The 2011 Tohoku, Japan Quake and Tsunami:
Provisional Financial Impact Assessment

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Abstract

The financial aspects of the March 2011 Tohoku, Japan quake and tsunami are explored from a financial risk management perspective. While it is still very early to assess the full picture, some provisional assessment seems appropriate. In particular, one can analyze the normalized transient market impact and learn lessons for financial risk management, and also compare this disaster on a normalized basis with other extreme financial events such as the Kobe earthquake, the 2008 Lehman default, 9/11 and the “flash crash” event of 2010. Financial markets react quantitatively so such cross-comparisons may be made regardless of the cause. One can also explore some of the immediate commentary on the broader economic impact, and look at the particular consequences for the global insurance, energy and nuclear industries. The impact on the nuclear industry would also benefit from proper quantitative normalization of the risks.

Keywords: Japan, quake, earthquake, tsunami, risk, market impact, Sendai, Honshu, Tohoku, Nikkei.

1 Introduction

This short and provisional study is the written form of a short talk given at the University College London Institute for Risk and Disaster Reduction\footnote{www.ucl.ac.uk/rdr/} interdisciplinary seminar on the 2011 Japan (Tohoku, Honshu) earthquake and tsunami, held on March 23rd 2011. The assessment presented here is of necessity interim and incomplete, but it is hoped may provide a small contribution to assessing the lessons of the tragedy in the financial domain. In particular, the use of a simple statistically normalized viewpoint may be of use in comparing disasters.\footnote{This presentation is for an interdisciplinary audience. The statistics of market movements are my own. For other aspects the sources of information are quoted and are presented as a compendium of hopefully relevant quantitative observations.}

1.1 Mathematics vs human tragedy

In this note I will try to present some suitably normalized interpretation. The use of statistics and mathematics to characterize such a tragedy may raise issues for some. After the 2008 financial crisis “quants” were criticized for not having an appreciation of the social impact of models and numbers. In reality it is the job of risk practitioners to look past the impact on individuals, families and communities and look at the scale of the recent events. It is only by getting a grip on the scale and facts of the problem that we might inform both the appreciation of the recent events and learn lessons for the future that will mitigate the impact of this and similar future events on people. Understanding the real scale of events also helps counter media hysteria. One can look at the financial aspects from a few different perspectives:

- What is the perception of the financial impact of this event, expressed by market reaction?
- Japan’s financial relationship with the world
– FX market impact

• Economic effects overall and by industry
  – insurance and nuclear special cases

I will begin by looking at the local perceived financial impact assessed by the local market.

2 Perceived local financial impact

The financial markets respond to a mixture of hard facts and perception by people. Major indices are a reflection of a combination of both, with an amalgamation of many investor types. If we look at suitably normalized measures of impact we can compare this event with others inside/outside Japan.

• Tohoku, Japan 11/03/2011
• Kobe, Japan quake 17/1/1995
• US Terrorism 11/9/2001
• US 2008 Financial Crisis
• US May 6th 2010 - “nothing” happened (flash crash day)

I will work with local indices - global impacts present further normalization issues. One might wonder how appropriate it is to focus on an index as an indicator. While it might be an imperfect distillation of the impact of an event financially, one has to remember that a large number of financial products depend very critically on the index.

2.1 Headlines vs history

On the 13th March 2011 the UK Guardian newspaper carried the headline “Japan’s economy heads into freefall”. Let’s take a closer look, first over 1/4 century, then over last two years of the Nikkei-2225 index. Even from the point of view of a few days following the quake, the scale of the quake impact and the beginnings of a bounce were evident. The quake just created a one-year low, and did not create a two-year low. Seen against the longer-term history it is less significant.

Figure 1: N225 1984 to week end of Tohoku event (L), last two years (R) (data src: Yahoo)

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³These plots were produced the weekend following the quake and are those shown in the seminar.
2.2 A simple scale for daily movements

One of the issues with financial reporting in the media is how such movements are reported. There are two essential flaws with media reporting of such movements. First, they often set no idea of the background scale against which events should be calibrated - so thousand-point drops were noted following both the Kobe and Tohoku quakes without much regard for the index scale at the time. This might sometimes, but not always, and not in headlines, be sorted out by quoting the movements as a percentage. A more common flaw is that the scale of the movement is not calibrated against the normal variations within the market. A large movement is less significant on a market that is intrinsically more volatile.

