Energy Economics and Policy:
Minimizing Risk for Icelandic Electricity Suppliers by Exploiting the Oil-Aluminum Price Correlation

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1 Introduction

Aluminum smelters are responsible for three quarters of Iceland's electricity consumption. The main reason for this is that resources for electricity production in Iceland are both cheap and relatively abundant. The aluminum firms make long term steady supply contracts with the Icelandic electricity companies, where the price of the MWh paid is directly dependent on world market price of the Aluminum alloy. This ensures that the aluminum firm has a less risk for marginal costs versus income and the risk is shared by the smelter and the electricity provider. As the market price of aluminum is not very stable, and thus the income of the electricity provider, it is obvious from the point of view of stability that they could benifit from predicting or foreseeing those changes. On the modern global market it is just as obvious that this is almost impossible. Instead of forseeing instability, would it be possible to stabilize the income in some way while keeping the same contractual statuses?

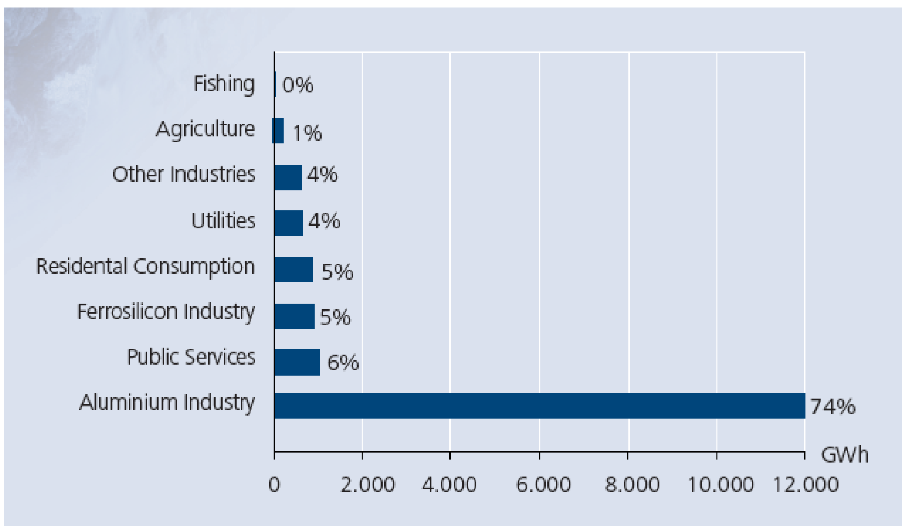

Figure 1: The distribution of electricity consumption in Iceland in 2009. Acquired from (Orkustofnun [8])

It has been observed, as will be shown in the paper, that there is quite some correlation between market prices of aluminum and crude oil. Would it then be possible to use oil and the correlating prices to stabilize this income? In this paper I will try to find methods to do exactly this, using historical data, simple mathematical models and computational programs.

1.1 Notes

As can be seen on the figure above, the uses of dots and commas for thousands and decimals are different between English and Icelandic. The figures and graphs in this paper use the Icelandic notation. In the text the notation 0.30 and $1'000$ will be used for decimals and thousands. The notation should usually be obvious from the context, but be aware.

Here the word "aluminum" will be used for the metal alloy Al, instead of the other common option "aluminium". This is simply a matter of taste.

2 The basis to be built on

2.1 Correlation of oil and aluminum prices

First we take a look at the data for the prices of aluminum and oil. The data used for the analysis here is taken from the website of IndexMundi. Monthly average prices are used. For the current purpose this is considered a good resolution, as it is high enough to see the behavior of the prices while minimizing noise and short term price changes which are not of interest here. Data is available from beginning of 1981 to first quarter of 2011. The oil prices data is acquired from (IndexMundi [4]) and is described as follows:

> Description: Crude Oil (petroleum), simple average of three spot prices; Dated Brent, West Texas Intermediate, and the Dubai Fateh, US$ per barrel Unit: US Dollars per Barrel.

The aluminum prices data is from (IndexMundi [3]) and is described as:

> Description: Aluminum, 99.5% minimum purity, LME spot price, CIF UK ports, US$ per metric tonne Unit: US Dollars per Metric Ton

