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JAPANESE ENERGY SECURITY AND CHANGING GLOBAL ENERGY MARKETS:

An Analysis of Northeast Asian Energy Cooperation and Japan's Evolving Leadership Role in the Region

PROBABILISTIC SEISMIC HAZARD PERSPECTIVES ON JAPAN'S NUCLEAR ENERGY POLICY: IMPLICATIONS FOR ENERGY DEMAND AND ECONOMIC GROWTH

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ABSTRACT

This report reflects an effort to assess the status of seismic risk implications on the nuclear plants providing energy in Japan. In this regard, existing and projected plants along with their power capacity have been identified and cataloged. Further, historical data of seismic events deemed significant for the functionality and safety of the plants are included in terms of the Richter magnitude. Also, documents describing standard procedures for aseismic design of power plants have been perused. The coping of the Japanese industry with the major seismic event of Kobe (January 17, 1995) has been considered. It is believed that the procedures followed in designing and operating nuclear power plants reflect sound engineering practices. Barring an extraordinary seismic event, it is expected that the nuclear plants based energy supply in Japan can be maintained with manageable disruptions. Nevertheless, it is recommended that more focused studies regarding individual plants, especially the older ones, be undertaken in the future, regarding the probability of 'incapacitating' seismic events. In this manner, a reasonable, reliable model can be calibrated providing the expected percentage of nuclear power loss in Japan, in any given time period.

In view of Japan's stated policy of heavy reliance on nuclear energy, it is nonetheless prudent to plan for aseismic events that could significantly reduce its electricity generating capacity. Such a shortfall would have substantial impacts on world energy markets, on Japan's ability to provide clean energy in line with its commitments in the Kyoto Protocols, and on Japan's economic growth. Under standard growth scenarios, we estimate that seismic events that prevent planned new capacity from being brought on line would reduce growth in total factor productivity by about ½ percent per year. This would dampen Japanese energy demand to a level of 2400 (10^{13} Btu) instead of a level of 2488.5 (10^{13} Btu) that we forecast in 2010. The impact on economic growth is due to the increase in CO_2 emissions caused by substitute energy sources, particularly imported oil. Such increases would need to be moderated by modifying the aggregate production process, and such a change has implications for technical and efficiency change and thus for growth in total factor productivity.

1. Introduction

Seismic activity in Japan on the four main islands (Hokkaido, Honshu, Shikoku and Kyushu) has had a long and well-documented history. The country's lack of natural resources, in particular carbon-based energy sources, also has been well documented. In 1996 Japan imported 80% of its primary energy needs, including uranium. In order to provide a security hedge against a cut-off of its oil and natural gas imports, Japan adopted an ambitious plan to construct substantial new nuclear power capacity in the 1980's and 1990's and in the new millenium.

In 1996, electricity was generated in Japan using 18.2% coal, 21.0% oil, 20.2 % natural gas, and 30.1% nuclear, with the remainder coming from hydro and other sources. This composition represents a substantial displacement of oil in electricity generation since 1973. Much of this displacement has occurred as a result of increases in natural gas and nuclear power generation. The share of nuclear has increased from 2.1% in 1973 and the share of natural gas has increased from 2.3%, trends indicative of Japan's environmental policy and its goal to insulate itself from oil market disruptions. As of early 1999, Japan had fifty-one operating nuclear power plants with generating capacity of almost 45 billion kWh. Recently, plans were announced to construct 13 new nuclear plants by 2010. According to IEA projections, the proposed new nuclear facilities will generate an additional 180 billion kWh by 2010, increasing nuclear's share of electricity to 41%.

However, as the building of nuclear power plants and breeder reactors began to follow Japan's ambitious plans, it became clear to the public, if not the scientific community, that seismic uncertainty in areas contiguous to proposed and existing nuclear power stations may not have been properly assessed, or understood, when construction techniques and building standards were put in place. In particular, the distribution of seismic activity, the lateral and vertical stresses produced by earthquakes in and around existing and proposed plants, the possibility that seismic activity would affect clusters of plants built in the same geographic area, and the likelihood of rare catastrophic quake events were considered but not necessarily properly assessed.

In this paper, we address such issues from the perspective of statistical data to reassess the likelihood of earthquake cause disruptions to the power generating capacity of Japan's nuclear energy sector. Much of Japan's domestic and international environmental policy is based on an enlightened perspective toward emissions of greenhouse gases and other industrial pollutants. Recent research by Boyd et al. (1999) and Jeong and Sickles (2000) has indicated that the need to moderate the generation of $C0_2$ emissions, in line with the Kyoto Protocols, will have an impact on the growth of total factor productivity, the mechanism through which living-standards are raised. The reason for this is that production of goods and services (gdp) is carried out jointly with the production of bads (e.g. $C0_2$). Reducing one, or at the least moderating its growth, will possibly do the same to the other. Based on the increased $C0_2$ owing to a relative increase in carbon-based energy consumption due to a shortfall in nuclear power capacity relative to Japan's long-run plans, we can then formulate new estimates of Japan's carbon intensities. These will then allow us to calculate how much $C0_2$ reductions will be necessary to return Japan to its current carbon intensities and the direct impact this will have on Japan's ability to raise living-standards.

Our paper is organized as follows; section 2 provides an overview of Japan's current energy policy and some detail on where existing and planned capacity is (will be) built. In section 3, we discuss the geological characteristics of the areas surrounding the existing and proposed plants and review historical seismic activity in those areas as well as others' and ours estimates of future seismic activity. Section 4 examines the impact that the use of carbon-based alternatives to nuclear power generation will have on the carbon intensities of Japanese aggregate production. We then simulate how total factor productivity, and hence the ability to raise living standards for the average Japanese citizen, will be affected by the need to curb $C0_2$ production due to the unforeseen seismic events. Section 5 provides concluding remarks.

2. Japan's Current Nuclear Energy Position

During the last two centuries, global primary energy consumption has grown at an average rate of 2% per year, doubling about every three decades. Although growth is observed in all sources of commercial energy and fuelwood, there is a substantial variation in growth rates over time, between different regions and different resources. Much of the increase in energy consumption has occurred in the developed countries. It is found in the literature that about 25% of the world's population consume almost 80% of the global energy. Among the several energy sources, oil products, followed by coal and natural gas, today take the largest energy share. It is estimated that global fossil energy reserves (economically and technically recoverable occurrences with current technology and prices) are about 50,000 EJ. This estimation is made at the 1990 level of global energy consumption of 385 EJ, providing a finite quantity of fossil reserves to last for the next 130 years. The energy supply security demand and the environmental impacts of fossil fuels have shifted the attention of several countries towards the use of nuclear energy as a basic power generation contributor (Climate Change, 1995).

Japan is included among these countries. There are three broad goals that characterize the Japanese energy policy at the beginning of the 21st century. The first is a reduction in energy intensity. The second is achievement of a more balanced energy mix with lower dependence on oil and lower CO_2 emissions. The third is security of energy supplies.

Energy security for Japan is an important concept combining political, military and economic dimensions. The efforts of Japan to direct its energy resources away from oil and towards coal and nuclear power have started in the aftermath of the 1970 oil crisis. Since then, important steps have been taken in order to promote nuclear power as a main electric power generation source. As of 1999, fifty-one nuclear power plant units were generating 44,917 Mwe. In 2010, the nuclear energy share is expected to exceed 40% of the total Japanese electricity demand. Nuclear power plants in Japan can be classified under three different perspectives that provide insight into both generating capacity and geographical proximity to seismically active areas and population centers. The distribution of existing generating capacity is shown in Figure 1. It indicates that plant sizes in the 800-1100 Mwe range appear to be the optimal design size, presumably based in part on the scale economies of existing technologies and in part on assessments of seismic risk and proximity to large population centers. The distribution of plants according to their location is provided in Figure 2, while the distribution of plant vintages is given in Figure 3. This later figure points to the relatively large portion of existing capacity that is based on engineering blueprints that are two to three decades old. Tables 1, 2 and 6 provide the data used in the first three figures.

In fiscal 1996, there were 82 approvals for construction plans of existing plants (including change approvals) and 79 reports (including change reports and minor change reports). New planned capacity follows the schedule in Table 3. The table contains information about the expected number of Japanese nuclear power plants, their capacity and operation date. It is important to note that the availability of sites for nuclear installation, including radioactive repositories, must be checked by region, taking into consideration several factors such as the risk of earthquakes, the need for cooling, and population density. Especially for a country like Japan that is highly prone to earthquakes, regional seismic hazard identification and earthquake design practice for buildings should play an important role in the NPP decision making.

We thus turn our attention to issues of seismicity and earthquake design practice in Japan.

3. Seismicity and Earthquake Design of Japanese Nuclear Power Plants[1]

3.1 Seismicity in Japan

Earthquakes are the consequences of the breaking and shifting of rocks beneath Earth's surface. Most of them take place along faults or breaks in the Earth's crust. Japan's increased seismic activity is the result of the convergence of several tectonic (huge rock sheets about 70 km thick) plates below its surface.

