ECONOMIC CONSIDERATIONS FOR INTERNATIONAL ELECTRICITY INTERCONNECTION IN NORTH-EAST ASIA

Karsten Neuhoff[1]

University of Cambridge

1. SYNOPSIS

Economic aspects of electricity interconnection between Russia, North Korea and South Korea are presented and related to recent experiences in other countries. Political issues of the interconnection are excluded from the analysis as far as possible. I believe the political process is simplified if it can build on a shared technical and economic perspective.

Data on generation costs suggests that cost differences between countries are insufficient to justify an interconnection for base load energy. Initial assessment of additional economic benefits due to peculiar electricity characteristics suggests that the project is very profitable.

The interconnection can supply response energy and reserve energy to stabilise the North Korean grid in the presence of large generation units. International data suggests that provision of primary response costs about $15 per MW per hour. 700 MW would be required by North Korea and could be provided by either South Korea or Russia at little cost even when the transmission line is used at full capacity.

A second additional advantage of the interconnection line is that it allows hedging uncertainty of long-term demand forecasts. The analysed 2 GW interconnection for base load exports to South Korea allows Russia to reduce generation capacity by 0.45 and simultaneously commit to 2 GW energy exports. South Korea could reduce generation capacity by 1.86 GW and maintain the same level of supply security.

Russian hydro reserves can be used to provide flexibility during ramping times of the coal and nuclear based South Korean system. Further economic advantages of the interconnection could be the improved usage of Russian excess generation capacity in the initial years and greater diversification of energy resources in South Korea.

[1] I want to thank organisers and participants of the Workshop on International Electricity Grid Interconnection in Northeast Asia for insights and discussions, Professor David Newbery, Andreas Park and Andreas Pick for discussions of techniques and feedback and the ESRC, Gottlieb Daimler Foundation and Nautilius Institute for financial support.

European experience shows that successful planning, construction and operation of international interconnections requires that all countries continuously and mutually benefit. The proposed interconnection not only satisfies this participation constraint but it is even politically feasible. Every country incurs costs by not participating. No individual country, however, can use the transmission line to exert power over their neighbours.

The financing of the interconnection should be done through private-public partnerships or in public ownership or ownership by the national transmission grid. A purely private project would provide fewer participation incentives for the countries, offers little flexibility for future restructuring and creates monopoly dead-weight losses.

This essay points out economic issues specific to international electricity interconnection and is intended as the basis for a subsequent and more detailed analysis. It is no cost benefit analysis; numbers presented are to my best knowledge but insufficiently accurate for a cost benefit analysis. The first part describes the economic benefits. The second part analyses how these benefits would be attributed to the involved counter-parties. It will be discussed whether and under which conditions countries have incentives to reduce participation or interfere with the operation and which financing approach is feasible.

2. ECONOMIC BENEFITS OF INTERCONNECTION

The 1998 IEA projection for electricity generation costs in Table 1 suggests that Russian exports to South Korea can generate revenues between $6 per MWh if Korean coal generation is replaced by Russian gas generation and $9 per MWh if Korean nuclear generation is replaced by Russian gas generation. The corresponding cost components would consist of $4 per MWh to pay for 10% transmission losses and capital costs of the same order of magnitude. Based on the base load revenues the project seems economically nonviable. The analysis in the following paragraphs will prove that additional benefits can be gained from the interconnection, which will ultimately change the judgement about its economic feasibility.

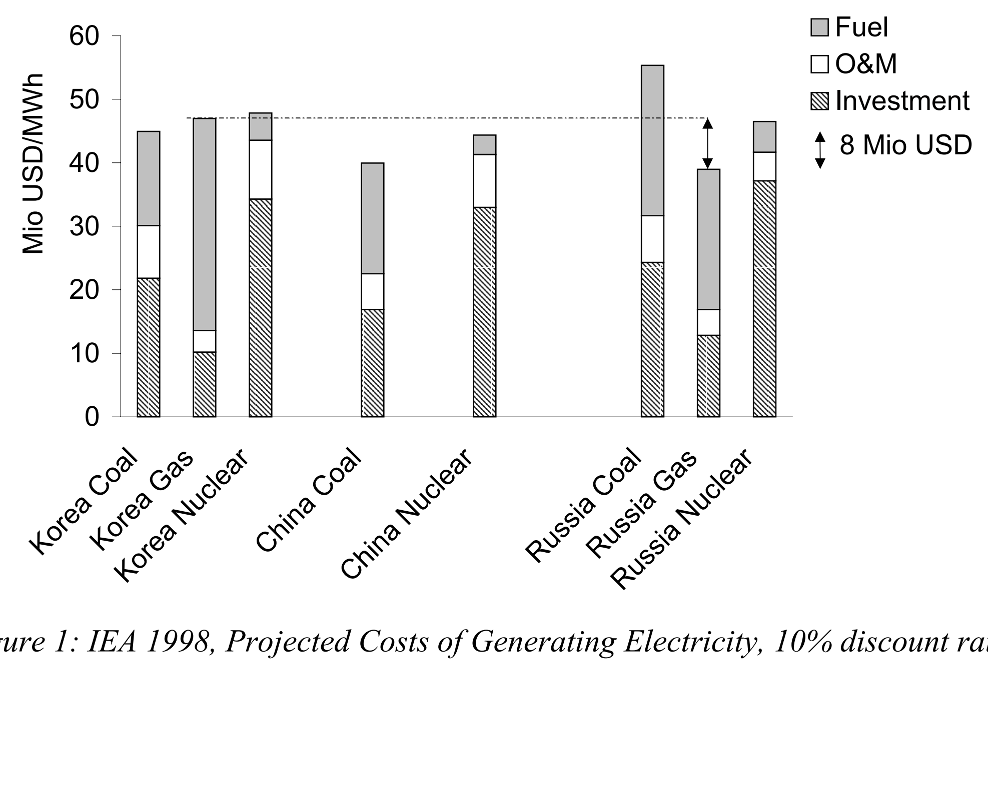


Figure 1: IEA 1998, Projected Costs of Generating Electricity, 10% discount rate

2.1 USE OF HISTORICAL ASSETS

The new Russian Energy strategy assumes that energy demand will not reach its 1990 level in the near future (IES 01). This gives rise to the conjecture that a significant proportion of generation assets are currently under-utilised. Historic investment represents sunk costs not to be included in benefit analysis. As long as no additional generation investment is required, generation costs equal variable costs plus operation and maintenance costs. In the period of Russian over-capacity the cost differential between Russia and South Korea is larger than assessed in section 2.1 and the benefits of the interconnection increase.