So I will assess market movements based on a normalized basis that first looks at movements as proportions and secondly as comparison to recent volatility. For the purposes of this note “recent” will be taken to mean the last two years. On a 2Y timescale one can compute the standard deviation\(^4\) of daily log returns up to the point before the earthquake, for the Nikkei 225:

\[
\sigma = \text{s.d.} \{ \log(S_{t+1}/S_t) \} \sim 0.0141
\]

\[
\text{quake} - 2Y < t , \quad t + 1 < \text{quake}
\]

The quake hit just before Friday closing. The following week’s normalized log movements, as multiples of \(\sigma\), were:

\[-4.5, -7.9, +3.9, -1.0, +1.9\]

We can see that the worst day, based on closing prices, was almost an “eight sigma” event, at least referred to the 2Y scale of variation. In fact it’s little different when benchmarked over a quarter of a century, where \(\sigma = 0.0147\).

The normalization against two-year standard deviations is one of many possible. If one does not believe that variance is a sensible financial parameter (perhaps because it is symmetric, perhaps because it makes no sense for very fat-tailed distributions), then one might use, for example, the median of the negative log-returns on a period of choice as the base level for a typical bad day on the markets, against which extreme downward movements might be compared.

2.3 How often do we expect 8\(\sigma\) on Nikkei?

This is the sort of question that should really be banned from being asked. It is up there with the length of a piece of string. Some have called it charlatanism to estimate the tail distribution and come up with such event frequencies. We simply do not know it. On the other hand regulators want some basis for capital adequacy, and postulating a combination of event frequency, risk measure and probability distribution allows one to come up with sigma-multiples, or, given a sigma multiple, to infer a frequency. I will give you a few “true” statements of the form: “This is a one in N year event”, based on your choice of the statistical model. The following choices are based on the Student t-distribution model given at [6] for VaR and CVaR estimates expressed as \(\sigma\)-multiples. Using this same model, we can give the following frequencies of a 7.9\(\sigma\) loss, for various risk measures and distributions:

- Gaussian model of daily log returns:
  - VaR: One in \(3 \times 10^{12}\) Y event
  - CVaR: One in \(10^{12}\) Y event

- Student T, four degrees of freedom index model of daily log returns:
  - VaR: One in 21 Y event
  - CVaR: One in 7 Y event

The Gaussian model has been thoroughly discredited by proper data studies in the last few years, though it should also be noted that the statistical kurtosis of asset returns was already established no later than the 1960s in studies by Fama [1] and Mandelbrot [4]. The \(T_4\) model employed above is based on statistical

\(^4\)While the symbol \(\sigma\) is used this is of course not the volatility typically employed in option pricing.
maximum likelihood studies from a symmetric generalized hyperbolic distribution [2], in which things could get this bad without a quake and tsunami every decade or two. The MIT-BU studies [3] of asset returns suggest cubic tails in the CDF, then a $T_3$ gives even higher frequency of an $8\sigma$. Some $\sigma$-multiples based on various power-laws were calculated in [6] and a summary table is given in the Appendix.

So while quoting such numbers is riddled with conceptual difficulty, provided one abandons crude Gaussian models and bases such observations on real statistics, there is at least a methodology. It should be pointed out that such frequency-dependent VaR/CVaR numbers can move around a great deal depending on the distributional model - Variance Gamma, Johnson-SU statistics would lead to different frequencies for example. Models of the pure tail region would produce different numbers again.

Media quotes on the quake focused on different measures of frequency. The BBC on 15th March had a headline that the tsunami “Could be a 1,000 year event” based on the comparison with a similar event in 869AD. Fortunately the article expressed caution about inferring any frequency from this. This was really about the time since the last similar event in the region.