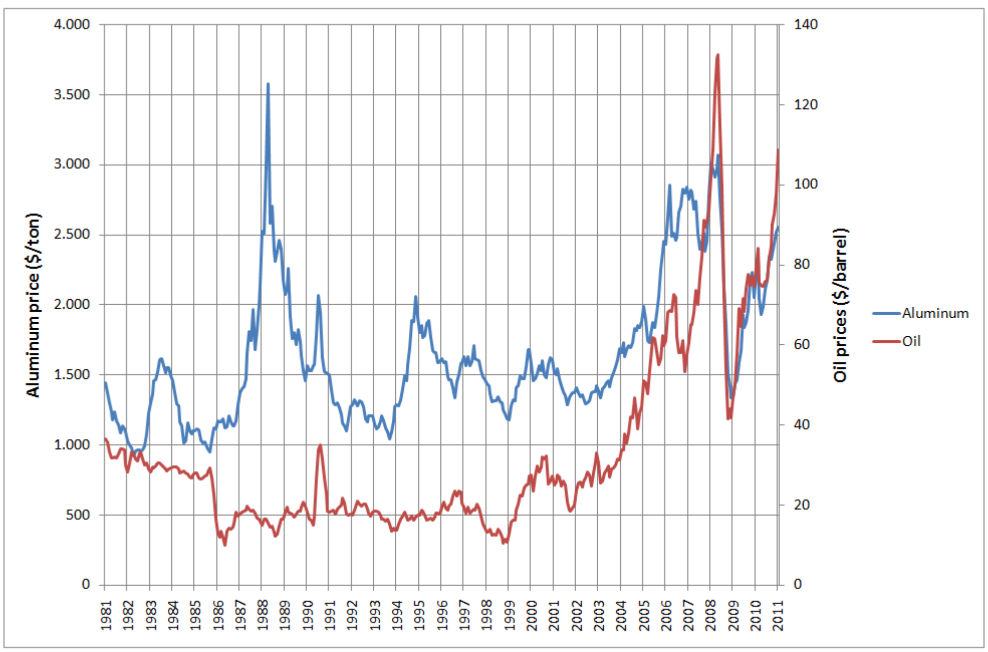

Figure 2: Monthly averages of oil and aluminum prices from 1981, correlation factor, $R = 0.64$

The behavior of the prices in time can be seen on figures 2 and 3. This is plotted for these two time periods to see it clearer in the shorter one (1990-2011) since there is a more strange behavior in the 1980's. Even though there are some deviations, one can clearly see by only looking at the figure that the correlation of the prices is high. For a more quantitatve analysis the statistical term correlation factor was calculated for the datasets. The correlation factor is defined:

$$R_{xy} = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \quad (1)$$

where x and y are items in the data sets and $\bar{x}$ and $\bar{y}$ are their averages.

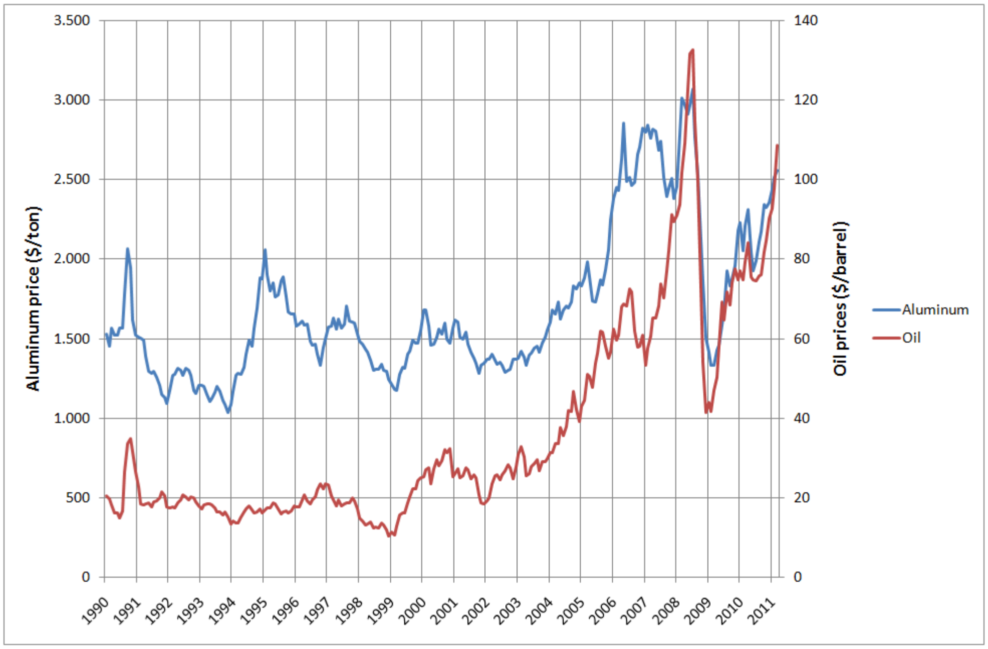

Figure 3: Monthly averages of oil and aluminum prices from 1990, correlation factor, $R = 0.85$

Calculating this, using the function *correl* in Excel, gave the values

$$R_{\text{oil-al}}(1981 - 2011) \quad = 0.64 \tag{2}$$
$$R_{\text{oil-al}}(1991 - 2011) \quad = 0.85 \tag{3}$$

which are high correlation factors, especially for the shorter period. Thus it has been shown that oil and aluminum prices are reasonably correlated.