The continuous increase of seismographic stations installed all around the world and the significant improvements in technology and global communications, have resulted to an increase in the number of reported earthquakes every year. Nevertheless, the number of large earthquakes remains relatively constant throughout this century as shown in Tables 4 and 5. According to the National Earthquake Information Center, there is a 100% chance of experiencing an earthquake on any given day somewhere in the world. This is not really a prediction. It is just an acknowledgment that several million earthquakes occur annually (even if most of them are so small that it is difficult to be located). The real issue here is to identify the area and the time where a strong shock will

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[1] Detailed seismic vulnerability analysis of each and every power plant in Japan could be pursued for a more exhaustive assessment of potential disruption of the energy supply; this task however would require personnel, temporal margin and research resources greatly exceeding those of the project's temporal margin and research resources greatly exceeding those of the project.

occur. Since most of annual world's earthquakes occur around the rim of the Pacific Ocean, this would be the most probable location for 'today's' earthquake.

The seismic occurrences in Japan between the period 1975-1995 have been monitored and illustrated according to the depth of the source, in Figure 4. Several small earthquakes are recorded daily in Japan. Figure 5 summarizes the larger earthquakes (magnitude 5 or higher) recorded the decade between July 1985 and June 1994. Also, Table 6 presents an effort to classify these earthquakes according to the prefectures where the NPPs are located.

3.2 General Earthquake Design Practices

A first step towards the reduction of seismic hazard is the completion of a Seismic Hazard Assessment. In this manner, important information on possible site effects will be provided. In addition to that, the damage resulting from previous earthquakes can become an important lesson since it gives an understanding of the building behavior in earthquake motion. In the relevant literature, two are considered the most important earthquake design objectives (Key, 1988). The first is consideration of risk to the site itself from large soil movements due to consolidation, liquefaction, landslides or avalanches (coastal sites would also need to consider tsunamis). The second is the identification of the nature of ground motion to be expected to the site. Usually, several design levels should be considered, related to minor, moderate or major earthquakes. Additionally, specialized criteria exist for nuclear installations and major industrial earthquakes. Three definitions are commonly used in these contexts. The first is referred to as the *operating basis earthquake.* During this earthquake, the installation should continue in operation. The second is the *safe shutdown earthquake.* During this earthquake, shutdown could take place but critical facilities should not get damaged. The third is *critical facilities* that are the facilities in which damage could lead to a release of dangerous chemicals or radioactivity

Finally, the uncertainty in soil-structure interaction effects is captured in the regulations for the design of NPPs by taking variations in the shear modulus G from the design value used. This is usually based on engineering judgement, considering the accuracy of estimation, but a minimum spread of values can be defined as ranging from 0.67G to 1.5G.

Earthquake engineering takes into consideration several factors. Figures 6 and 7 describe some important trends between distance, magnitude and period used given in the references below. It must be emphasized though that Fig. 6 and Fig.7 should be interpreted as indicating trends basis only and should not be construed as reflecting exact relationships. Also, there are several measures of earthquake's capacity to cause damage. The most commonly used is the peak acceleration. But this has proven unreliable since it may occur as only the briefest of transient values. Thus, the design earthquake uses instead the 'effective peak acceleration' that represents bounding values for typical ground motion response spectra over the frequency ranges of interest in building design.

It is conceivable that after all the design, there is always a small but finite risk of failure. And this happens because it is frequently difficult to estimate the most damaging earthquake that might occur. It is also not financially efficient to design for the extreme event.

3.3 Seismic guidelines for NPP earthquake design in Japan

According to the literature, there are three stages of development of aseismic design in Japan. The first stage extends until 1978. During that period, the design of each NPP was based on designs of predecessor plants, using simultaneously the latest knowledge and experience. In the second stage (1979-1986), aseismic proof studies were carried out and provided new information and a kind of standardization of the aseismic design technology. The third stage, from 1987 and on, represents a transient period to rational design in which new knowledge has been added, and the guidelines of the JAEC (Japanese Atomic Energy Commission) have been reviewed and included a new provision for incorporation in design. The new guidelines paid attention in methodologies covering the following points. The first is aseismic classification of the reactor facilities and establishment of allowable limits for the facilities against the seismic forces. Through that, the design basis seismic force is determined. The second is composed of two parts. The first part is the determination of the maximum design basis earthquake (S1) for class A (after examination of historical earthquakes and highly active faults with 1mm/y or higher average dislocation velocity and activity potential of one or more times per 10,000 years). The second part is determination of the extreme design basis earthquake (S2) for class AS (after examination of active faults with 1mm/y or higher average dislocation velocity and activity potential of one or more times per 50,000 years).

The data resulting from the investigation of historical data and active faults can be organized in a list of earthquake magnitude (M) and distance (Δ) between the earthquake epicenter and the site. Based on this list and the seismic characteristics (amplitude, frequency and response spectrum), the ground motion at the hypothetical free surface of bedrock is calculated as basic ground motion spectrum as shown in Fig.8.

Furthermore, geological surveys and soil stability evaluations are conducted (wide area investigations and site area investigations). On important buildings/structures and equipment/piping, aseismic design and analysis methods were introduced. Thus, for NPPs the following safety measures are taken. In the design phase, selected a strong-based rock on which the nuclear reactor buildings are directly constructed. In that manner, the structures obtained are more rigid and more resistant to deformation than common buildings. Furthermore, critical equipment and piping networks are fixed to such rigid buildings. Aseismic design also involves anticipative determination of earthquakes based on thorough examination, where in addition to the points mentioned on the previous page, the seismic force taken into account is three times larger than the one specified in the Building Standards Act. Finally, aseismic design requires confirmation of safety of NPP facilities by carrying out experiments and simulation analyses with the use of computer and specialized installations. In operation phase there must be automatic shutdown of nuclear reactors with the detection of vibrations in the unit (~ 5 on the Japanese scale). These basic steps for nuclear power plant design are summarized in Figure 9.

Perhaps the preceding seismicity data and aseismic design/ operation procedures can be supplemented with information referring to Japan coping with the significant event of the January 17, 1995 Kobe earthquake.

The Hyogo-ken Nanbu earthquake is considered one of the worst disasters of the 20th century in Japan. It occurred at 5:46 am, local time, on January 17, 1995. It had epicenter just north of the Awaji Island and was assigned by the Japanese Meteorological Agency a 7.2 magnitude on the Richter scale. Since the earthquake had epicenter close to densely populated cities, it exposed many modern and older buildings to an intense near-source ground shaking. Many buildings were destroyed, and several people were killed or injured in the area affected by the earthquake (Architectural Institute of Japan, 1995). Damage also resulted from geotechnical failures (landslide that buried a dozen residences), from liquefaction at the outerbank, as well as the bulkhead of artificial islands and failure in the transportation structures (bridges, highways and railways). Finally, some districts were completely burnt down due to the break out of over 100 fires.

Shortly after the earthquake, a team consisting of over one hundred university scientists, architects and structural engineers addressed the affected from the earthquake territories. Their main goal was to survey and document the types of building damage from a structural engineering point of view. For the purpose of that study, they gathered and analyzed both ground motion and structural damage data. The geological aspects of the areas were considered in order to relate mapped damage concentrations and ground motion intensities. Building damage was examined both with respect to the region and to the structural type of the buildings. Extensive and often severe damage was observed to a large number of buildings in the Kobe area as shown in Table 7. Mostly, the traditional wood frame Japanese residences suffered. In general, the damage in the reinforced concrete or steel buildings was limited to: (i) structures located near the fault, (ii) structures with inadequate shear reinforcement, (iii) older, deteriorated structures or (iv) structures considered to be of poor construction quality (Architectural Institute of Japan, 1995).

Building performance examination provided a very useful input for the evaluation and further improvements of existing seismic codes, design practice and construction methods in Japan. The consequences of the Hyogo-ken Nanbu earthquake (infrastructure, societal, economic) as deriving from the collected data, were enormous. However, the information provided about the nearby NPPs has shown that the earthquake did not influence their normal operation (Table 8). Nevertheless, it was pointed out that due to the distance of the majority of the NPPs from the epicenter of the earthquake, caution should be exercised in concluding that the Kobe experience should be deemed as reflecting collectively the preparedness of the Japanese Nuclear Power Industry for a near-site seismic event (Nuclear Admission Committee, 1995).

It is believed that the procedures followed in designing and operating nuclear power plants reflect sound engineering practices. Barring an extraordinary seismic event, it is expected that the nuclear plants based energy supply in Japan can be maintained with manageable disruptions. However, it is recommended that more focused studies regarding individual plants, especially the older ones, be undertaken in the future, regarding the probability of 'incapacitating' seismic events. In this manner, a reasonable, reliable model can be calibrated providing the expected percentage of nuclear power loss in Japan, in any given time period.

In view of Japan's stated policy of heavy reliance on nuclear energy, it is nonetheless prudent to plan for aseismic events that could significantly reduce its electricity generating capacity. Such a shortfall could have substantial impacts on world energy markets, on Japan's ability to provide clean energy in line with its commitments in the Kyoto Protocols, and on Japan's economic growth. It is to these issues that we now turn.