2.2 PEAK BALANCING

Current technology does not allow storing electric energy. The energy must be balanced instantaneously. Peak balancing refers to provision of anticipated higher energy demand during a defined period, for example the ramping of the generators, daily peaks and seasonal peaks.

2.2.1 PEAK BALANCING DURING RAMPING

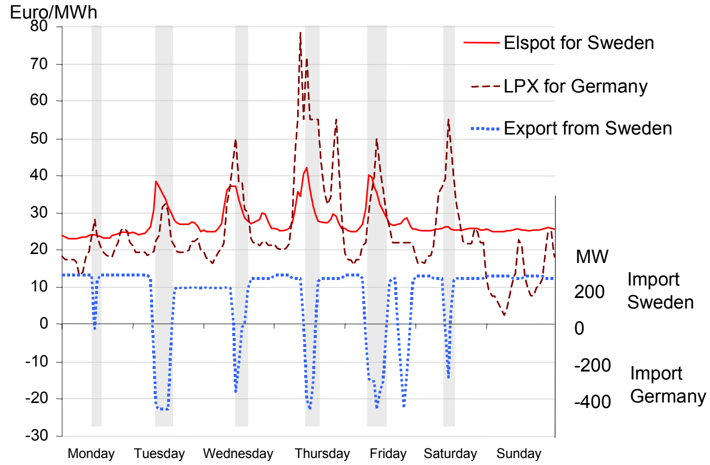
Balancing during ramping times is best illustrated by an example from the Netherlands. Demand picks up faster in the morning hours than generators can ramp up their output. To compensate for that effect generators start increasing their output before demand picks up and base load imports are reduced during that time.

The South Korean system with 35% coal and 41% nuclear generation faces the same challenge and could presumably save costs of pump storage when being interconnected with flexible hydro reserves of the Russian Far East.

2.2.2 DAILY PEAK BALANCING

Using Russian hydro reserves to balance daily peak demand seems less promising, because Russia can export base load electricity generated at cheaper plants. If base load occupies the transmission line the line cannot be used to supply additional energy at peak times. The interconnector can therefore either be used to provide base load or peak balancing to South Korea. Given the high capital costs continuous usage for base load transmission appears to be more economic.

The Swedish-German interconnection in Figure 2 illustrates that balancing is possible if base load exports from the inflexible German system are directed opposite to imports from the Scandinavian hydro system. The additional peak load capacity for the German system equals twice the capacity of the interconnector.



Source: www.LPX.de data, www.nordpool.no, week 16-

Figure 2: German base load electricity prices are below Swedish prices resulting in base load exports. Peak demand drives up prices in Germany leading to imports to the higher demand from the hydro dominated Scandinavian system.

2.2.3 SEASONAL PEAK BALANCING

Seasonal peak variations can offer significant gains for an interconnection. Nordic country N incurs demand peaks due to heating during winter, whilst in southern country S demand is highest during summertime when air conditioners are used.

For illustrative purposes suppose that the difference between winter peak demand and summer peak demand is 4 GW, twice the transmission capacity. N substitutes 2 GW of generation capacity required to cover the winter peak with 2 GW of imports. Further, 2 GW of capacity are usually idle in summertime, but can now be used for exports. N can reduce generation capacity by 2 GW. S performs the same analysis, changing winter with summer, and also reduces generation capacity by 2 GW. The 2 GW interconnection allows for reduction of 4 GW of generation capacity.

A more precise analysis would incorporate the effects of seasonally changing generation capacity due to reduced cooling, co-generation, non-storable renewables and stored hydro. At the moment it is not clear what result can be expected from such an analysis. Therefore this paper only assumes base load exports. All benefits described in this section can be achieved with a system used for seasonal balancing, but economic benefits of seasonal balancing would be higher than of pure base load exports. Therefore assuming base load exports is a safe bet.

2.3 ANCILLARY SERVICES

One of the goals of the interconnection line is to secure operation of the North Korean electricity grid by providing ancillary services.

2.3.1 FUNCTION OF ANCIALLARY SERVICES

Secure operation of the network requires sufficient response and reserve capacity to cover the outage of the largest generation unit, assumed to be 1 GW in North Korea. The definition of response and reserve capacity varies slightly between countries, but technical characteristics imply that capacity, which can react within fractions of a second, cannot sustain the additional output for long and has to be replaced by primary response within seconds. Secondary response is assumed to come in more slowly, increasing output during half a minute and required to sustain output for some time, in the UK 30 minutes. Reserve capacity should pick up after that.

North Korea has big hydro capacity (currently estimated to be 5GW out of 10 GW nominal capacity based on UN Energy statistics). Hydro generators can be started quickly, but not fast enough to provide frequency response or primary response. Storage hydro can potentially be used to provide secondary response and reserve capacity for the case of an outage of 1 GW.

Frequency and primary response are to be provided within fractions of a second and therefore require running and synchronised generators. Usually these generators are operated at reduced output to provide for the additional response capacity. Provision of 1GW of frequency and primary response in the small North Korean system would therefore require all generators to run at inefficient low levels, if at all possible. Imports of i.e. 500-700 MW of frequency and primary response could offer significant economic gains to North Korea.[2]

2.3.2 DELIVERY OF ANCILLARY SERVICES

Preliminary statements of electrical engineers and grid planners suggest that AC as well as DC interconnections should enable neighbouring systems to provide the required energy difference. In the discussion people expressed concerns about reliability of DC interconnections. These have to be addressed, as it must be ensured that the interconnection provides sufficient security for the North Korean grid.