The reason for this correlation is hard, and probably impossible, to explain in detail. Even though it is not the scope of this paper one could think of few reasons for this. One could simply be the world market behavior in general, where aluminum and oil are commodities that behave in a similar way and their correlation thus a coincidence. Another reason could be that in many places when the oil prices get higher the electricity spot price, which smelters pay in some regions, also gets higher so they would be inherently correlated. In a similar fashion the transportation costs would get also higher and help drive up the prices, but never be the main contributor as transportation costs are a minimal fraction of the total production costs (Burns [2]). But these are all speculations.

2.1.1 Correlation of oil and natural gas prices

Someone, who is not an expert in the field of world commodities' economics (myself), could think that the prices of oil and natural gas should be correlated to some extent. The relationship of the prices of oil and natural gas is therefor studied in comparison. The data is taken from (IndexMundi [5]). The correlation factor is calculated in the same way as before:

$$R_{\text{oil-gas}}(1991 - 2011) = 0.71 \tag{4}$$

We see then that there is a lower correlation of oil and gas than for oil and aluminum. This is considered as strengthening the argument that there is a correlation of oil and aluminum prices.

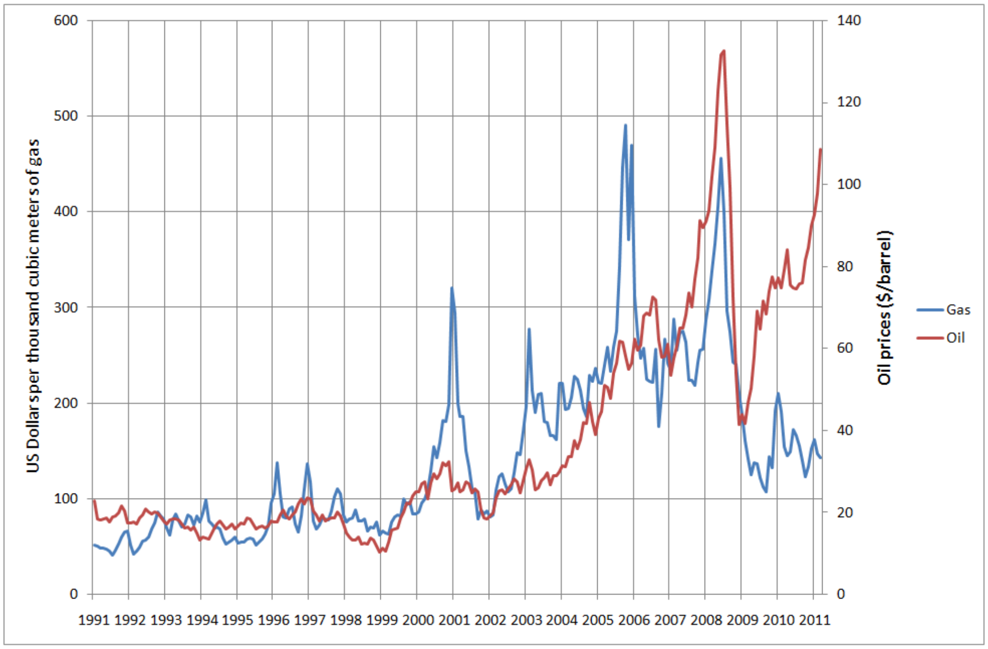

Figure 4: Monthly averages oil and natural gas prices from 1991, correlation factor, $R = 0.71$

2.2 The contractual electricity price

2.2.1 Landsvirkjun and the "aluminum dilemma"

Landsvirkjun is the "Icelandic National Power" company, responsible for around 72% of the annual electricity production in the country. It's ownership divided between the Icelandic government and the city of Reykjavik. 82% of Landsvirkjun's production goes to providing heavy industry, almost entirely aluminum smelters, with electricity (Landsvirkjun [7]). In the last few years the company has been under hard criticism for being selling electricity to aluminum giants for a way too low prices. There have also been many conspiracy theories held aloft concerning corruption involving the Landsvirkjun, aluminum smelters and the government of Iceland. Still, neither the criticizers nor Landsvirkjun could prove anything or provide any evidence for their point. This was because of the confidentiality Landsvirkjun was bound by by the price contracts with the smelters.

These contracts were made in such a way that the electricity price paid by smelters is connected to the price of aluminum, how exactly was only known to the negotiators. This has always been controversial for the aforementioned reasons. Especially controversial was the construction of Káranhnjúkavirkjun. Found in the Icelandic highlands, this 690 MW hydro power plant built in the years between 2002 and 2008 had the sole purpose of providing electricity to a 346'000 ton/year aluminum smelter from Alcoa (Wikipedia [9]). The size of Kárahnjúkavirkjun in an Icelandic perspective is not minimal. Apart from being one of the biggest dams in Europe, it increased electricity generation capacity of Iceland by around 30%, where average production today is around 2'000 MW (Landsnet [6]). During the construction and after it, Landsvirkjun and the Icelandic government were accused of "giving the country's resources to foreign investors" and it was often claimed that the project could never finance itself because of the alleged low prices negotiated with the smelters. But still, as mentioned before, no one in the public really knew how these prices were and the spokespeople of Landsvirkjun and the government could always hide behind the "curtain of confidentiality".