4. Impacts of Potential Catastrophic Seismic Events on Japanese Energy Demand and Economic Growth

In traditional productivity analysis, environmental by-products of the production or development process are ignored and, as such, are assumed to be freely disposable. Using a recently developed technique, the directional distance method, we can analyze the effect of the valuation of carbon dioxide on the productivity growth of the Japanese economy. We can also decompose productivity growth into changes in technical efficiency over time and shifts in technology. These allow us to identify the major factors in Japan's growth process. Since we do not observe the true production frontier, but estimate it from our sample, we adopt a statistical interpretation of the indices via recently developed bootstrap methods introduced by Simar and Wilson (1997, 1998a,b) and Kneip, Simar, and Wilson (1999).

Farrell (1957) first developed radial technical efficiency measures. Caves, Christensen, and Diewert (1982) define the input-based Malmquist productivity index as the ratio of two input distance functions while assuming no technical inefficiency in the sense of Farrell. Fare, Grosskopf, Norris, and Zhang (1994) extended the Caves et al. approach by dropping the assumption of no technical inefficiency and developed a Malmquist index of productivity that could be decomposed into indices describing changes in technology and efficiency. This approach has been used widely. These indices have been used to study issues ranging from deregulatory dynamics in the U. S. airline industry (Alam and Sickles, 2000) to the convergence of per capita incomes of the OECD countries (Fare et al., 1994).

Chung, Fare, and Grosskopf (1997) introduce a directional distance function approach, the Malmquist-Luenberger index, to analyze the models of joint production of goods and bads. This method credits firms for reductions in bads and increases in goods. The Malmquist index can also be applied to the undesirable output case by modifying the direction in which the goods and bads are traded-off. Boyd, Fare and Grosskopf (1999) have recently analyzed OECD countries assumed to possess a two input two-output technology using deterministic Malmquist and Malmquist-Luenberger indices. Jeon and Sickles (2000) extended their work to statistical deterministic frontiers in their analysis of OECD and Asian economies. They focused special attention on constraints in China's development prospects owing to a proper environmental accounting of $C0_2$ emissions and to adoption of carbon intensities similar to those of the OECD.

Below, we apply Malmquist and Malmquist-Luenberger index methods to analyze how productivity growth is affected by lifting the free disposability assumption explicit in previous international productivity growth studies of Japan, and test the statistical significance of this point estimate using bootstrap methods. Historically, the growth in an economy has been due to the growth of inputs, or growth at the intensive margin, and growth in the productivity of those inputs, or growth at the extensive margin. Factors that influence the later will influence wealth creation, as well as the ability of the economy to maintain wealth levels, as it reallocates resources to pay for pollution abatement. In Japan, especially, these reallocations may be substantive since its energy endowments are limited, and because its planned nuclear capacity may be politically unrealistic and/or impacted by future seismic events. Changes in the rate of growth in the Japanese economy due to pollution controls will clearly impact its derived demand for energy as a main input in the production process. Thus, the explicit treatment of pollution in the production process will modify existing forecasts for Japanese energy demand and for its growth prospects.

4.1 The Productivity Indices

Following Shephard (1970) the output distance function at time t is defined $D_0^t(x^t, y^t, b^t) = \inf\left\{\theta \mid (x^t, y^t/\theta) \in F^t\right\}$

where F^t is the production technology for each time period t=1,…,T that transforms inputs x^t into outputs, goods y^t and bads b^t. Fare et al. (1994) noted that the output-based Malmquist total factor productivity change index

$$M_0^{t,t+1} = \left[\frac{D_0^t(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^t(x^t, y^t, b^t)} \cdot \frac{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^{t+1}(x^t, y^t, b^t)}\right]^{\frac{1}{2}}$$

The equivalent representation is

$$M_0^{t,t+1} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^t(x^t, y^t, b^t)}\left[\frac{D_0^t(x^{t+1}, y^{t+1}, b^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})} \cdot \frac{D_0^t(x^t, y^t, b^t)}{D_0^{t+1}(x^t, y^t, b^t)}\right]^{\frac{1}{2}}$$

where the first term reflects changes in relative efficiency between period t and t+1 and the second term relates changes in technology between the time periods. This index can capture productivity change by accounting for technical and efficiency advances which incorporate data from two adjacent time periods. To estimate the Malmquist productivity index in the "more goods" direction, we need to solve four linear programming problems for each adjacent set of observations for each country. Details of these programming problems can be found in Jeong and sickles (2000).

The Malmquist-Luenberger productivity index is based on the output oriented directional distance function (Chung et al., 1997). This is different from the Malmquist index that changes the desirable outputs and undesirable outputs proportionally since we choose the direction to be $g = (y^t, -b^t)$, more good outputs and less bad outputs. The rationale of this kind of directional choice is that there might be institutional regulations limiting an increase in bad outputs, in particular pollutant emission. [Figure1] shows three different reference directions for each index.

To accomplish this first redefine the production technology in terms of the output sets, i.e.

$$P(x^t) = \left\{ (y^t, b^t) \,|\, (x^t, y^t, b^t) \in F^t \right\}$$

The directional distance function is defined as

$$\vec{D}_0^{\,t}(x^t, y^t, b^t; g) = \sup\left\{ \beta \,|\, (y^t + \beta g_y, b^t + \beta g_b) \in P(x^t) \right\}$$

where g_y and g_b are the subvectors for y^t and b^t of the direction vector g. The Malmquist-Luenberger productivity index is then defined as above with the directional distance function replacing the standard distance function.

4.2 Seismic Impacts on Productivity Growth for Japan

We now turn to our attention to the impacts of future seismic events on the growth in energy demand and in the growth in productivity for the Japanese economy. We estimate Japan's productivity growth along with 11 other Asian countries for the period 1980-1995. The countries are China, Japan, Korea, Taiwan, Hong Kong, Singapore, India, Thailand, Indonesia, Malaysia, and the Philippines. Aggregate country data are from the Penn World Tables (Mark 5.6) and International Financial Statistics of IMF, while $C0_2$ emission data come from the U. S. Energy Information Administration. Productivity growth can be found only in Japan, Korea, Taiwan, Singapore and Hong Kong. This is consistent with the finding of Young (1995) who pointed out that the bulk of post-WWII growth in Asian countries was due to input growth and not TFP growth.

When we apply the directional distance function methods, Japan is the only country that shows a significant productivity growth over the entire sample period. Productivity growth in Asia is based largely on efficiency change rather than technical change. These results may be highly leveraged by the reference technology since the Asian sample consists of developing countries with the exception of Japan. The developing countries are arguably less interested in and well-equipped to handle waste by-products in pursuing their economic policy.

In Tables 9-12, we provide estimates of total factor productivity growth for Japan based on a peer group East Asian and OECD countries. We also control for stochasticity in the underlying frontier technology using bootstrapped re-sampling techniques. It is clear from the results that 95% confidence bands are broad enough for estimates of efficiency growth and technical change components of productivity change so that no particular confidence can be placed on their separate impacts on the growth process. However, their sum, total factor productivity change, is significant and ranges between 1 and 2.5%.

We next assess the impact of Kyoto targets on Japan's economic growth and energy demand when catastrophic seismic events have halted new construction of nuclear power capacity. We assume that this happens in the year 2000. We also assume that the future population growth rate of Japan is 0.2% per annum and construct three GDP growth rate scenarios, low (2.0%), standard (2.5%) and high (3.0%) growth respectively. The standard growth rate comes from Japan's average GDP growth rate over the last 15 years.

Results of this exercise are in Table 13. Under standard growth scenarios, we estimate that seismic events that prevent planned new capacity from being brought on line would reduce growth in total factor productivity by about ½ percent per year. This would dampen Japanese energy demand to a level of 2400 (10^{13} Btu) instead of a level of 2488.5 (10^{13} Btu) that we forecast in 2010. The impact on economic growth is due to the increase in CO_2 emissions caused by substitute energy sources, particularly imported oil. Such increases would need to be moderated by modifying the aggregate production process, and such a change has implications for technical and efficiency change and thus for growth in total factor productivity.

5. Conclusions

In this paper, we have assessed the status of seismic risk implications on the nuclear plants providing energy in Japan. The coping of the Japanese industry with the major seismic event of Kobe (January 17, 1995) also has been considered. Our conclusions are that procedures followed in designing and operating nuclear power plants reflect sound engineering practices. Barring an extraordinary seismic event, it is expected that the nuclear plants based energy supply in Japan can be maintained with manageable disruptions. Nevertheless, it is recommended that more focused studies regarding individual plants, especially the older ones, be undertaken in the future, regarding the probability of 'incapacitating' seismic events. In this manner, a reasonable, reliable model can be calibrated providing the expected percentage of nuclear power loss in Japan, in any given time period.