2.4 Previous major events on the same local scale

We have seen that with regard to index movements, when properly normalized, this is a significant event. With some extrapolations on the choices of tail distribution we would expect events on this scale with a frequency as high as a decade or more. Can we give a more down-to-earth scaling? We can certainly compare with the other events in my introduction. I will look at a few post-event losses scaled per standard deviation over previous two years for events of geological, terrorist and financial origin:

- Kobe, 1985, Nikkei, $\sigma_{2Y} = 0.012$, this was also characterized as a “thousand-point drop” at the time. But the Nikkei was much higher, but had prior to than been less volatile. When scaled we find the key local movements were the following multiples of $\sigma_{2Y}$

  \[
  \{\cdots - 1.0, -4.8, \ldots\} 
  \]

- “9/11’, 2001, DJIA, $\sigma_{2Y} = 0.012$, scaled:

  \[
  \{-5.9, \ldots, -3.6, \ldots\} 
  \]

- Lehman Default 2008, DJIA, $\sigma_{2Y} = 0.0105$, scaled to end of Oct: Max Losses at

  \[
  \{-7.8, -7.2, -6.9, -5.7, -5.0\} 
  \]

  Max Gains at \{+9.99, +9.8, +4.3\}. More of an extended event, but max loss on comparable scale to Honshu.

- May 6th 2010 - Flash Crash day - no external shocks, drops on several markets, as low as $6 - 7\sigma$ to intraday low.

On this basis the local market impact of the Tohoku quake is comparable with the Lehman default, but rather larger than Kobe or 9/11. It is not, however, much larger than the maximum intra-day loss during the Flash Crash.

Lord Turner, in a speech at Cass Business School, as reported in the *Financial Times* on March 16, said that while Basel III rules require 7 % protection, he is looking for 15-20%. A crude comparison suggests if we want $8\sigma$ protection then depending on volatility we should ask for double figures in percentage terms. A table produced in [6], reproduced here in the Appendix, suggests $20\sigma$ losses are accessible, taking us well over 20 per cent as the kind of protection against margin calls that might be needed.

3 Japan’s financial relationship with world

This is less easily addressable via simple statistical normalizations. A measure of global market impact could be worked out based on some weighted amalgam of index movements, but the weightings change with time.

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as economies emerge. I do not have the ownership of suitable global index data to address this. We should also note that in February 2011 China passed Japan to become world’s second-biggest economy. At current rates of growth, China may overtake US in a about a decade. So Japan is not the prime regional economic driver it once was. We can look more quantitatively in other ways.

3.1 The Yen surge

Let’s take a look at daily intra-day minima of USD/JPY. Such a plot gets lower when the Yen is stronger. The following figures show longer and shorter periods - the quake impact is clearly visible on both graphs: While the strength of the Yen was already a concern, the quake made matters worse, achieving a post-WW2 high. The surge has been attributed to massive fund re-patriation in preparation for reconstruction, cf Kobe. It might help raw material imports needed for redevelopment in the very short term but beyond that would seriously hinder exports, a critical driver of the Japanese economy.

A World Bank report - “East Asia and Pacific Economic Update” on March 21[7] indicated wider regional consequences. About a quarter of East Asia’s long-term debt is denominated in Yen. Regional exposure ranges from 8% in China to 60% for Thailand. This report suggests that it costs about USD 1/4BN in debt servicing costs per 1% increase in Yen. However, a UBS foreign exchange strategist argued in the Financial Times[8] on 15th March, that the Yen strength is likely to prove short-lived. While the fund repatriation effect as in common with Kobe, there are several differences between now and then. For example, if Japan’s willingness to use nuclear power is diminished, dependence on imported oil will increase and impact their trade surplus. Foreign investment in Japan has been long of late cf short in 1995, creating a brake rather than an accelerator. UBS also believe that Japan sovereign debt ratings might also worsen as reconstruction costs worsen government budgets.

4 Insurance

Data on insurance costs are provisional and changing. The initial World Bank appraisal[7] based itself on Japan government data, which was later revised up. There were also provisional loss announcements based on modelling studies from major re-insurers. These reinforce the market index perception that this is a bigger event than Kobe, which also had a large proportion of uninsured losses. The data of [7] published on 21/3 was revised up by 23/3, and the later numbers are shown in bold in the following table. The reports indicate real GDP growth to slow through mid-2011, with reconstruction impact to benefit it. There are regional impacts on trade and debt depending on country-specific export and Yen exposure. See [7] for details. In the week ending 25/3, modelling losses were reported as follows