In 2010 there was a change. Landsvirkjun hired a knew CEO, Hörður Arnarsson, which made a turn in policy. He wanted to ease the skepticism the public had on the company. By doing this he would still need to fulfill the confidentiality to the customers and hold up the future contractual status of Landsvirkjun, which usually was the main argument for not revealing prices. What he did was quite clever. In his first annual meeting in 2010 he showed the average price received from aluminum companies each year from 2002 until second quarter of 2010 which can be seen in figure 5 (Arnarsson [1]). Note: MWst = MWh.

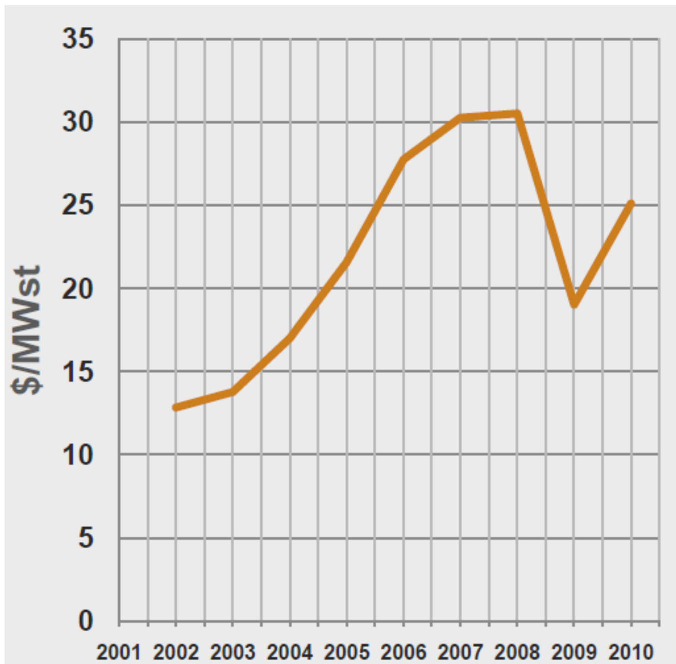

Figure 5: The price of electricity received by Landsvirkjun from Aluminum industry (note: MWst = MWh). Figure acquired from (Arnarsson [1])

2.2.2 Determining the relation of aluminum prices and electricity prices

The contractual electricity prices paid by the aluminum smelters are hard, if not impossible, to come by because of the reasons already mentioned. Still, thanks to the new CEO of Landsvirkjun, we now have something to work with. The initial idea and assumption here is to guess that the electricity price would have a linear relationship with aluminum prices, thus:

$$\text{Electricity price} = \text{Basic price} + \text{factor} \times \text{aluminum price} \quad \Rightarrow \quad y = m + kx \tag{5}$$

The values from the graph given by the CEO (figure 5) are estimated and drawn up in table 1. For every year, the average aluminum price is also calculated from the data above.

Now let's plot the values of this table and fit according to equation (5). Here the aluminum price is x and electricity price paid by the smelter is y. This can be seen on figure 6

It can be seen that the assumed model made by equation 5 fits very well to this relationship, with an $R^2 = 0.984$. The best estimate fit for the relationship of electricity price paid and aluminum prices is thus:

$$\text{Electricity price [\$ /MWh]} = -4.43484 + 0.01316 \times \text{aluminum price (in \$ /ton)} \tag{6}$$

Table 1: Average aluminum price and electricity price paid by aluminum smelters

Year	Average aluminum price (x) [$ /ton]	Average Electricity price (y) [$ /MWh]
2002	1351	13
2003	1433	14
2004	1719	17.5
2005	1901	21
2006	2573	28
2007	2640	30
2008	2578	30.5
2009	1669	18.5
2010	2173	25