In view of Japan's stated policy of heavy reliance on nuclear energy, it is nonetheless prudent to plan for aseismic events that could significantly reduce its electricity generating capacity. Such a shortfall would have substantial impacts on world energy markets, on Japan's ability to provide clean energy in line with its commitments in the Kyoto Protocols, and on Japan's economic growth. We estimate that aseismic events that prevent planned new capacity from being brought on line would reduce growth in total factor productivity by about ½ percent per year. This would dampen Japanese energy demand to a level of 2400 (10^{13} Btu) instead of a level of 2488.5 (10^{13} Btu) that we forecast in 2010. The impact on economic growth is due to the increase in CO_2 emissions caused by substitute energy sources, particularly imported oil. Such increases would need to be moderated by modifying the aggregate production process, and such a change has implications for technical and efficiency change and thus for growth in total factor productivity.

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Figures and Tables

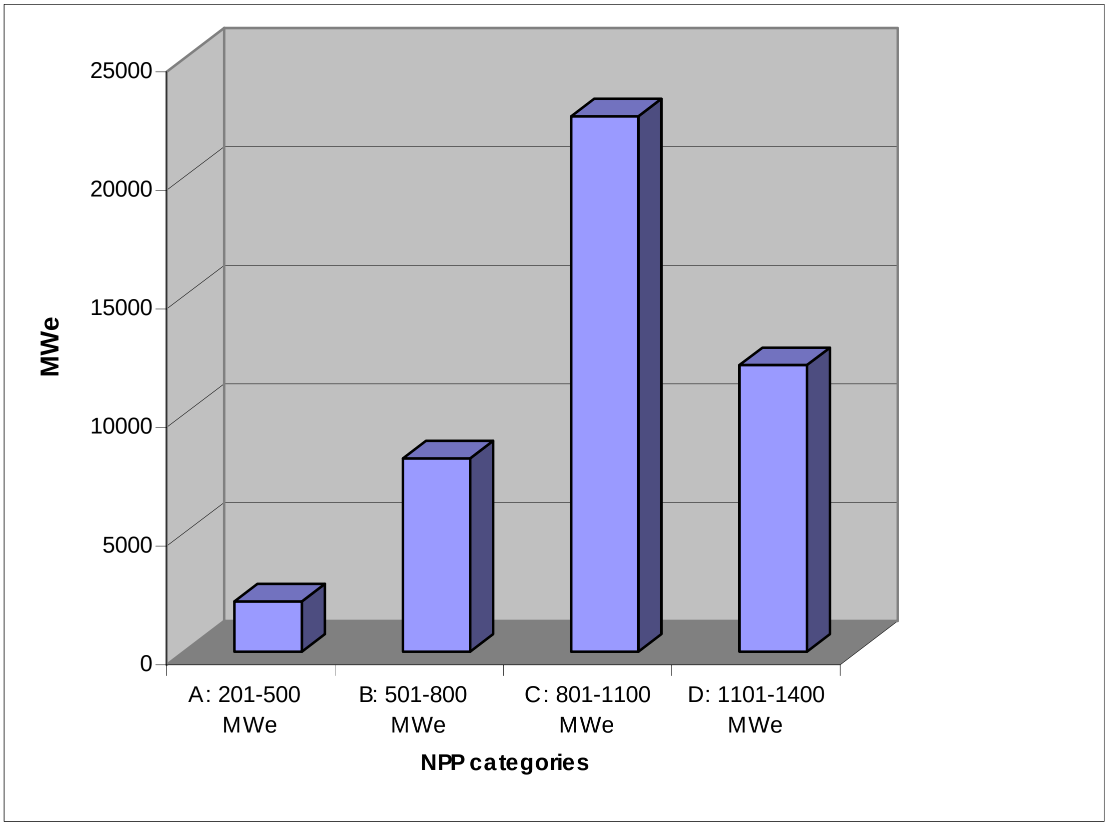


Fig. 1: The distribution of existing generating capacity among the 51 NPPs

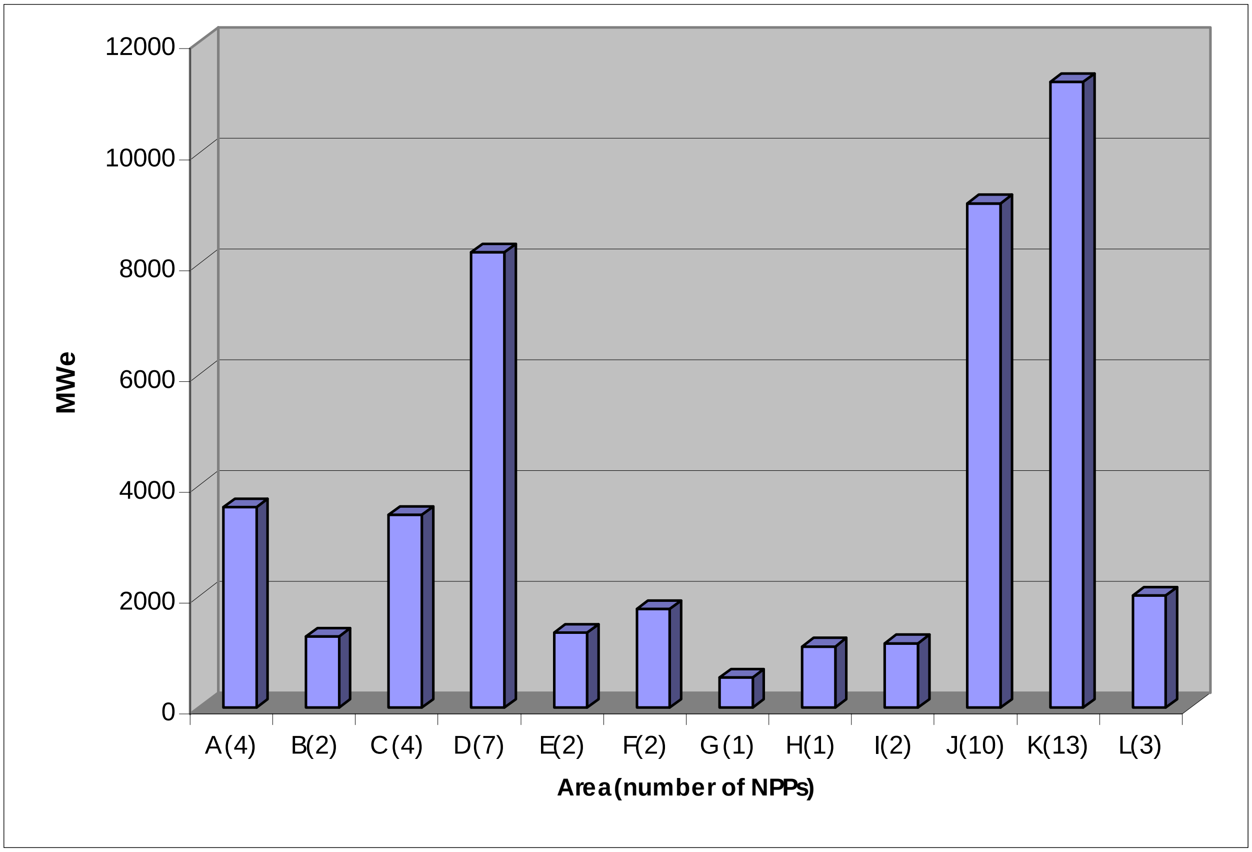


Fig. 2: Number of NPPs / prefecture and their corresponding overall output capacity