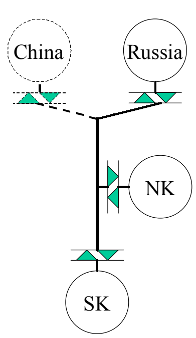


Figure 3: Schematic drawing of initial interconnection between Russia, North Korea and South Korea with capacity of 2GW and three terminals. Alternatively NK and SK are connected with an AC link.

Figure 3 illustrates the interconnection, assuming a three terminal DC link with 2 GW capacity. Alternatively North Korea or parts of North Korea could be interconnected to South Korea with an AC link whilst any interconnection with Russia requires a DC converter.

[2] At present high frequency (up to +/- 10 Hz) and voltage fluctuations are observed in the North Korean system, indicating insufficient capacity or regulation. I assume North Korea targets stabilising the grid in order to reduce wear of generation assets and appliances and to reduce need for expensive filter devices for IT devices.

Table 1 illustrates that it is physically feasible to use a transmission line for energy transmission between Russia and South Korea at full capacity and simultaneously for provision of ancillary services to North Korea. The three leftmost columns show the initial base load flow. The following columns show the inflows after a fault on a Russian North Korean circuit, a fault on the North Korean - South Korean circuit, loss of load in North Korea and loss of generation in North Korea. A plus sign represents 1 GW export and a minus sign 1 GW import.

The *(n-1)* security constraint requires any system to sustain a load change due to the failure of one circuit. If the 2 GW transmission line consists of two 1 GW circuits then the South Korean and Russian system needs to sustain a load change of 1 GW. In order to supply energy balancing of 1 GW to North Korea, both Russia and South Korea have to reconfigure their generation by 1 GW.

Initial Flow			Fault RU-NK			Fault NK-SK			LL in NK			LG in NK		
R U	N K	S K	R U	N K	S K	R U	N K	S K	R U	N K	S K	R U	N K	S K
++	-	-	+ ⇓	-	0 ⇑	+ ⇓	-	0 ⇑	+ ⇓	0	-	++	--	0 ⇑
+	+	--	0 ⇓	+	- ⇑	0 ⇓	+	- ⇑	0 ⇓	++	--	++ ⇑	0	--
--	+	+	- ⇑	+	0 ⇓	- ⇑	+	0 ⇓	--	++	0 ⇓	- ⇑	0	+
++	0	--	+ ⇓	0	- ⇑	+ ⇓	0	- ⇑	+ ⇓	0	--	++	0	- ⇑

Table 1: Illustrative contingency analysis. Auxiliary services of 1 GW additional load/power can be provided to North Korea while using the transmission system at full capacity (Symbols in units of 1 GW: + export, - import, ⇓ reduced generation, ⇑ increased generation).

2.3.3 VALUE OF ANCILLARY SERVICES

The value ancillary services have to North Korea can be seen by the costs incurred in the UK, Germany, Spain and California for the provision of ancillary services. It can be expected that the costs for the provision of large amounts of response capacity are higher in small systems than in big systems, therefore the auction data—taken as cost estimates—are a lower bound to the costs incurred in North Korea for the provision of response services.[3] The ancillary services have to be provided by South Korea and the Russian Far East for their own system and can be shared with little additional cost. This implies that the value of transmission interconnection corresponds to the value of ancillary services provided to North Korea.

---

[3] In a large system with many generators any generator only needs to reduce output by a small amount to provide response inducing a small deviation from the optimal output. In a small system generators have to reduce output significantly and deviate significantly from optimal output. Engine efficiency is not a linear function of output, therefore large deviations can be overproportionally less efficient than small deviations. If large deviations would be more efficient then a large system would acquire response capacity by large deviations of few generators. Then the costs of the large system would be the same as the costs of a small system. The assumption that costs in a small system are not lower than in a large system is still true.

Table 2 highlights prices, which the system operator has to pay to obtain ancillary services in the liberalised UK market. Provision of frequency response is required from generators under the terms of the Grid code, while other services are contracted bilaterally or in competitive tender. About half of the remuneration is cost-based; the other half is value based. Cost of provision of 1 MW reserve capacity for one hour has been calculated based on the information provided in the Ofgem '99 publication. It should only be understood as indicative value, because many services are contracted in a bundle such that only estimates of the individual components are available.

Table 2 shows that the provision of frequency response (~ms to ~5s), primary response (~5s to ~30s), secondary response (~30s to ~30min) and reserve capacity (>10 min) each cost more than $6 per MW per hour. This is due to the fact that the provision of these services requires not only a fast responding capacity to be idle but also generation to run at reduced load. The required amount of contracted response and reserve capacity corresponds to, at least, the capacity of the biggest single unit in the system.

	Volume	Cost/year	Price MW per hour
Primary response	715 MW		
Secondary response	825 MW	$170 Mio.	$6.5
High response	550 MW		
Response contracted in Pool	550 MW		
Scheduled reserve (synchronised)	1100 MW	$85 Mio.	$8.5
Standing reserve*	880 MW	$20 Mio.	$2.3
Black Start		$15 Mio.	

*Table 2: Approximate costs incurred for ancillary services in the UK, average of years 1996-1998, * includes 0.1% utilisation, exchange rate 1.42$/£*
Source: Ofgem '99

California has implemented a daily auction for provision of response and reserve capacity. As prices of response capacity are related to electricity prices I chose data from May 1999 to May 2000 before the price increases. The average price for regulation (primary response) was $18.9 per MW. The average price for spinning reserve was $5.61 per MW and non-spinning reserve was priced at $2.42 per MW. These numbers express the high costs which a system has to incur to provide primary response and illustrates the difference between primary response and reserve.