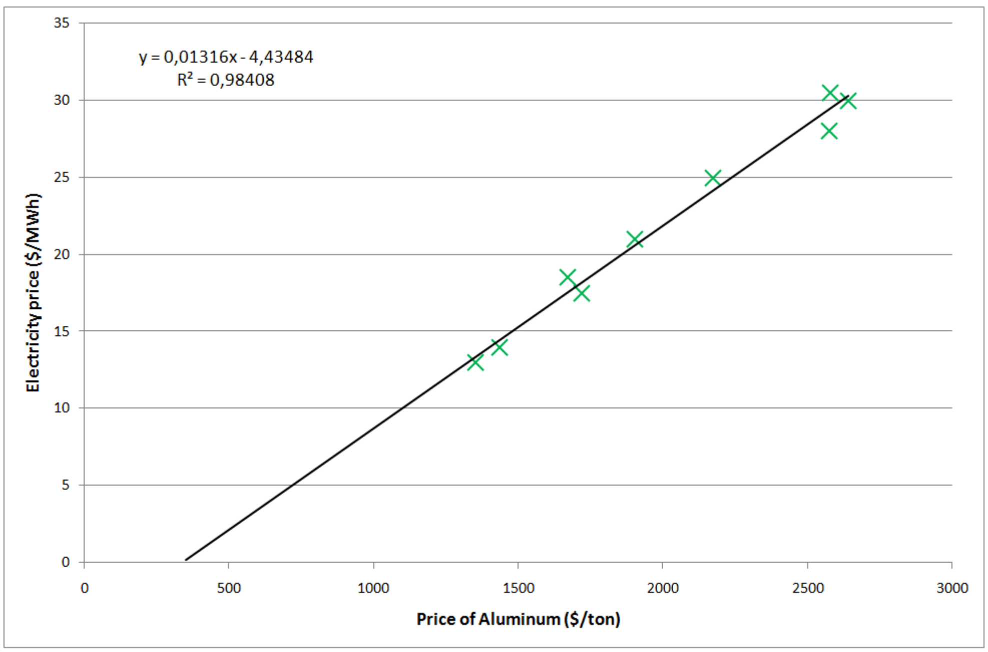

Figure 6: The price of electricity paid by aluminum smelters versus aluminum price

It came as a surprise that the y-intercept in the fit is negative. This means that when the price goes to zero the electricity company would have to pay the aluminum smelter to use their energy (becomes negative around $x = 350\$\ /\text{ton}$). Whether this is true or not will not (and most probably cannot) be evaluated here. Still, it would seem logical that when the aluminum price goes to extreme values, the electricity price might saturate at some point. On the other hand, it would be better for the electricity company to keep the smelter going while prices are low so they would be able to sell them later if the prices would recover. In the meantime they would also be able to get rid of the electricity. This could especially be the case for the Icelandic market which is small and not internationally connected. Buyers of 500 MW steady power, a quarter of the countries average production, are not found on every corner, and thus it's important to keep those that are already there in business.

Note that in the rest of the paper, the terms aluminum price and oil price refer to the world market prices and electricity price refers to the price paid by smelters to the Icelandic energy companies.

3 Oil to the future

Since it is more or less impossible to fit or predict the prices of these commodities on the global market from historical data, there will be a fictitious example set up instead. We will imagine that we are running an electricity company in Iceland and it is the end of 2005. We want to use data from 1990 to end of 2005 to see what we can do to minimize the variations in income by the changing aluminum prices. If we do that we also minimize the risk we are facing. This prediction will then be used to see how well it works for the following years of 2006-2011.

3.1 Production and monthly income

The electricity company we are running provides 500 MW of steady power year long to an aluminum smelter. The company gets paid for the electricity according to equation (5). It is assumed in all cases here that there is no change in supply/demand with changing prices. This would hold most probably for all but the most severe cases, as the production studied here has an extremely small fraction of the total market. The production monthly of these 500 MW is thus

$$P_{\text{monthly}} = 500\text{ MW} \cdot 30\text{ days} \cdot 24\text{ hours/day} = 360'000\text{ MWh}. \quad (7)$$

We can now transform the equation for the electricity price found in the previous chapter to an equation representing the income per month depending on the prices of aluminum in that month. The relation found in equation (6) is therefor simply multiplied by the monthly production given in equation (7). This gives that the monthly income from selling electricity will be

$$\text{Income}_{\text{el}}\ [\$] = -1'596'542 + 4'738 \times \text{aluminum price } [\$\ /\text{ton}\ ] \quad (8)$$

which will be on the order of $5'000'000$ \$.

3.2 The oily investment

As has already been mentioned, the electricity company wants to minimize the risk it is facing by the changing aluminum prices. The goal here will thus not be really to try to make more profit on any investments based on the oil market, but simply to minimize the fluctuation of total money flow.

Now as we saw in equation (8), the income has a simple relationship with market price of aluminum. It is assumed, that an investment can be found that has a similar income relationship as the aluminum except with the price of oil as a variable. This relationship will be inversed, that is the lower the prices of oil, the higher the income. We want to find an investment that will give us an income which looks like:

$$\text{Income}_{\text{oil}}\ [\$] = M + K \times \text{Oil price} \quad (9)$$

where K will be assumed negative. It is not clear whether such investment exists to the extent we have here. Example of an income scheme that could look like this would be of an airline or transportation of any sort, which make less profit when oil prices go high. There will be no effort made to try to find this investment but it is assumed that it exists.