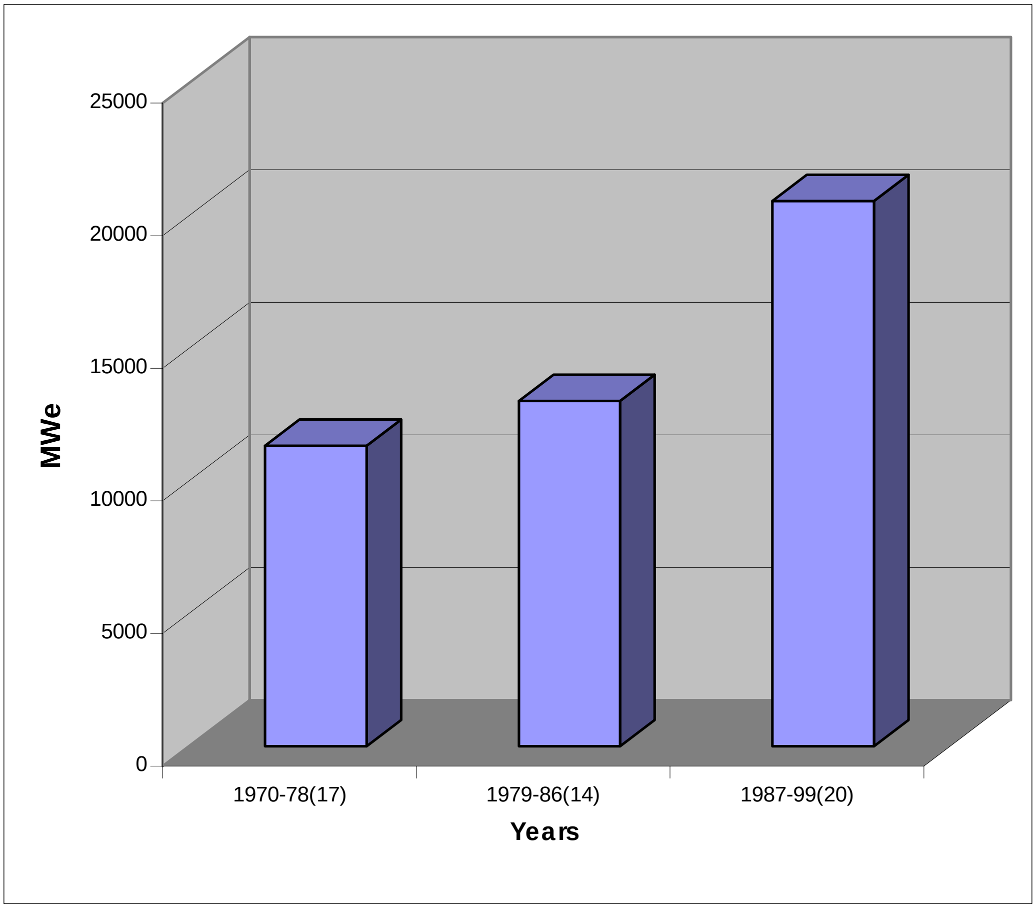


Fig. 3: Share of output capacity between NPPs of different age

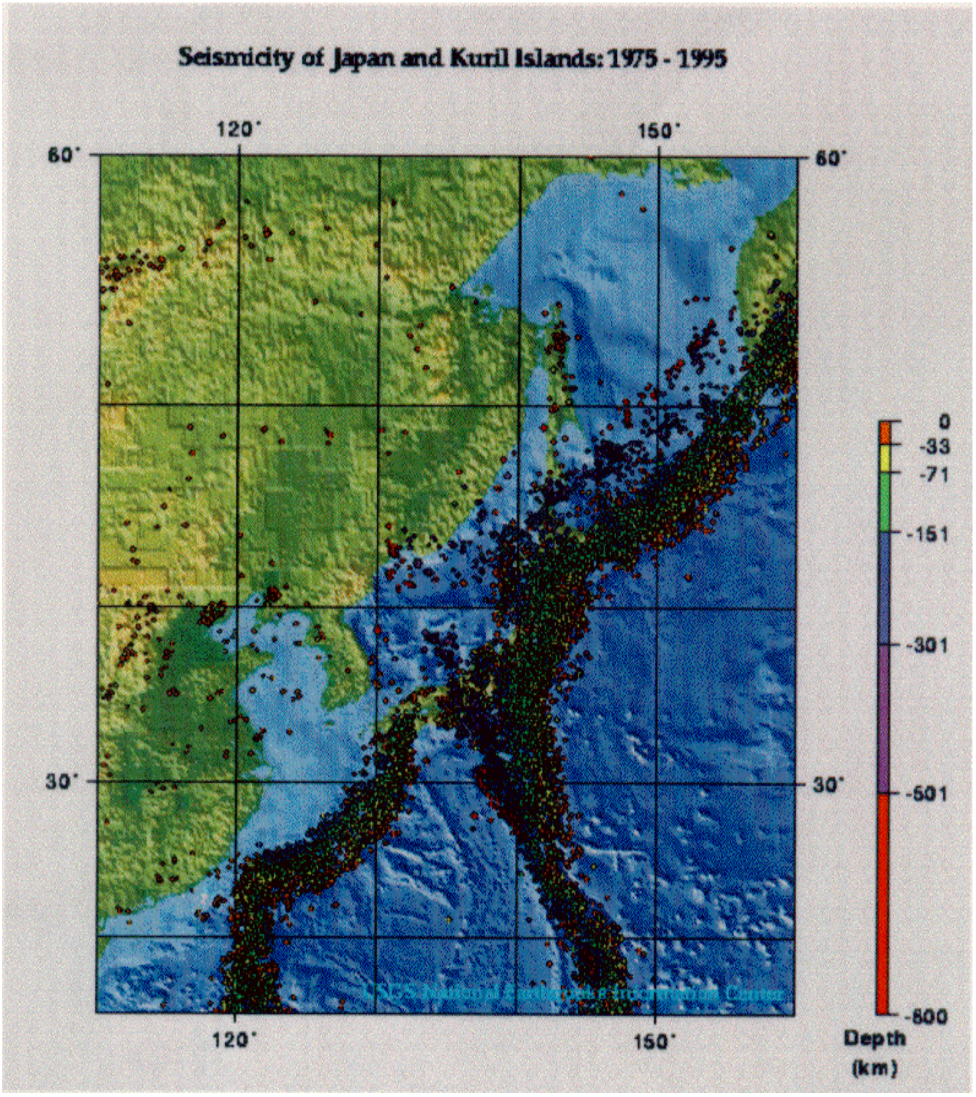


Fig.4: (source: National Earthquake Information Center, World Data Center for Seismology, 1999)

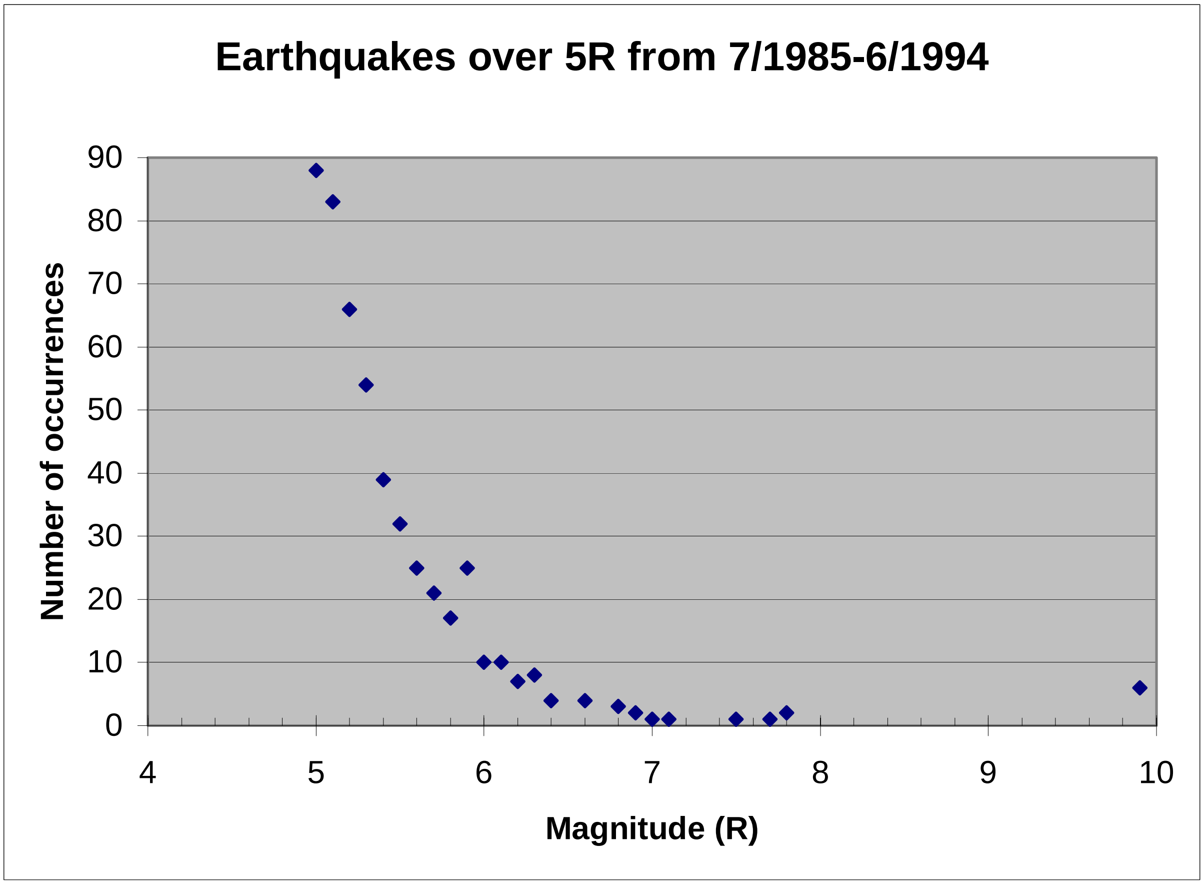


Fig. 5: Earthquake observations in Japan with magnitude over 5R (source: Earthquake Information Center)

