t} \tag{1}$$

The hazard measures the instantaneous risk of a stockout over time, conditional on survival until that day. To estimate it, we use a non-parametric approach from Nelson (1972) and Aalen (1978), which does not require any distributional assumptions.[17] It starts with a simple estimate of the cumulative hazard function $H(t)$, given by:

$$\widehat{H}(t) = \sum_{j | t_j \leqslant t} \frac{c_j}{n_j} \tag{2}$$

where c_j is the number of failures at time t_j and n_j is the number of goods that can still fail at time t_j. The incremental steps c_j/n_j are an estimate for the probability of failure at t_j,

[17]Results are robust to the use of a semi-parametric Cox model that can incorporate covariates and account for unobserved heterogeneity at the category level.

taking into account only those goods that have survived until that point in time. Unlike the product availability index in previous sections, the hazard rate for stockouts will therefore not consider goods that are new after the earthquake (goods that were not available for sale before the earthquake, but that appear some time later on). This allows us to isolate the effects of the earthquake on goods that existed at the time of the disaster.

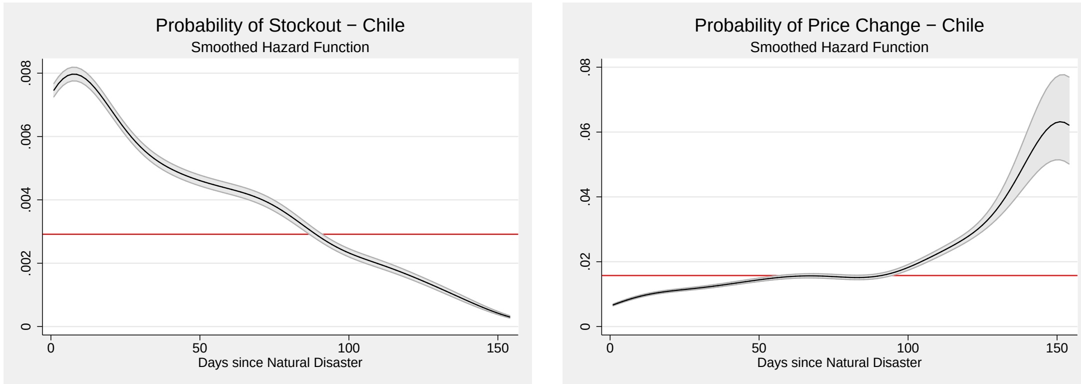
To obtain the smoothed hazard function $\widehat{h}(t)$, we take the discrete changes in $\widehat{H}(t)$ and weight them using a kernel function:

$$\widehat{h}(t) = \frac{1}{b} \sum_{j \in D} K\left(\frac{t - t_j}{b}\right) \Delta \widehat{H}(t_j) \tag{3}$$

where K is a symmetric kernel density, b is the smoothing bandwidth, and D is the set of times with failures.

We conduct the analysis separately for price changes and stockouts. Only the first occurrence of each of the failure events is considered for each good. That is, a good that disappears from the store at time t will not be used to compute the stockout hazard rate from then on, even if it re-appears later on. This is a fair assumption because any subsequent stockouts will not likely be linked to the natural disaster itself. Similarly, if a good has a price change after the natural disaster at time t, it will drop from our price-change hazard estimates from then on. We are implicitly assuming that the retailers fully adjust to the earthquake at the time when the first price change is implemented. An alternative assumption would be that retailers adjust gradually, implementing a series of small price changes over time. We do not, however, find any evidence of this behavior in this data.

Figures 14 and 15 plot the estimated hazard functions with 95% confidence intervals for both countries. In all cases, we include a horizontal line at the unconditional probability over the sample period.

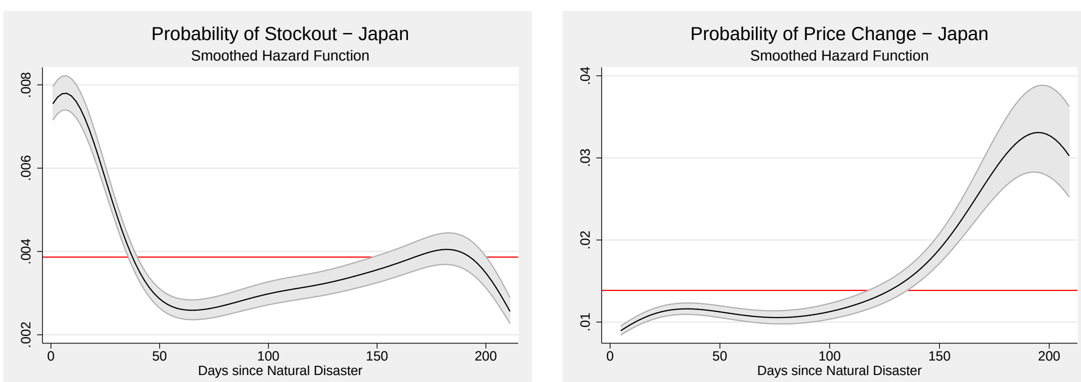


(a) Stockout Hazard

(b) Price-Change Hazard

Figure 14: Hazards in Chile

These hazards show that the daily probability of going out of stock immediately after the earthquake was close to 0.8% in both countries (approximately 20% in a month). This is significantly higher than the unconditional daily probability 0.3% per day in Chile (9% per month) and 0.4% in Japan (12% per month). This initial similarity between countries disappears after the first week. In Chile the stockout hazard falls gradually. The longer the amount of time since the disaster, the lower the probability a good has of disappearing from the store. The effect is persistent, with the stockout hazard remaining above the unconditional probability until around 90 days.