The goal of the following procedure will thus be to find the parameters M and K that will make this look like a realistic income scheme. As the electricity-aluminum income equation is something that is already considered realistic it will be used as a benchmark for the income of the oil scheme. If now we denote p_{al} and p_{oil} as the prices of aluminum and oil the first restriction used to solve for parameters M and K from equation (9) is

$$\sum_{i=\text{Jan 1990}}^{\text{Dec 2005}} \text{Income}_{\text{oil}}(i) \quad = \quad \sum_{i=\text{Jan 1990}}^{\text{Dec 2005}} \text{Income}_{\text{el}}(i) \quad (10)$$

$$\sum_{i=\text{Jan 1990}}^{\text{Dec 2005}} (M + K \cdot p_{\text{oil}}(i)) = \sum_{i=\text{Jan 1990}}^{\text{Dec 2005}} \left(-1'596'542 + 4'738 \cdot p_{\text{al}}(i)\right) \quad (11)$$

This means that the total income of the period from 1990 to the end of 2005 should be the same for both. A second restriction to solve this equation is that there will not be an inherent risk minimizing by adding this investment to the money flow. For this reason our measure of risk, the standard deviation (Wikipedia [11]), of the monthly incomes are restricted to be the same. This restriction is formulated as:

$$\sigma_{\text{el}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(I_{\text{el}}(i) - \bar{I}_{\text{el}})^2} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(I_{\text{oil}}(i) - \bar{I}_{\text{oil}})^2} = \sigma_{\text{oil}} \quad (12)$$

where I denotes the respected income and $\bar{I}$ represent the averages of those incomes in the period, $i = \text{Jan 1990}, ..., \text{Dec 2005}$. Other restriction are

$$K < 0 \quad (13)$$
$$M > 0 \quad (14)$$

which are designed so that the scheme has the right properties. When equation (9) is solved with a simple regression program for the given restrictions, the solution is

$$\text{Income}_{\text{oil}}\ [\$] = 7'970'002 - 105'642 \times p_{\text{oil}} \quad (15)$$

The incomes of these two schemes as a function of their relative prices can be seen on figure 7. The behavior for 1990-2006 can also be seen on figure 8. The correlation can be clearly seen but this time they are inverted. Note that the schemes have the same total income and thus the same average.

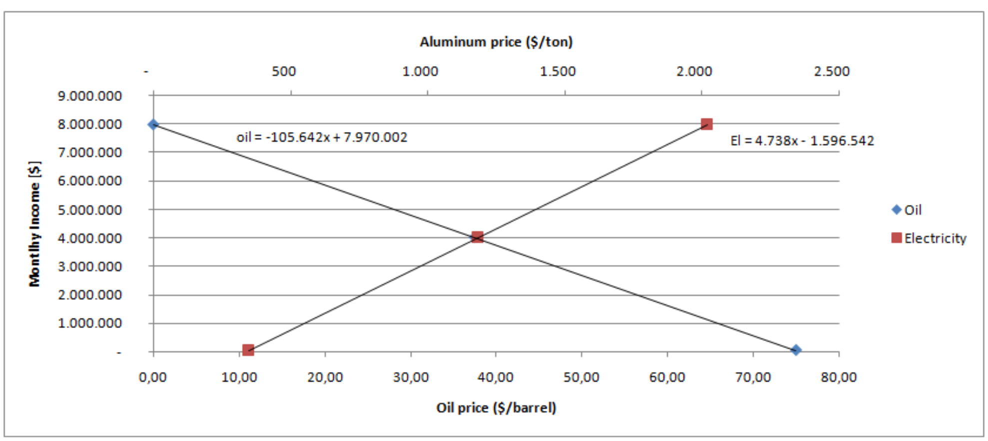

Figure 7: The two income schemes, for the electricity and the hypothetical scheme connected to price.

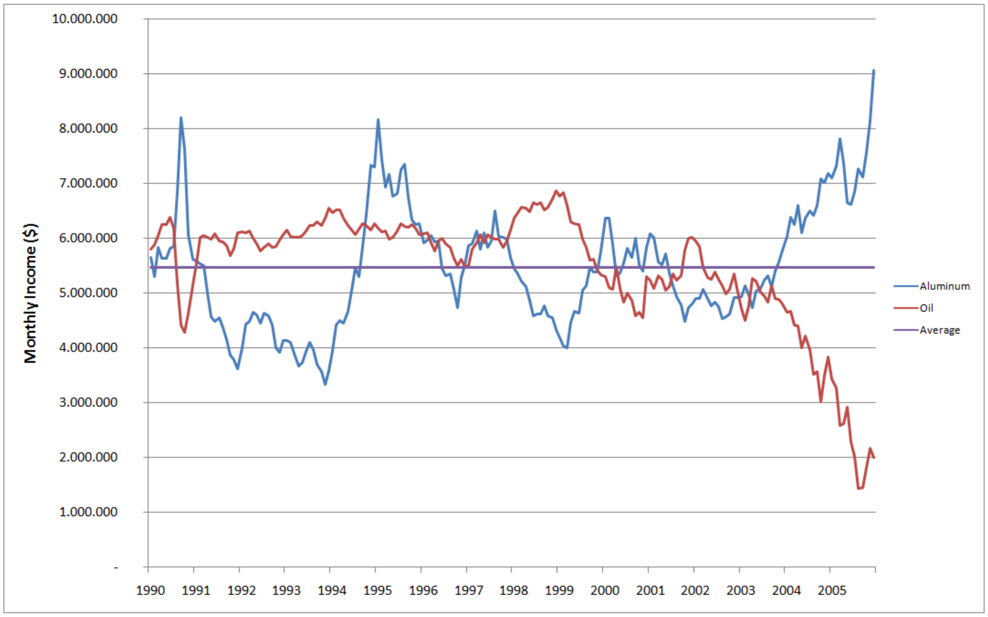

Figure 8: Incomes of the two schemes from 1990 to end of 2005. Note that they have the same total income and standard deviation over this period.