In Spain currently only secondary response is acquired in a market based approach. The average auction revenue in the last year (5/00 to 4/01) was 8.57 Euro per MW per hour. The average monthly price varied in this period between 1.92 and 20.23 Euro. The variation did not correspond to the energy prices, suggesting that the variation was a result of strategic market interaction rather than scarcity of capacity.

In Germany RWE has performed a first pay as bid auction to acquire an unspecified quantity of ancillary services for half a year starting in March 2001. Primary response is provided for prices between 12.1 and 30.4 Euro per MW per hour, secondary response for between 21.6 and 25.8 Euro per MW per hour and reserve (Minutenreserve) for 3.7 to 9.7 Euro per MW per hour. The capacity prices bid into the auction varied significantly, indicating the difficulty participants have to associate a value with these services.

The only direct information for primary reserve from RWE in Germany and California indicate that the capacity price per MW per hour provision is above $15.

2.4 HEDGING OF DEMAND UNCERTAINTY

Future electricity consumption is difficult to anticipate. Figure 4 illustrates that Italy underestimated demand growth in the 1980s.[4] Interconnection to the UCTE system allowed Italy to import the missing electric energy from other European countries. Historical data is used to determine the error for demand predictions. Central planners and market players provide for more generation capacity than average predictions require as a reaction of demand uncertainty. Electric interconnections can be used to provide the extra capacity in the case that only one country experiences unexpected high demand growth. Historical data is used to estimate forecast errors and the correlation of errors between countries and then to calculate how much generation capacity countries can save while still providing the same level security to meet future demand.

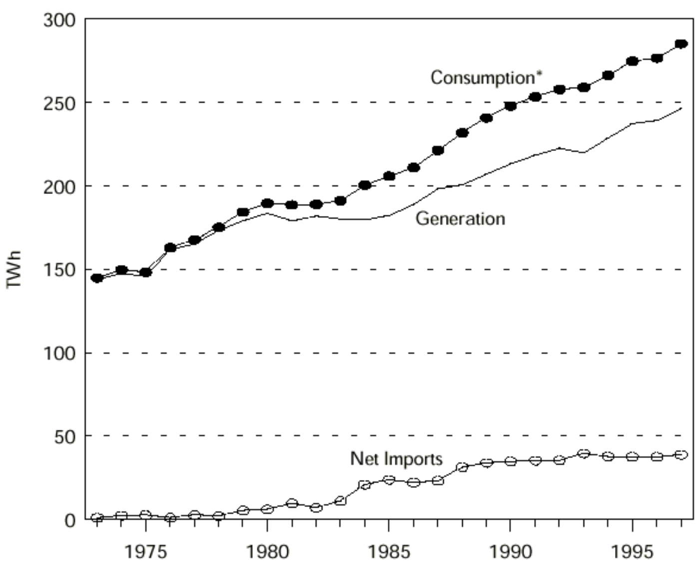


Figure 4: Electricity consumption, supply and imports to Italy, Source OECD '98

2.4.1 HISTORICAL ELECTRICITY GENERATION DATA

For a systematic approach to East Asian countries Figure 5 represents the total electricity generation in the period from 1950 to 1999. Generation jumps between 1969 and 1970 are artefacts due to different preparation of the data. The logarithmic representation suggestes that annual growth rate only changes a little over time.

[4] The nuclear moratorium preventing construction of nuclear power plants and the availability of cheap imports to replace inefficient stations has been cited as further reason for high imports.

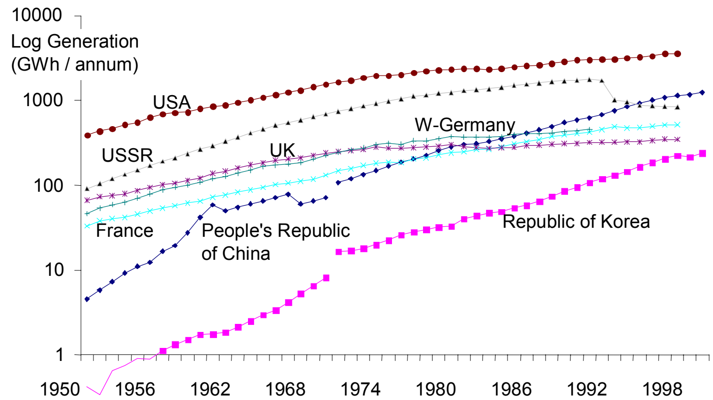


Figure 5: Development of electricity generation from 1950 to 1999 (UN/ADB)

Due to limited data quality and significant political regime shifts in China and South Korea the statistical analysis was confined to 1970-1999.

2.4.2 STATISTICAL ANALYSIS

The accuracy of demand predictions is estimated with historical data. It is shown that the logarithm of annual electricity generation can be described by a random walk with drift. Market participants as well as central planners can only predict the average growth rate, but not the random component. The average growth rate corresponds to the drift of the random walk. Planners or market players cannot predict the variations of growth around the average growth rate. If demand growth is faster than average growth then there is a risk of insufficient generation capacity. To reduce this risk more generation capacity has to be constructed than would be implied by the average growth rate. The random component is uncorrelated over time and can therefore be modelled as a random walk. This allows predicting the error of demand forecasts.

The Dickey Fuller test is a standard test to identify whether a time series represents a random walk. Dicky Fuller does not reject the assumption that output growth is a random walk with linear changing drift. The Chinese data was close to being rejected at the 10% level—indicating higher serial correlation probably induced from the traditional five year planning cycles. Figure 6 illustrates output development, fitted results and residuals for France and South Korea.

