Capital Price and Productivity: An Appraisal of the Energy Market

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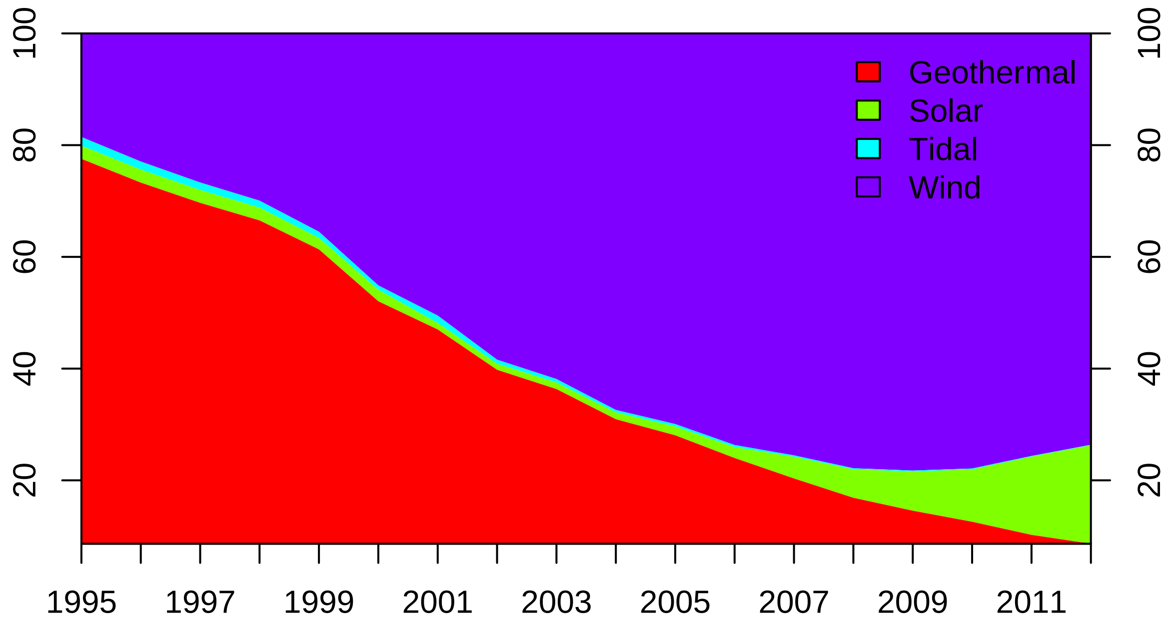
Introduction

Capacity Factors

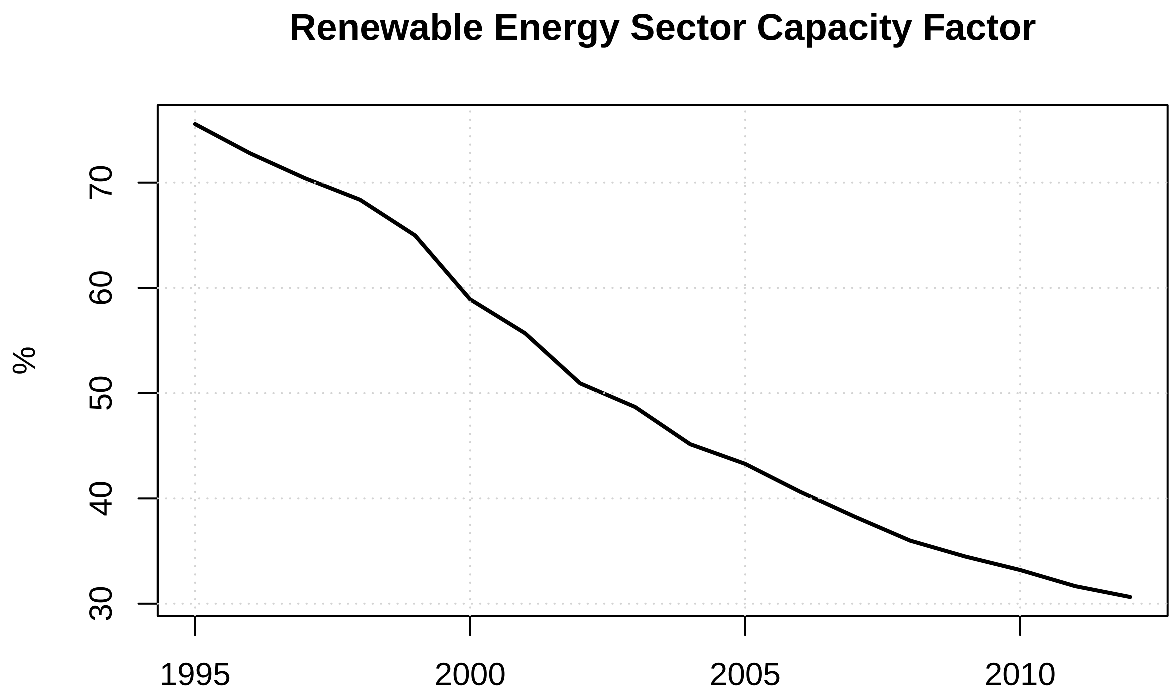
Capacity Factors represent the percentage of the time a specific production unit is available to produce electricity. Renewable energy producers usually have a lower capacity factor. The following table highlights this.