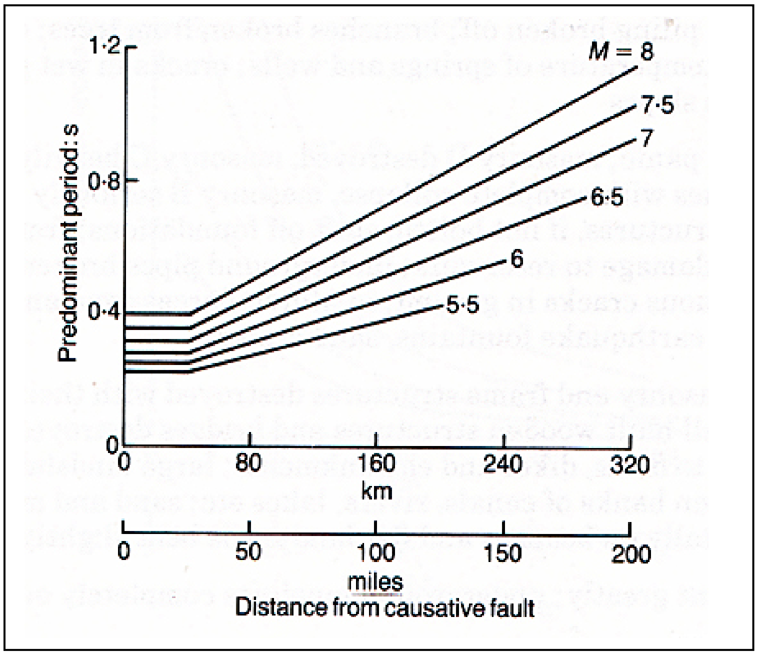


Fig. 6: Predominant period-distance relationship for the maximum acceleration in the rock (source: Key after Seed (1968))

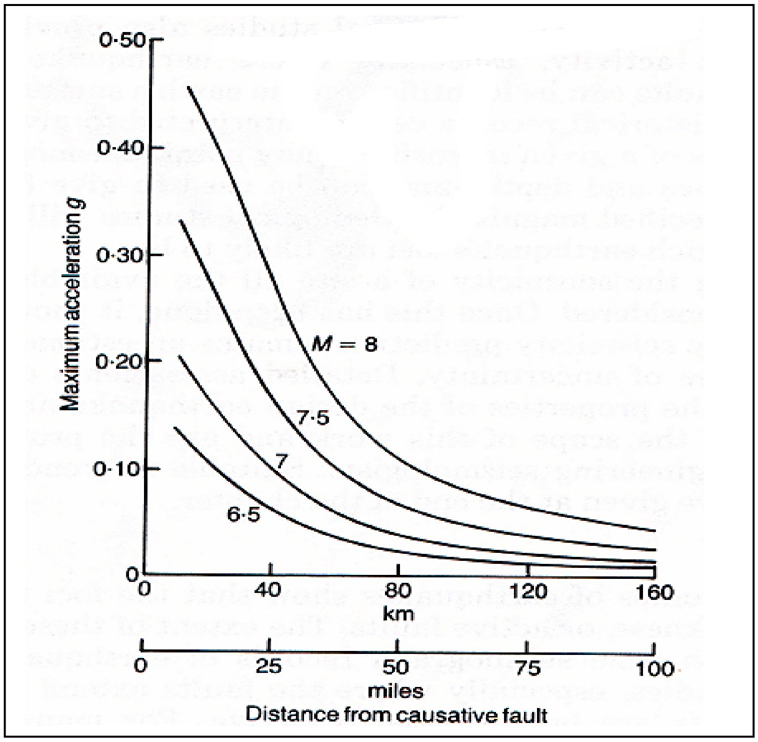


Fig.7: Acceleration- magnitude- distance relationship (source: Key, after Seed et al. (1976))

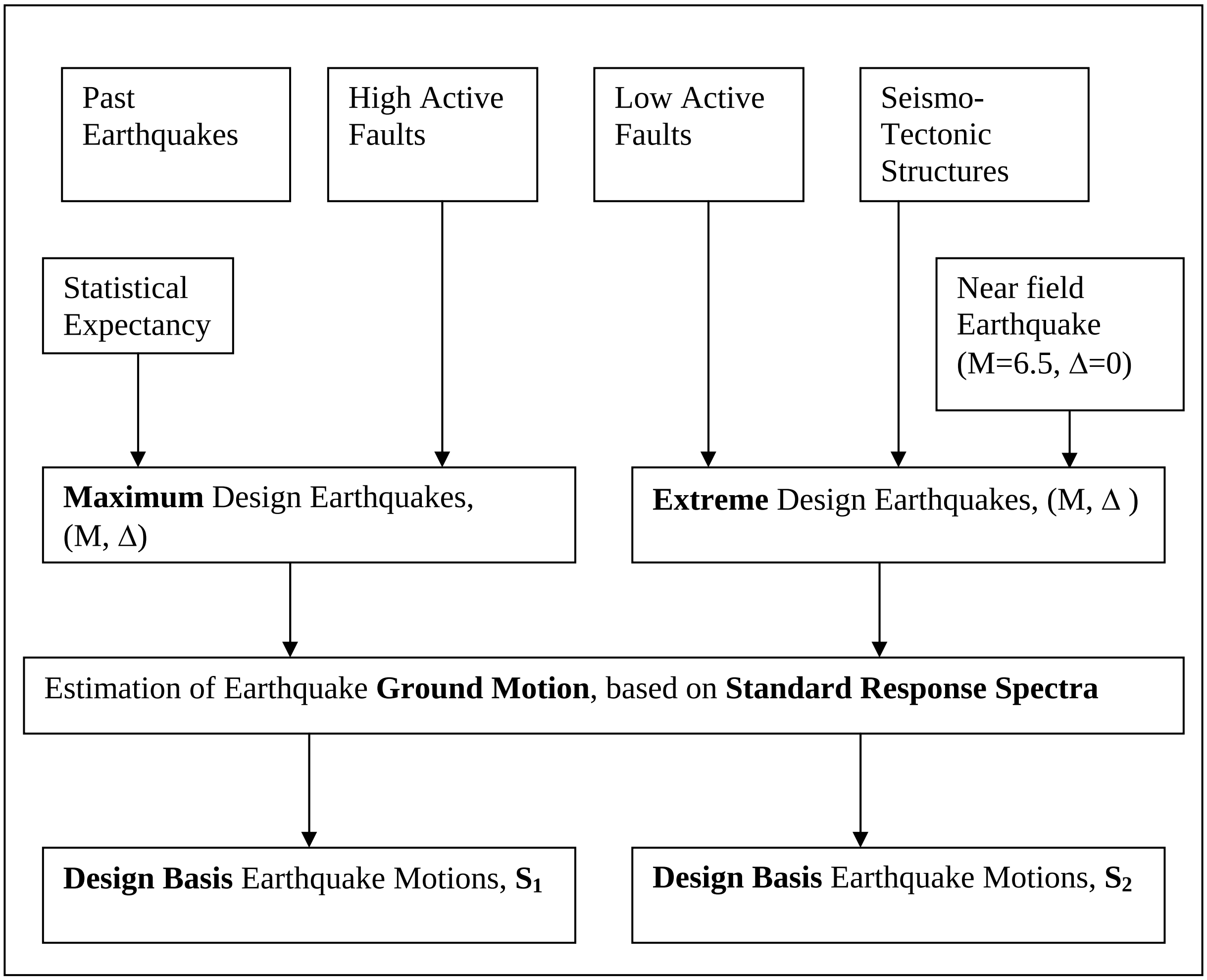


Fig.8 : Flow Chart for Determining Basis Earthquake Ground Motions (Source: M. Kato)
M: magnitude; Δ:: epicentral distance in kilometers; S_1*: maximum design earthquake:* S_2*: extreme design earthquake.*