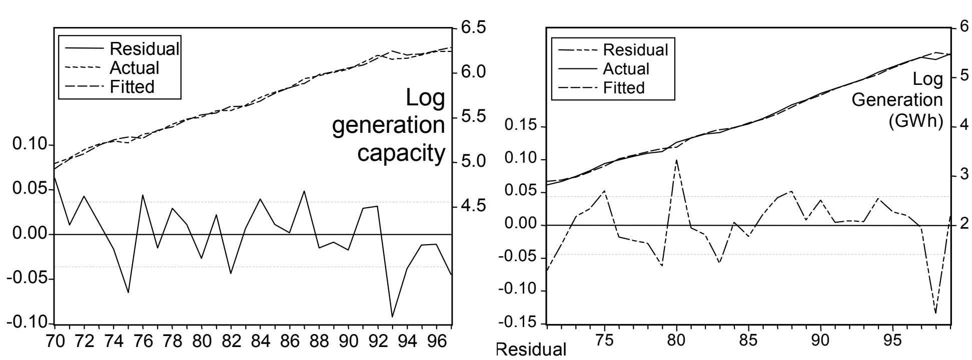


Figure 6:French electricity generation South Korean electricity generation

The corresponding growth rates and annual standard deviations of growth rates for seven countries are presented in Table 4. The centrally planned USSR incurred the lowest fluctuations. Large countries incur lower fluctuations because generation is aggregated over larger regions.

	Average Growth	Standard Error	Period
S-Korea	9.7%	4.5%	70-99
China PR	8.8%	2.7%	70-99
USSR	4.1%	1.4%	70-91
W-Germany	3.4%	3.5%	70-91
France	5.5%	3.0%	70-97
UK	1.2%	2.8%	70-97
USA	3.0%	2.4%	70-97

Table 4: Annual average growth rate and standard deviation based on UN Energy Statistics.

If growth variations are identical in neighbouring countries then international interconnections cannot support a country with higher than expected demand growth. Table 5 gives the correlation of demand growth among 7 countries. It shows that high economic interdependencies such as those between the European nations and the US result in correlation coefficients of around 0.5. This indicates a significant probability of simultaneously higher than expected growth. The past development of South Korean energy demand was anti-cyclical relative to all other observed countries—it would have been a perfect match for any interconnection. Since the data only covers 27 observations it should however not be over-interpreted.

Lack of historical correlation between South Korean and Chinese growth variations and different future economic and political perspectives suggests that correlation of demand variations can be expected to stay small.

	S-Korea	China PR	USSR	Germany	France	UK	USA
S-Korea	1.004	**-0.09**	**-0.13**	*-0.39*	*-0.33*	*-0.31*	*-0.11*
China PR	**-0.09**	1.00	0.40	*0.24*	*0.05*	*0.27*	*0.34*
USSR	**-0.13**	0.40	1.00	0.63	**0.05**	**0.10**	*0.39*
Germany	*-0.39*	*0.24*	0.63	1.00	0.52	0.43	*0.55*
France	*-0.33*	*0.05*	**0.05**	0.52	1.00	**0.30**	*0.41*
UK	*-0.31*	*0.27*	**0.10**	0.43	**0.30**	1.00	*0.59*
USA	*-0.11*	*0.34*	*0.39*	*0.55*	*0.41*	*0.59*	*1.00*

Table 5. Cross country correlation of variations of growth rates 1970-1997, except USSR 1970-1991, UN Energy Statistics.

Based on the historical analysis I conclude that in not centrally planned economies realised electricity demand variations from country specific average growth have a standard deviation of more than 2.5% per annum. Errors of annual growth rate forecasts are not serially correlated.

2.3.3 REQUIRED CAPACITY TO COVER DEMAND FORECAST ERRORS

The last subsection showed that demand growth in any year equals the country specific growth rate plus a random component. This random component results in errors in demand forecasts. Generation capacity cannot be increased instantaneously as it requires planning, permission and construction of additional power plants. I assume that the entire process takes at least four years. Assuming furthermore that errors in demand fluctuations are normally distributed, the following formula gives the standard deviation of forecast errors for a four-year period:

$$\sigma_{\text{Demand forecast}} = \sqrt{T}\sigma_{\text{Per period}} = \sqrt{4}\ 2.5\% = 5\% \qquad (1)$$

A planner needs to decide how certain she wants to be to meet the future demand. If she decided on an 85% level of certainty equation (1) tells her that she needs to provide 5% more capacity than would be required if demand will grow at the average growth rate. The subsequent analysis is based on the 85% security assumption. The final result only changes a little with changes to this assumption.

Continuing with the previously analysed scenario, South Korea is assumed to import base load capacity. Imports will already be incorporated in the South Korean planning process and result in a reduction of capacity requirements of up to 2 GW or 2.5%.[5] Now let us incorporate the advantages of international demand hedging, from the perspective of Russia. Assuming the Russian planner calculated that 10 GW extra capacity is required to offer 85% security to satisfy future demand. How much capacity can she save due to hedging with South Korea whilst maintaining the same level of security to satisfy future demand?

The planner knows that, in principle, she needs 2 GW more generation capacity. This requirement can be reduced because if demand growth is high in Russia but low in South Korea the energy exports can be renegotiated. Stopping the exports reduces demand by 2 GW. If demand in South Korea is even lower then Russia can buy electricity from South Korea and import 2 GW, de facto reducing demand by 4 GW.

I assume demand forecast errors are normally distributed to allow usage of the cumulative normal distribution function $\Phi(x/\sigma)$.[6] Given the standard error of demand forecast σ, function Φ gives the probability that the error will be smaller than x.

Equation (2) calculates the probability that South Korea has sufficient capacity to export 2 GW. It is the probability that excess capacity minus exports suffices to satisfy demand.

$$p_{\text{Export potential}} = \Phi\left(\frac{\text{Excess capacity - Export}}{\sigma_{\text{Demandforcast}}}\right) = \Phi\left(\frac{5GW - 2GW}{5GW}\right) = 72\% \qquad (2)$$

The same method is used to calculate the probability that 4 GW can export: 58%.

---

[5] Based on the year 2000 generation capacity of 47.8 GW and based on assumed growth of 5% per year generation capacity is expected to be 78 GW in 2010.