3.3 Model minimizing risk

Standard deviation is the most commonly used representation of risk in finance (Wikipedia [11]). This is what will be used here. It can be said that if we would minimize the standard deviation of the income, we would be minimizing the risk. The following procedure is fairly simple: we will find an optimal portfolio which will minimize the standard deviation. Portfolio is the representation of the share that each income scheme has in our total income (Wikipedia [10]).

A simple linear regression model will be solved like before. It will have the following properties

$$I_{tot}(i) = \mu_{El} I_{El}(i) + \mu_{oil} I_{oil}(i) \tag{16}$$
$$\mu_{El} + \mu_{oil} = 1 \tag{17}$$
$$\mu_{El}, \mu_{oil} > 0 \tag{18}$$

with the goal of minimizing the standard deviation of the new income portfolio, $\sigma(I_{tot})$, by changing μ_{El} and μ_{oil} for the most desirable portfolio. Excel solver is used for this. It gives the following results

$$\mu_{El} = 0.5 \tag{19}$$
$$\mu_{oil} = 0.5 \tag{20}$$
$$\sigma(I_{tot}) = 497'952 \tag{21}$$
$$\sigma(I_{El}) = 1'080'611 \tag{22}$$
$$\frac{\sigma(I_{tot})}{\sigma(I_{El})} = 0.46 \tag{23}$$

where the total income of this period is the same as for the electricity-only portfolio. Amazingly the portfolio is arranged exactly into two equally sized shares of 0.5. Our goal would have been quite successful as the standard deviation is lowered to 46% of its original value. As can be seen on figure 9 the risk is obviously much smaller. Now as chiefs of this electricity company we have

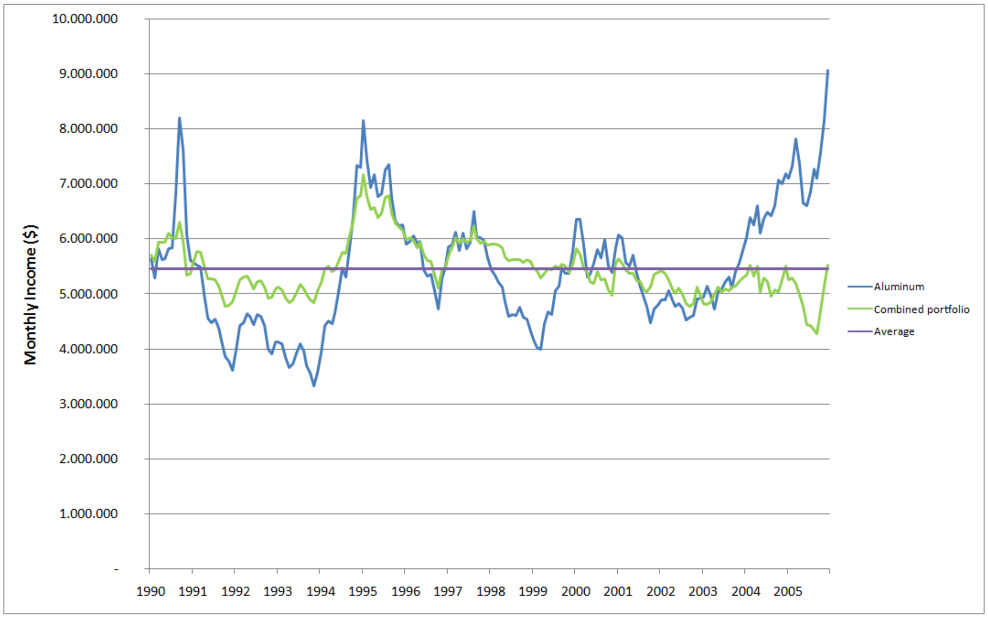

Figure 9: The portfolio solution of the income with the basic electricity income from aluminum as a comparison. Note that the total income of the period is the same, but the standard deviation of the portfolio is only 46% of the electricity-only's one.

shown that we can lower the risk and the variations of the income for the company by a lot. This has been done quite easily by using historical data. Now we will apply this to the coming years. It could be noted here that the management of the company would probably look skeptically on this strategy for this year (2005) because of how the oil income scheme is constructed with rising oil prices as a big threat. Still their urge to minimize income fluctuation is stronger.