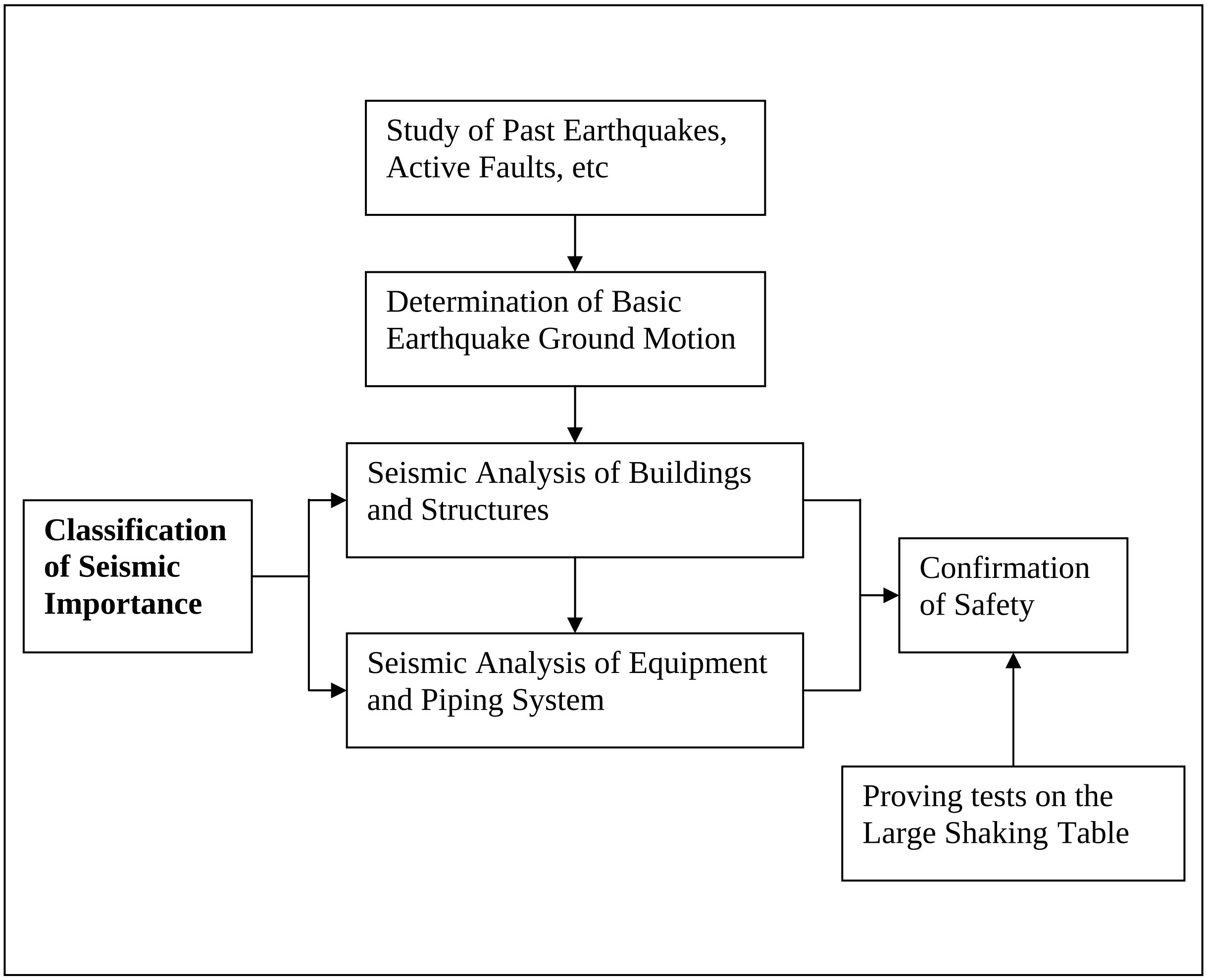


Fig. 9: Flow of Seismic Design (source: Agency of Natural Resources and Energy, 1995)

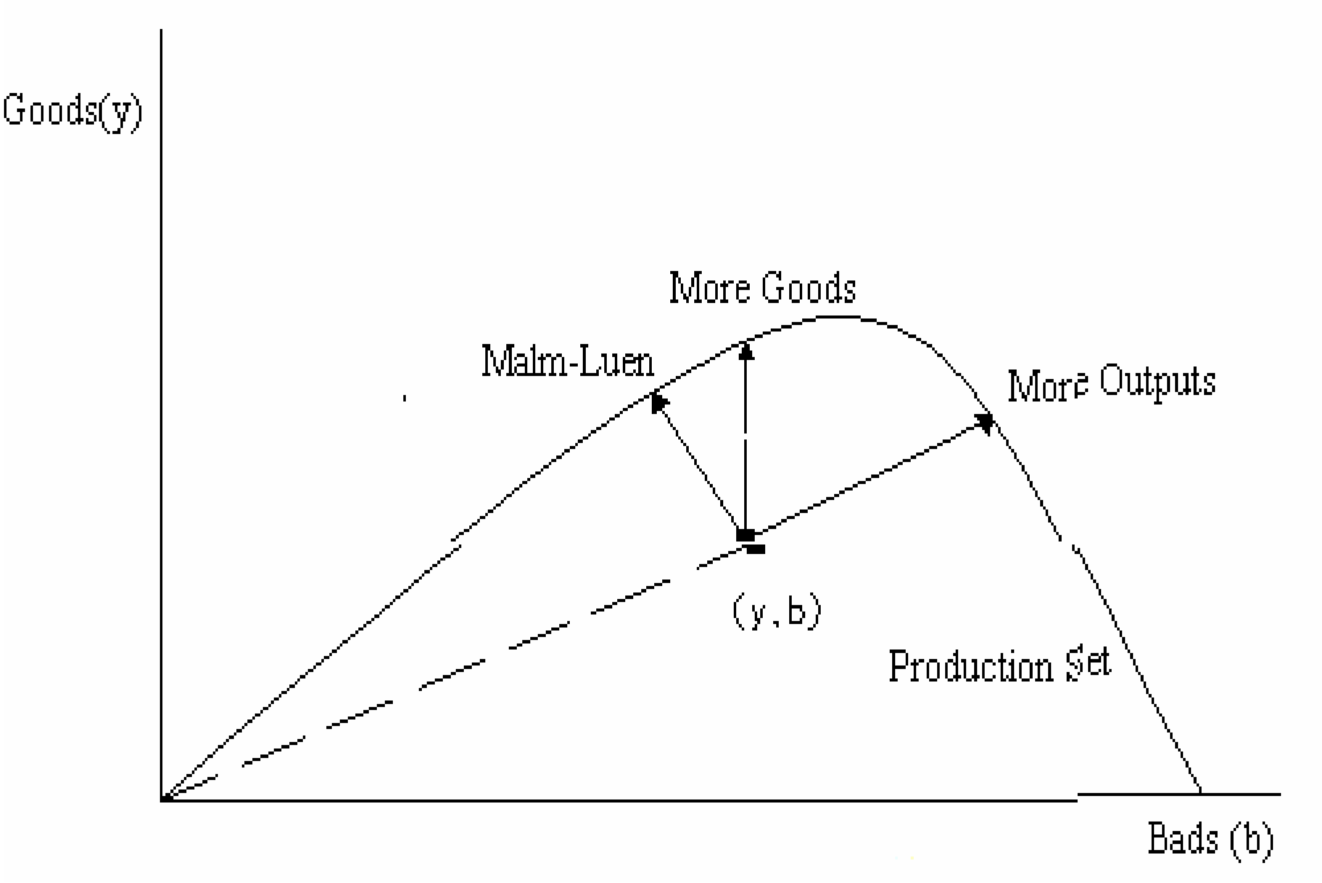


Fig. 10: The Malmlquist Luenberger Productivity Index

List of Tables

Sizes	Number of NPP	MWe
A: 201-500 Mwe	5	2117
B: 501-800 Mwe	13	8148
C: 801-1100 Mwe	23	22573
D: 1101-1400 Mwe	10	12079
SUM		44917

Table 1: Distribution of existing generating capacity among the 51 NPPs

Operation year	Number of NPP	MWe
1970-78(17)	17	11336
1979-86(14)	14	13019
1987-99(20)	20	20562
OVERALL: 1970-99	51	44917

Table 2: Share of output capacity between NPPs of different age

	Unit	Licensed output (MWe)	Decision at Power Supply Development	Reactor installation permission date	Scheduled start of commercial operation
NPP under construction	2	1. 825 2. 1100	1. May .94 2. Jul. 96	1. Apr. 96 2. Aug. 98	1. Jan. 2002 2. Jul 2005
Prepared for construction	3	1. 825 2. 1,380 3. 1,358	4. Nov. 81 5. Mar. 97 6. Mar. 97	1. Application pending 2. Dec. 25. 1998 3.Application pending	1. Fiscal 2008 2.Aug. 2005 3. Mar. 2006
SUM		5488			

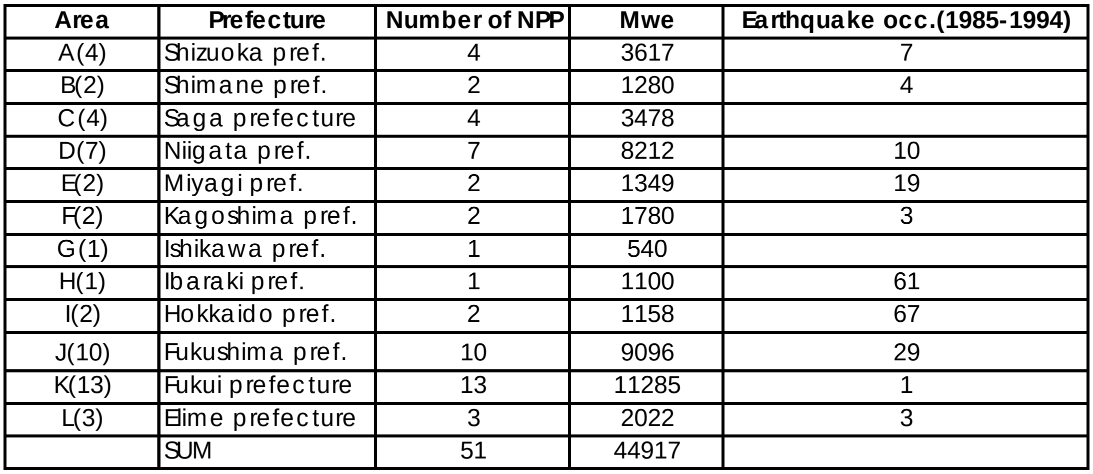
Table 3: Expected Nuclear Power Plants in Japan (source: 1999)

Descriptor	**Magnitude**	**Average Annually**
Great	8 and higher	1
Major	7-7.9	18
Strong	6-6.9	120
Moderate	5-5.9	800

Table 4: Frequency of occurrence of earthquakes based on observations since 1900 (source: Geological Survey National Earthquake Information Center)