[6] This approximation can be improved upon by using the historical observed distribution of error terms. The accuracy of the result can be improved at the cost of a little numerical implementation.

Assuming that demand growth in both systems is uncorrelated, the probability that Russia can satisfy energy demand is proportional to the weighted sum of the probability that demand can be satisfied when 4 GW, 2 GW and 0 GW are available for export from South Korea.

$$58\%\Phi\left(\frac{X+4GW}{\sigma_{\text{Demandforcast}}}\right)+14\%\Phi\left(\frac{X+2GW}{\sigma_{\text{Demandforcast}}}\right)+28\%\Phi\left(\frac{X+2GW}{\sigma_{\text{Demandforcast}}}\right)=p_{\text{OK}}\equiv\Phi\left(\frac{10GW}{\sigma_{\text{Demandforcast}}}\right) \tag{3}$$

For $\sigma_{\text{demand forecast}}$=10 GW, the resulting value of X equals 7.55 GW. Russia can reduce 2.45 GW of reserves required to cover uncertainty of demand forecasts. If demand growth errors are positively correlated between countries, the resulting capacity savings are smaller. The interesting result is that the interconnection allows Russia to maintain the same level of energy security, guarantee base load exports of 2 GW and reduce generation capacity by 0.45 GW relative to the scenario without interconnections.

2.5 REDUCING EXPOSURE TO ENERGY RISK BY DIVERSIFYING

Building on the idea presented in Neff '97 a country wants to reduce its economic risk by diversifying energy inputs. In order to allow intertemporal, inter-scenario and cross-country analysis, the amount of energy diversification has to be quantified. In competition policy the Herfindahl-Hirschman (HH) index is used as a measure of concentration. It can be equally applied to the energy flows in a country. To calculate the HH index the relative contribution x_i of energy type i to total energy supply is determined. The HH index is the sum of the squared contributions:

$$HH=\sum_i x_i^2 \tag{4}$$

Low HH index values represent a high diversification, while high values of HH show concentration on few energy sources. Table 6 gives HH values for some countries. Like most countries Korea is highly dependent on oil and coal.

The advantage of international electricity trade based on long-term contracts is that it creates an additional energy source with different risk and price characteristics. The HH value is reduced when 2 GW of energy imports replaces coal and oil generation.

Country	Oil x_i^2	Gas x_i^2	Coal x_i^2	Nuclear x_i^2	Hydro x_i^2	Elect x_i^2	Total (HH)
Japan	0.289	0.014	0.031	0.024	0.000		0.358
USA	0.153	0.071	0.059	0.007	0.000		0.291
France	0.14	0.014	0.003	0.178	0.001		0.336
Korea	0.186	0.008	0.103	0.019	0.000		0.317
Korea 2GW	0.190	0.008	0.092	0.020	0.000	0.000	0.311

Table 6: Data for Japan, USA, France from Neff '97, Korea based on IEA '01, UN '97, assumption for efficiency of generation: (oil, gas, coal, nuclear, hydro, imports) = (0.35, 0.5, 0.33, 0.3, 1, 1).

3. DISTRIBUTION OF BENEFITS

3.1 ECONOMIC PERSPECTIVE

This section illustrates how economic rents from interconnecting two systems are shared. The result varies depending upon whether a competitive market is implemented in both systems, a competitive market faces an integrated monopoly or two integrated monopolies exchange energy. Examples from the European market are used to illustrate the results.

3.1.1 WELFARE ANALYSIS

Figure 7 shows the basic model referred to in the following discussion. I assume perfect competition and ignore transmission losses, but the insights gained from the model can also be translated to monopolies. The dotted line represents variable generation costs. If more capacity is required more expensive generators have to be scheduled, therefore the slope is positive. The continuous line represents demand in zone A, which decreases if prices rise, resulting in a negative slope. The intercept at A_0 is the competitive equilibrium if zone A is isolated, B_0 is the competitive equilibrium for an isolated zone B. Prices in zone A are higher, therefore electricity will be sold to zone B. The transmission line has a limited capacity, therefore additional energy imported to zone A can only reduce prices and increase demand to the point A_1 whilst increased prices reduce demand in zone B to point B_1.

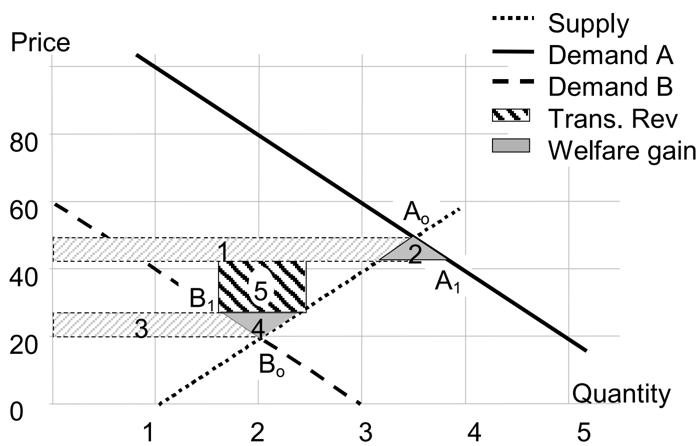


Figure 7: Distribution of welfare gain of interconnection in presence of competitive markets.

Reduced prices reduce profits for generators in zone A. The size of area 1 represents these lost profits. The area equals the product of price change and quantity of output sold plus lost profits of generators that reduced their output. At the same time reduced prices increase consumer surplus in zone A. The combined size of areas 1 and 2 equals consumer surplus. Consumer surplus is the product of the quantity consumed times price change plus additional surplus due to electricity consumption, which was prevented at higher prices. The difference between consumer surplus and producers loss equals welfare gains in zone A, represented by area 2. Applying a similar argument in zone B shows that generator profits increase more due to price increases than consumer surplus is reduced, resulting in welfare gains in zone B corresponding to area 4.