3.4 Looking to the future

Now according to the portfolio weight already calculated the company sells 50% of the right to the income of the electricity and buys an equal share for the right of the income of the oil scheme found above. It is assumed that they have the same price. That means that instead of having all the income as from equation (8), half will come from there, and half from the relationship described by equation (15). This will be applied to the years 2006 to the first quarter of 2011 and the results are following

The time behavior of both incomes can be seen on figure 10. It is evident by quickly looking at the graph, that there is quite some loss of total income between the portfolio and the original income. It turns out that the main parameters for 2006-2011 are

$$\sigma(I_{tot}) = 904'009 \tag{24}$$

$$\sigma(I_{El}) = 2'149'821 \tag{25}$$

$$\frac{\sigma(I_{tot})}{\sigma(I_{El})} = 0.42 \tag{26}$$

$$\sum I_{tot} = 377'477'551\$ \tag{27}$$

$$\sum I_{El} = 596'350'578\$ \tag{28}$$

$$\frac{I_{tot}}{I_{El}} = 0.63 \quad (29)$$

This means that 37% of the income was lost in this period due to the purchasing of the oil scheme. In the same way the standard deviation was lowered to 42 % of its original value. It is then pretty obvious that the cost of the lowering of the risk would turn out to be too high for this period. The reason for this is the high rise in oil prices that are evident. Our profit scheme was designed on a basis which consisted of much lower oil prices.

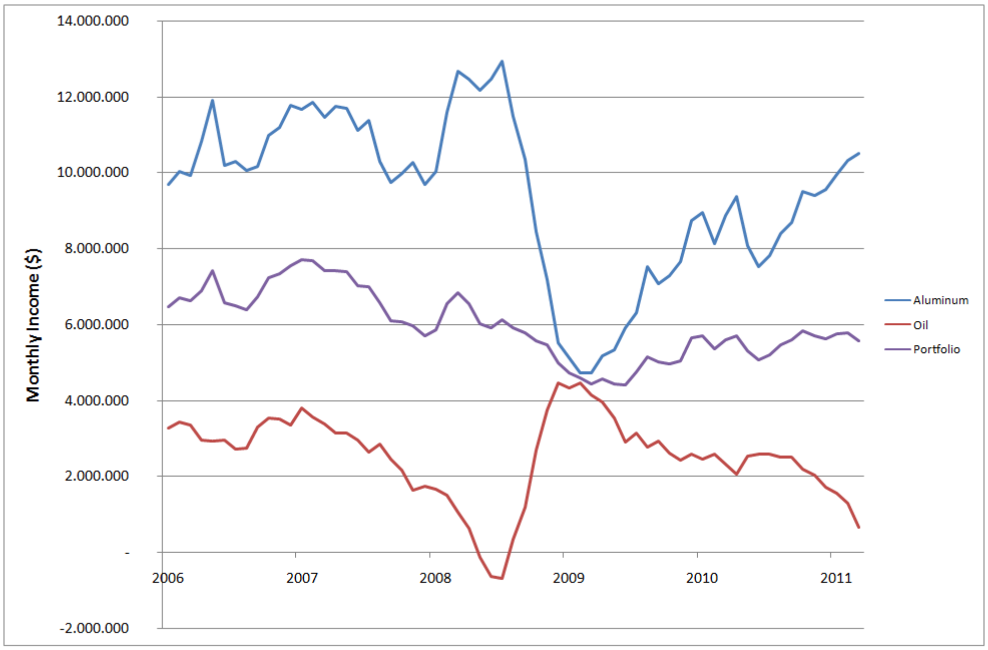

Figure 10: The income of the portfolio. The loss of income is very evident. Still the standard deviation of the income is clearly minimized.

4 Conclusions and remarks

It was shown in this paper that the prices of aluminum and oil are correlated to a certain extent. There was found a relation between the price of aluminum and electricity prices for Landsvirkjun, which will be considered quite a feat. It was also shown that if there exists an income scheme connected with oil prices with similar properties to the one found here, the risk in income for the Icelandic electricity company could theoretically be decreased dramatically. For that the standard deviation was lowered to 46% of it's original value by introducing a portfolio where half of the income would come from the oil price scheme while still receiving the same total income over the period. This is easy to do when the prices were known, which will not be the case in reality.

When trying to minimize the deviation of the income into the future, it did not turn out very successful. In short, the management of the company would have been fired immediately. When the calculated optimal portfolio was used for the years 2006-2011 we saw that, because of skyrocketing prices, this solution came unstable very quickly and the company lost 37% of it's income. This is partly due to the fact that the oil price income scheme was based on lower prices compared to the latter period and the income even became negative. Still it is not definite that this would hold like this forever. A longer time solution might in theory turn out to be a bit more successful. But as most experts predict, the oil prices are not going down soon, so that would not be very likely. The goal of the portfolio was still reached though, as the standard deviation was lowered to 42% of it's value otherwise.

This can teach us, as it has taught so many before, that playing with the global commodities market is not easy. One can easily get burnt.

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