Magnitude Change	**Ground Motion Change**	**Energy Change**
1.0	10.0 times	about 32 times
0.5	3.2 times	about 5.5 times
0.3	2.0 times	about three times
0.1	1.3 times	about 1.4 times

Table 5: Magnitude vs. Ground Motion and Energy (source: National Earthquake Information Center)



Area	**Prefecture**	**Number of NPP**	**Mwe**	**Earthquake occ.(1985-1994)**
A(4)	Shizuoka pref.	4	3617	7
B(2)	Shimane pref.	2	1280	4
C(4)	Saga prefecture	4	3478	
D(7)	Niigata pref.	7	8212	10
E(2)	Miyagi pref.	2	1349	19
F(2)	Kagoshima pref.	2	1780	3
G(1)	Ishikawa pref.	1	540	
H(1)	Ibaraki pref.	1	1100	61
I(2)	Hokkaido pref.	2	1158	67
J(10)	Fukushima pref.	10	9096	29
K(13)	Fukui prefecture	13	11285	1
L(3)	Elime prefecture	3	2022	3
	SUM	51	44917	

Table 6: Classification of earthquake occurrences related to the prefectures of NPPs

Location (City/Ward)	**Number of Buildings**[*] **(x 1,000)**	**Number of buildings damaged**[**]		
		100%	50%	Fire
Kobe/ Higashi-Nada Wrd	~ 40	2,788	7,923	89
Kobe/ Nad Ward	~ 25	600	400	176
Kobe/ Chu Ward	~ 25	2,437	3,142	30
Kobe Hyoo Ward	~ 25	1,000	500	145
Kobe/ Nagata Ward	~ 30	6,672	9,322	3,089
Kobe/ Suma Ward	~ 40	1,161	1,724	993
Kobe/ Tarumi Ward	~ 45	26	40	5
Kobe/ Nishi Ward	~ 30	0	0	0
Kobe/ Kita Ward	~ 40	1	4	1
Kobe(all wards)	~ 300	14,685	23,055	4,528
Ashiya	~ 15	359	363	5
Nishinomiya	~ 80	555	565	48
Amagasaki	~ 100	85	333	76
Itami	~ 35	99	297	7
Kawanishi	~ 30	170	732	3
Takarazuka	~ 40	1,339	3718	2
Sanda	~ 15	56	754	0
Akashi	~ 55	111	258	5
Awaji Island (north section)	~ 10	1,361	2436	1
Other Hyogo Prefecture cities	~ 70	4	16	0
Total Hyogo Prefecture cities	~ 750	18,824	32,527	4,675
Total Osaka Prefecture cities	~ 40	106	104	0
Total for other Prefecture cities	~ 10	2	23	0
Total for all cities	~ 800	~ 20,000	~ 35,000	~ 5,000

Table 7: Building Damage Data (source: Earthquake Engineering Research Institute, 1995)

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[*] Number of buildings estimated s one building per five of city or ward population

[**] The Sanki Shimbun newspaper, January 21,1995

Name of NPP	**Location**	**Distance from Epicenter (km)**	**Earthquake intensity at plant (Japanese scale of 7)**	**Shaking recorded at plant**	**Setting level for Automatic shutdown (gal)**	**Effects**
Takahama	Fukui prefect.	112	3	22	160	None
Mihama	Fukui prefect.	150	3	16	160	None
Ohi	Fukui prefect.	120	3	13	160	None
Tsuruga	Fukui prefect.	158	3	11	300	None

Table 8: Effects of the Southern Hyogo Prefecture Earthquake on various NPP (source: Agency of Natural Resources and Energy)

Time Period	**Malmquist Luenberger**	**Efficiency Change**	**Technical Change**
1980-1981	1.0443*	1.0000	1.0443
1981-1982	1.0248*	1.0000	1.0248
1982-1983	1.0190*	1.0000	1.0190
1983-1984	1.0248*	1.0000	1.0248
1984-1985	1.0426*	1.0000	1.0426
1985-1986	1.0174*	1.0000	1.0174
1986-1987	1.0345*	0.9882	1.0469
1987-1988	1.0472*	0.9811	1.0675
1988-1989	1.0386*	1.0162	1.0221
1989-1990	1.0416*	1.0020	1.0395
1990-1991	1.0407*	0.9919	1.0492
1991-1992	1.0014	0.9389	1.0655
1992-1993	1.0073	1.0005	1.0068
1993-1994	0.9905	0.9545	1.0377
1994-1995	1.0144*	0.9946	1.0199
Average	1.0259	0.9913	1.0352

Table 9: Malmquist Luenberger productivity growth for Japan Using East Asia data

Time Period	**Malmquist Luenberger**	**Efficiency Change**	**Technical Change**
1980-1981	(1.0238, 1.0525)	(0.9193, 1.1108)	(0.9328, 1.1154)
1981-1982	(1.0194, 1.0317)	(0.8939, 1.0567)	(0.9745, 1.1434)
1982-1983	(1.0157, 1.0222)	(0.9641, 1.0609)	(0.9607, 1.0582)
1983-1984	(1.0126, 1.0352)	(0.9580, 1.0545)	(0.9706, 1.0707)
1984-1985	(1.0383, 1.0451)	(0.9441, 1.0782)	(0.9670, 1.1006)
1985-1986	(1.0138, 1.0216)	(0.9354, 1.0720)	(0.9521, 1.0853)
1986-1987	(1.0243, 1.0354)	(0.9015, 1.0133)	(1.0169, 1.1466)
1987-1988	(1.0290, 1.0553)	(0.9225, 1.0232)	(1.0216, 1.1269)
1988-1989	(1.0227, 1.0418)	(0.9355, 1.1620)	(0.8926, 1.1000)
1989-1990	(1.0264, 1.0460)	(0.9452, 1.0987)	(0.9466, 1.0961)
1990-1991	(1.0238, 1.0447)	(0.9129, 1.0516)	(0.9841, 1.1330)
1991-1992	(0.9945, 1.0019)	(0.8875, 1.0064)	(0.9944, 1.1270)
1992-1993	(0.9990, 1.0130)	(0.9241, 1.0567)	(0.9497, 1.0913)
1993-1994	(0.9779, 1.0041)	(0.8984, 1.0197)	(0.9710, 1.0986)
1994-1995	(1.0007, 1.0217)	(0.9205, 1.0749)	(0.9425, 1.0978)

Table 10: Bootstrap confidence interval (95%) for Japan

Time Period	**Malmquist Luenberger**	**Efficiency Change**	**Technical Change**
1980-1981	1.0262*	1.0316	0.9948
1981-1982	1.0509*	1.0388	1.0117
1982-1983	1.0283*	1.0126	1.0154
1983-1984	0.9834*	0.9719	1.0119
1984-1985	1.0335*	1.0340	0.9995
1985-1986	1.0273*	1.0016	1.0257
1986-1987	1.0140*	1.0207	0.9935
1987-1988	0.9994	0.9735	1.0265
1988-1989	1.0079*	1.0157	0.9924
1989-1990	1.0112*	0.9985	1.0128
Average	1.0181	1.0096	1.0083

Table 11: Malmquist Luenberger productivity growth for Japan Using OECD Data

Time Period	Malmquist Luenberger	Efficiency Change	Technical Change
1980-1981	(1.0237, 1.0386)	(0.9897, 1.0635)	(0.9667, 1.0405)
1981-1982	(1.0479, 1.0620)	(0.9978, 1.0664)	(0.9873, 1.0553)
1982-1983	(1.0264, 1.0350)	(0.9857, 1.0425)	(0.9897, 1.0445)
1983-1984	(0.9696, 0.9841)	(0.9356, 1.0178)	(0.9626, 1.0442)
1984-1985	(1.0329, 1.0409)	(0.9990, 1.0712)	(0.9689, 1.0359)
1985-1986	(1.0201, 1.0286)	(0.9753, 1.0481)	(0.9788, 1.0506)
1986-1987	(1.0117, 1.0158)	(0.9815, 1.0617)	(0.9549, 1.0322)
1987-1988	(0.9971, 1.0081)	(0.9270, 1.0152	(0.9875, 1.0794)
1988-1989	(1.0060, 1.0121)	(0.9698, 1.0694)	(0.9435, 1.0394)
1989-1990	(1.0094, 1.0183)	(0.9573, 1.0300)	(0.9839, 1.0582)

Table 12: Bootstrap confidence interval (95%) for Japan

	Without CO2 Consideration			**With CO2 Consideration**		
	Low	**Standard**	**High**	**Low**	**Standard**	**High**
1995	2075.6	2075.6	2075.6	2075.6	2075.6	2075.6
2005	2218.7	2287.6	2358.2	2180.2	2248.0	2317.7
2015	2529.9	2689.4	2858.1	2400.4	2552.4	2713.2
2020	2701.6	2916.1	3146.5	2518.8	2719.7	2935.6
AAGR	1.06	1.37	1.68	0.78	1.09	1.40

Table 13: Japan's long term energy demand projection (10^{13} Btu)