This analysis shows interconnection of two countries increases welfare in each country. It has to be pointed out that the analysis is indifferent between consumer surplus and generators' profit—an assumption only valid if non-distorting redistribution mechanisms are available.

3.1.2 TRANSMISSION REVENUE IN A LIBERALISED MARKET

A third component of welfare gains is due to congested transmission lines. More access to transmission lines is required than available; therefore access rights can be sold at the price difference between zones A and B. Transmission revenue equals volume of auctioned transmission rights times price, represented by area 5.[7] Auction revenues can be observed in liberalised markets. Transmission rights between Germany and the Netherlands are auctioned for periods of one month, one year and three years. In May 2001 the value of access rights for base load transmission to the Netherlands was between 9.3 and 11 Euro per MW per hour, approximately $10 per MW per hour. The transmission operator can collect profits corresponding to area five from the interconnection, because prices in both markets are well defined in a competitive setting.

3.1.3 EFFECT OF ONE INTEGRATED MONOPOLIES

Now assume that an integrated monopoly is present either in the exporting or importing zone. The monopolist will never offer to export or import more than the transmission capacity allows for; therefore transmission capacity is not scarce and auction revenues are zero. The monopolist can sell to or buy from the neighbouring competitive market at market prices corresponding to the points A_1 or B_1, and retain all the transmission revenue of area 5. The Italian utility successfully applied this strategy by buying electricity all over Europe, obviously ensuring that transmission constraints were satisfied. After the liberalisation of the Italian market transmission capacity into Italy was auctioned, indicating the scarcity which was hidden during the monopoly time.[8]

3.1.3 EFFECT OF INTEGRATED MONOPOLIES IN BOTH ZONES

The situation with two integrated monopolies can be analysed with the tools from bilateral bargaining theory. However, the Nash bargaining theorem, which would determine a unique price, can not be applied because of the asymmetry between the countries. The price for the electricity will be between the costs of the exporting country and the costs of the outside option for the importing country. If long-term contracts are to be signed the outside option of the importing country is to construct new power plants. If short term prices are negotiated the outside option for the importing country can be anything between running inefficient diesel generators and cutting power supply to part of the demand side. If power trade is based on commercial interests and the exporting country has no competitive market and the import country has no short-term substitute for electricity imports then long term contracts are vital for the importing country.

---

[7] Part of the revenue associated with area is used to pay for transmission losses. Transmission investment is sunk cost and therefore not considered in welfare analysis, but capital costs are paid for from transmission revenue.
[8] The auction was subsequently annulled.

No auction revenues are incurred as neither monopoly gives away profit by over-contracting the transmission line.

3.1.4 IMPLICATIONS OF WELFARE ANALYSIS

The English-French interconnection exemplifies the shift from two integrated monopolies to one monopoly and then two competitive markets. The initial purpose of the interconnection was to allow for peak balancing between the two systems. The integrated monopolies agreed on pricing based on calculated costs of the importing country. After the English liberalisation in 1991, EDF exported to the UK at pool prices.[9] Market power in a highly concentrated market induced high pool prices in the UK, and EDF could keep the rent. After the liberalisation in the European market open access required auctioning access rights to the interconnection. Currently the price is 4.6 Euro per MW per hour, approximately $5, for a base load contract to import from France. The price difference is due to significant excess capacity in continental Europe that results in low continental wholesale prices for unconstrained areas like France and Germany.

The changes in revenue allocation due to a change in the regulatory regime indicate that it is difficult to establish binding long-term contracts for electricity sales. Nevertheless, incorporating lessons learned from the US and European markets can minimise future conflicts.

The three main results of the analysis are:

First, if imports constitute a significant proportion of the energy balance and the exporting zone is governed by a monopoly, then long-term contracting is required. In the short run the importing country cannot substitute electricity imports and is forced to pay high prices.

Secondly, transmission pricing (not auctioning) can serve to capture these welfare gains, but lack of information about generation costs of the integrated monopoly make the choice of an appropriate price a difficult task.

The third point is that price changes in the importing and exporting countries due to the interconnection result in welfare gains in each country (area 2 and 4). Assuming transmission capacity is scarce, the transmission operator can collect welfare gains if both zones are competitive. Otherwise welfare gains are kept by integrated monopolies.

3.2 PARTICIPATION CONSTRAINT

3.2.1 EUROPEAN EXPERIENCE

Electricity interconnections can only work successfully if all involved parties are interested in participating in the project at all times. This is best illustrated by the capacity declared available for transmission on the French-Spanish interconnection. After the liberalisation of the Spanish market and the subsequent higher revenues to be made from exports to Spain, the capacity, which was declared available, almost doubled.

[9] The author does not know whether the transmission link was already used for almost purely base load exports from France before liberalisation.

It is difficult to assess available capacity from the outside. This has been shown by a study commissioned by the Dutch regulator regarding the import capacity to the Netherlands. Any 'referee' will be reluctant to state that more transmission capacity would be available because it implies that security margins are reduced and the referee will be blamed for any subsequent blackout.

The English situation after liberalisation serves as a third example. During the first years, the costs due to transmission constraints multiplied. Costs due to transmission constraints have fallen from $308 million in 1993/94 to $21 million in 1999/2000. The main reason was that after 1994 the grid operator NGC received payments for reductions in constraint costs. Subsequently NGC reduced and optimised maintenance outages and invested to eliminate bottlenecks.[10]

3.2.2 REGIONAL INCENTIVES TO PARTICIPATE

Russia, North Korea and South Korea have the following incentives to participate continuously in the interconnection. Electricity exports generate revenues for Russia and the involved Russian electricity enterprises. Therefore Russia can be anticipated to operate the line at full capacity—a critical situation if generation capacity is insufficient to cover both Russian demand and export demand but suffices to cover only Russian demand. Experience in international financial markets suggests that countries honour their commitments in view of future interactions. An easy solution, however, for the Russian shortage would be to reduce exports, claiming technical constraints. South Korea has to anticipate some risk, according to our previous assumptions at most 15%, of reduced imports from Russia. This risk would reduce the savings of required generation capacity from base load imports to South Korea from 2 GW to 1.856 GW.[11] If Russia faces extensive generation capacity shortages then it would be interested in importing from South Korea and would likely also be able to pay for imports since unexpected demand increases are usually the result of an unexpected economic upturn.