- Swiss Re USD 1.2BN, quoted as “70% of max loss of 1/250Y” event;
- Munich Re EURO 1.5BN.
Table 1: World Bank view of Honshu cf Kobe 21/3 and 23/3

<table>
<thead>
<tr>
<th>Category</th>
<th>Honshu Estimates</th>
<th>Kobe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage USD</td>
<td>122-235BN [309]</td>
<td>100 BN</td>
</tr>
<tr>
<td>Damage % GDP</td>
<td>2.5-4 [6]</td>
<td>2</td>
</tr>
<tr>
<td>Private insurance USD BN</td>
<td>14-33</td>
<td>0.8</td>
</tr>
<tr>
<td>Reconstruction cost USD BN</td>
<td>12 cur Y ++</td>
<td>38 over 2Y</td>
</tr>
</tbody>
</table>

4.1 Is there re-insurance contagion?

I do not know the extent of any problem, but it is prudent to highlight the potential, illustrated in Fig. 3. The extent to which any insurance company exposed, *bearing in mind the network of re-insurance*, will only emerge with time when we know all the real claims and dependencies. The 2008 financial crisis was so amplified by corresponding contagion in credit exposure.

5 Industry specifics

For a mathematician working at a distance this is difficult to assess and my own preference is to cite expert analyst discussion. An early Nomura Securities report [5] suggested that the overall economy size of Sendai quake is similar to Kobe area, but that there are differences. This time road networks, power plants and other infrastructure are more significantly affected, and the region has a large number of IT companies. But Nomura is positive on companies being able to shift production to other sites, due to low operating rates generally - there is spare capacity elsewhere. Nomura characterized the impact as 6M delay in economic recovery in one report. There is detailed but early industry-specific comment in [5]. This report identifies spike impacts on companies concentrated in the area with no backup outside. By 23rd March JP government comments were suggesting that power and transport issues were causing problems.

5.1 Oil prices

This is more complicated, and is perceived to be different in the short, medium and long term.

- Initial price drop as Japan refining capacity drops;
- If refineries cannot re-open soon, imports will rise, pushing up prices;
- All price effects are confounded by Middle East conflict and production;
• Nuclear effect might rebalance demand in longer term.

5.2 Nuclear power industry

At risk of stating the obvious, this is looming large. The impact on the perceptions of nuclear safety is significant, and public perception of risk in this area has a huge amplification factor. Getting information properly normalized is the key, and my understanding, which I will leave safety professionals to correct, is that there is no scenario under which deaths due to the nuclear component will increase beyond a small fraction of those caused by the quake and tsunami itself. The impact of the perception has already been dramatic:

• Merkel suspends operations at 7 German nuclear plants;
• Switzerland suspends approval process for 3 plants;
• China suspends approval for new nuclear plants;
• US politicians back-pedalling on renewing nuclear.

I will leave it to nuclear professionals to comment on the rationality or otherwise of such reactions. However, the financial impact on energy prices, and the resulting economic consequences, of a global retreat from nuclear power are my own greatest concern. I cannot put numbers on it, and it is very country-specific, but it is the issue that worries me most, given both the global economic consequences of higher energy prices and the risk of the acceleration of CO₂ production by a returning to increased fossil-fuel burning.

The lack of correlation between decision-making and the real quake risk is at times bizarre. Given China’s history its desire to re-investigate the construction plans is entirely rational, but this does not apply everywhere. My understanding of the earthquake maximum magnitude history of these countries is as follows:

• Germany, 1756, less than 6.5;
• Switzerland, 1356, Basel, less than 6.5;
• China, 2008, 7.9, several large (including 8.0) historical quakes and the most deadly quake;

While the coast of Northern Germany has some small risk of tsunami, and the risk of a tsunami for Switzerland have been given credence⁶ based on quakes beneath a lake, it is hard to see the German and Swiss decisions as anything other than politically-based. The chart at [9] is very informative and should be required reading for politicians. In assessing media reports of radiation doses the following comparative estimates might also be interesting

• dose rates:
  - CT scan - about 720 mSv/h (a scan might last 15-30s)⁷;
  - Fukushima peak as of 27/3, about 1000 mSv/h;⁸

• Total doses
  - Maximum external dose from Three Mile Island accident - 1mSv[9];
  - Mammogram - 3mSv;
  - Chest CT scan 5.8mSv;
  - NASA lifetime limit for astronauts’ skin - 6000 mSv⁹