(a) Stockout Hazard

(b) Price-Change Hazard

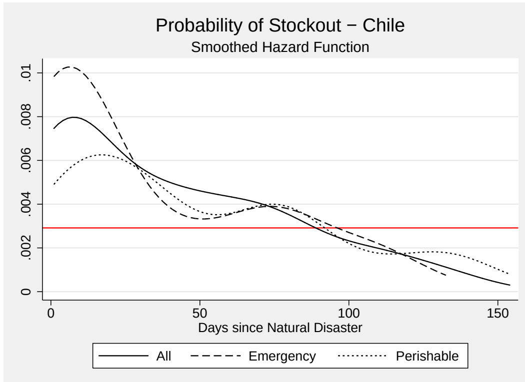
Figure 15: Hazards in Japan

In Japan the stockout hazard falls much quicker and starts to increase again 50 days after the disaster, as seen in Figure 15. Most of the stockout risk happens within a narrow window of time. If a good does not disappear quickly from the store, then it is not very likely to disappear at all. Once again, this result is consistent with disruptions in the supply chain. Those goods that managed to remain in stock are likely the goods that did not have any supply-chain problems to begin with, and therefore the retailer can keep then in stock over time.

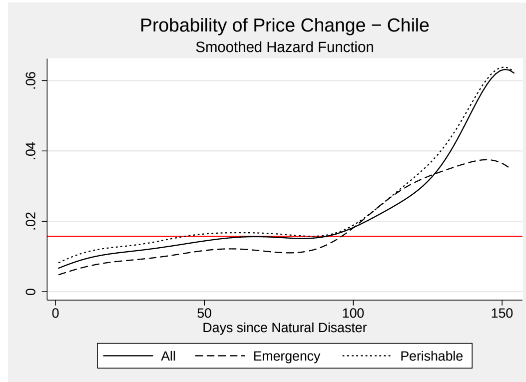
The price change hazards in both countries start at similarly low levels immediately after the earthquake, around 0.01% (an implied duration of 100 days). This level represent a significant drop in Chile compared to the unconditional daily probability of 0.018% (an implied duration of 55 days), but only a small drop for Japan, where prices are usually stickier and the unconditional probability is 0.014% (an implied duration of 75 days). From then on, these hazard rates remains low for several months in both countries, reflecting the reluctance of these retailers to make any price changes at all.

We can also compute hazards for different types of goods and see if there are any differences for "Emergency" products and "Perishable" goods, as suggested by the results in Section5. We do this only for Chile, were we have more detailed category information to classify goods into these two groups. Emergency products are those listed by the Chilean government as part of a suggested emergency kit in case of natural disasters[18]).

[18]See `http://www.onemi.cl/kit-de-emergencia.html`



(a) Stockout Hazards



(b) Price-Change Hazard

Figure 16: Perishable and Emergency Goods In Chile

Customer anger theories tend to have different predictions about the post-earthquake behavior of these two types of goods. The probability of a price change should be lower for emergency goods immediately after an earthquake (because people consider increases to be unfair), while the probability of a stockout should be higher (they are in high demand and their prices are not rising). Perishable items, by contrast, are the type of goods that are not likely to experience such a big demand shock and consumers would be more likely to consider price increases as fair (either because it is easier to understand that the cost to supply things like fresh vegetables goes up after an earthquake, or because people may actually experience less regret for not buying them before the earthquake). This is exactly what we find in Figure 16 for the earthquake in Chile.

8 Conclusions

We study the aggregate behavior of prices and product availability in the aftermath of two recent catastrophic natural disasters: the 2010 earthquake in Chile and the 2011 earthquake in Japan. We show that in both cases, the margin of adjustment during the disaster was in product availability, not prices. We find that this is consistent with the expected response in the context of "customer anger" models, such as Rotemberg (2005), particularly in Chile, where the frequency of price changes fell significantly after the earthquake. In Japan, we find evidence more closely linked to supply disruption and the retailer's inability to re-stock items than pricing behavior linked to consumer anger.

Our metrics capture the effects of both demand and supply conditions. The demand shock is associated with the needs and fears that people experience in the immediate aftermath of the disaster. Goods that disappear quickly from the stores are mostly nonperishable items that people are likely to hoard in fear of future supply disruptions. The supply shock affects the ability of retailers to replenish their stocks over time, even after the initial spike in demand dissipates. In some cases, as we showed for Japan, product availability disruptions could serve as early indicators of the magnitude of industrial production changes.

Online data have many advantages in the context of natural disasters. Data can be collected remotely, in real time, and without requiring any resources from the retailers involved. But there are also important limitations. Relatively few retailers and categories of goods are currently available online, particularly in poor countries.. Even when retailers are online, their servers could stop operating during natural disasters, so there is no way to scrape data. In other cases, retailers may simply stop updating prices and stock information online, voluntarily suspending their online service. Nevertheless, in the days after a natural disasters there is no other source of data that can provide such detailed real-time information on product availability and price changes. This information could not only facilitate short-term policy responses, but also used to create leading indicators of the disaster's impacts on supply-chain statistics and inflation trends.

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