North Korea may profit from electricity exports. A more significant incentive, however, for continuous participation is the dependence of the North Korean network on outside response and reserve power. Reserve power could be provided with less security even if the connection between Russia and North Korea or North Korea and South Korea is cut. Nevertheless, North Korea would restrain from intentionally interrupting the line because South Korea and Russia profit from energy transmission and could therefore interrupt any interconnection in order to convince North Korea to reopen the entire line. North Korea is not dependent on Russian or South Korean supplies of response and reserve power because one link suffices to operate the system—but they would incur a substantial increase in risk of failure.

---

[10] The NGC example suggests one solution to overcome the problem of uncontractable technology: contract incentives and punishment terms for non-delivery. Contracts of this kind work in short horizon projects—but seem to be difficult to set up for long time horizons. How should events like natural catastrophes be incorporate and evaluated?

[11] Assume that in the 15% chance of Russian generation energy shortage exports will be reduced to 1 GW instead of 2GW. Applying equation (3) to the South Korean system and assuming that Russian and South Korean shortages are uncorrelated shows that 0.164 GW additional generation capacity is required to offer the same level of security as would be offered by certain full Russian imports. Savings due to a reduction of 2.45 GW of the Russian generation capacity requirements are therefore reduced by 0.164 GW additional capacity required in South Korea.

South Korea continuously profits from electricity imports and flexibility during ramping times and is therefore motivated to operate the line at full capacity.

The incentive constraint is satisfied in almost all situations—all countries, except Russia during minor generation capacity shortages, have a continuous interest to operate the transmission line.

3.3 FINANCING APPROACH

Funding and operation options of the interconnection project can be divided into three broad categories: private ownership, public-private partnership and public ownership.

Private infrastructure investment is popular these days, but "Grid expansion and pricing would continue to present a need for regulatory oversight" (Hogan '98). Prices in liberalised electricity markets can serve to indicate investment need but unregulated private ownership of interconnections is inefficient. One reason can be deduced from Figure 7. The area of rectangle 5 represents the transmission revenue. A private transmission owner would maximise revenue by offering only part of the available interconnection capacity such that the area of the corresponding rectangle (and therefore profits) is maximised. This behaviour is inefficient, because consumers and generators lose more welfare than the transmission owner gains profit. It is the typical dead-weight loss of a monopoly (Bushnell '96). Private grid investment therefore requires regulated tariffs.

Private transmission investment within a country is legally possible in Argentina since 1994. Beneficiaries of grid expansion—usually the generators who incur less congestion after the expansion—are required to pay for grid investment. But reports by Abdala '99 and by Anderson '99 suggest that cost allocation seems to be difficult such that only two projects have been realised, one of which consisted of replacing the wires of an existing transmission line.

Projects of private investment in transmission capacity between countries exist between the USA and Canada and between Ukraine and Hungary. However, the aim of these projects is not to interconnect the electricity systems but only to connect an individual power plant, i.e. a new power plant in Canada to the US grid.

A particular disadvantage of private interconnections is that they loosen the participation constraint. Investment in a publicly owned transmission line is sunk cost, and all subsequent transmission revenues are therefore public revenues. If, on the other hand, a private, perhaps foreign, company paid for the transmission line, it will subsequently retain the revenue. The host country will therefore be less committed to supply the technical, regulatory and political framework required for the efficient operation of the line.

Private-public partnerships are a second financing option. The government makes a competitive tender for a certain transmission project. The winner signs a contract with the government specifying the characteristics of the transmission service to be provided and an annual payment for the provision. The private investor plans, finances, constructs, maintains and potentially operates the power line, and receives contracted payments based on availability but not usage of the interconnection. The only political and economic uncertainty for the investor is government default. A second advantage is that the government retains the flexibility for future restructuring of the transmission access regime. Given the limited experience with electricity liberalisation and the imminent changes of world energy policies, flexibility is a valuable asset. A third advantage of public-private partnership is that the participation constraint is not loosened because the country receives all revenue and has to pay lease irrespective of usage of the transmission line.

Public ownership or ownership by the regulated transmission owner differs from public-private partnership in that it lacks the initial competitive tender, which is supposed to reduce costs by introducing competition at the outset. On the other hand, publicly owned as well as regulated utilities have the advantage that they incur lower financing costs than private enterprises.

REFERENCES/SOURCES

Manuel Angel Abdala, Andres Chambouleyron, Transmission Investment in Competitve Power Systems, Privatesector 192, Worldbank, 1999

Kent P Anderson, Amy McCarthy, Transmission prcing and expansion methodology: lessons from Argentina, Utilities Policy No. 8, p. 199-211, 1999

James B. Bushnell, Steven Stoft, Electric Grid Investment Under a Contract Regime, Journal of Regulatory Economics, Vol. 10, p. 61-79, 1996

Electricity prices from www.LPX.de *and www.nordpool.no*

William W Hogan, Transmission Investment and Competitive Electricity Markets, Working Paper, 1998

IEA '98, Projected Costs of Generating Electricity, Update 1998

IEA '01, 2001 World Development Indicators

IES '01, Osnovnie Polozheniya Energeticheskiye Strategii Rossii na period do 2020 goda, IES, Moscow, 2001.

Thomas L. Neff, "Improving Energy Security in Pacific Asia: Diversification and Risk Reduction for Fossil and Nuclear Fuels", Centre for International Studies, Massachusetts Institute of Technology, 1997

Ofgem '99, The new electricity trading arrangement, Volume 2, July 1999

OECD '98, Energy Balances of OECD Countries, IEA/OECD Paris, 1998

UN Energy Statistics, several volumes between 1970 and 1997