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⁶http://www.swissinfo.ch/eng/Home/Archive/Tsunami_threaten_even_landlocked_Swiss.html?cid=4298900
⁷http://scienceblogs.com/deanscorner/2011/03/fukushima_radiation_levels_or.php
⁸http://www.bbc.co.uk/news/world-asia-pacific-12872707. Note that there were erroneous statements made about the comparison with normal levels.
⁹http://er.jsc.nasa.gov/seh/RB_Module3_10.pdf
Another interesting point of normalization is the real threat associated with various forms of energy production. While it is highly desirable that investment in nuclear is sustained and also balanced by investment in renewable energy technology, the risks associated with the latter make interesting reading. Japanese wind farms did a very good job of surviving the disaster, having been located high and designed to withstand significant quakes. However, the deaths from wind farm accidents are not insignificant. Various figures have been quoted but a study by a Caithness group\(^\text{10}\) identified 73 human fatalities from the 1970s to the end of 2010 arising from wind farms. Such figures are dwarfed by deaths in traditional mining and oil production. At least 598 workers died in the oil industry between 2002 and 2007, according to the U.S. Bureau of Labor Statistics. In 2006 alone more than 4000 miners died in China. While we do not yet know any lethal impact of the nuclear component of the tragedy in Japan, these are the sorts of numbers that should be compared with the Japanese reactor incident impact in the long term.

5.3 Industry impact via Uranium prices

The price of Uranium is not as widely quoted as that of other major commodities, but a brief return to the opening philosophy of this note might be of interest. Uranium daily prices, for \(U_3O_8\), were only introduced by TradeTech\(^\text{11}\) on 1/3/11. This indicator fell 20% after the Japan incident but has recovered a little since then.

Impacts on other commodity prices based on from Japan’s importer status have been noted on Copper and Aluminium.

6 Summary

Here the comments of this note are summarized.

- This was a major \(8\sigma\) financial event in the world’s 3rd largest economy, in which it will slow economic recovery;
- Locally comparable to Lehman default in local market impact;
- Consensus is that Japan can recover providing no other significant event;
- Full consequences and recover timescale remain to be seen;
- A reminder of the need for adequate capital reserves beyond Basel III
- Insurance contagion to be seen;
- Impact of possible retreat from nuclear?
- Energy price worries plus \(CO_2\) re-acceleration?

6.1 Acknowledgement

I am grateful to Professor Peter Sammonds of the UCL Institute for Risk and Disaster Reduction for his encouragement to present this brief study.

References


\(^{10}\)http://www.caithnesswindfarms.co.uk/accidents.pdf

\(^{11}\)www.tradetech.com
Appendix

Here, reproduced from [6], are $\sigma$-multipliers for the Student T distribution with various low degrees of freedom and compared to Gaussian. The degree of freedom coincides with the inverse power law associated with the tails of the cumulative distribution function. $\nu = 4$ was suggested by the 2006 maximum likelihood estimates (MLE) of [2], $\nu = 3$ is suggested by the work of [3]. Other numbers would be produced by the use of other parametric statistics, e.g. Variance-Gamma, Johnson-SU, and it should be noted that these numbers are based on tail-extrapolations of MLE statistics based on all asset movements, and should not be misunderstood as exact computations of the likelihood of extreme events. They are best interpreted as revealing the inadequacy of a Gaussian model, and a rough guide to event frequencies based on a power-law tail.

<table>
<thead>
<tr>
<th>DOF</th>
<th>Time $\sim$ $u = \tau$</th>
<th>Quantile Measures</th>
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</thead>
<tbody>
<tr>
<td>$\nu = \infty$ (Gauss)</td>
<td>$\psi_{GVaR}$</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>$\psi_{GCVaR}$</td>
<td>2.00</td>
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<tr>
<td>$\nu = 6$</td>
<td>$\psi_{TVaR}$</td>
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<tr>
<td></td>
<td>$\psi_{TCVaR}$</td>
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<td>$\nu = 5$</td>
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<tr>
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<td>$\psi_{TCVaR}$</td>
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Table 2: $\sigma$-multipliers for Student T VaR and CVaR loss functions