Technology	Capacity Factor (%)
Coal	85
Gas	87
Nuclear	90
Geothermal	90
Solar	25
Wind	25
Tidal	35

Given the increased share of non-geothermal sources of energy in the group of renewable sources of energy, the average capacity factor of that group is decreasing through time. This is highlighted by the following two graphs. This is the share of each type of renewable technology inn total renewable output.

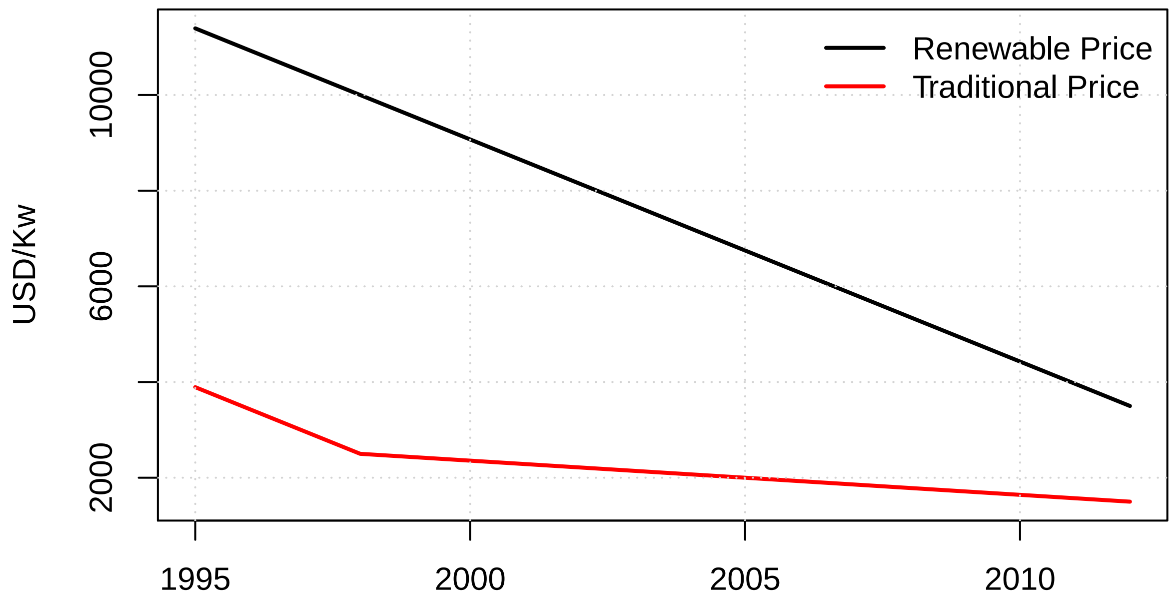


Now using the capacity factor described here above, we get the following aggregate capacity factor for the renewable sector as a whole:



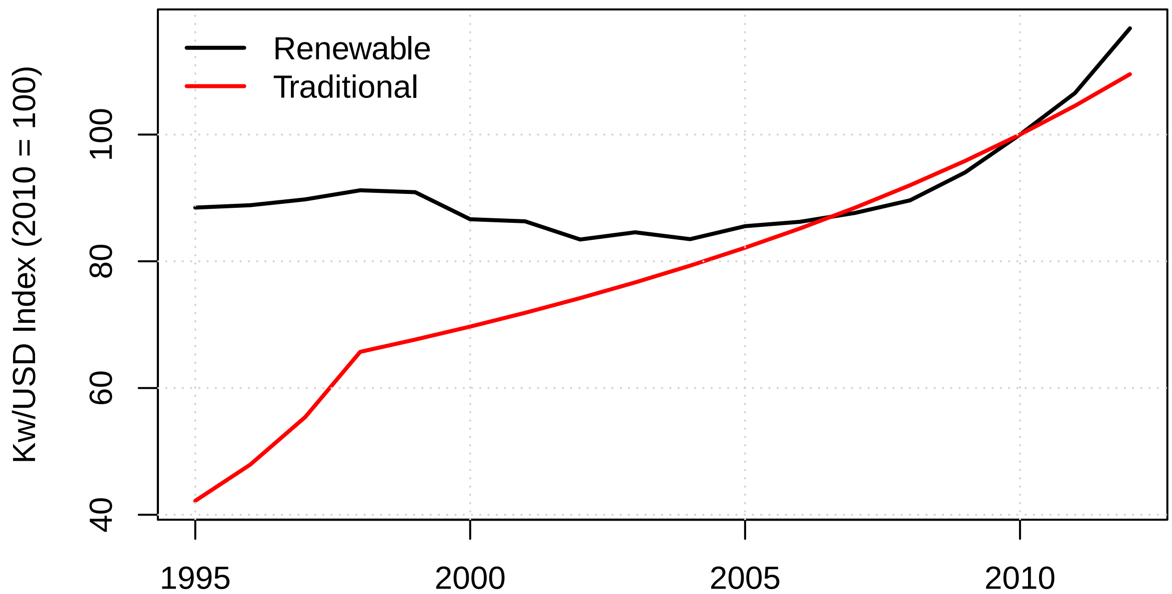
Pricing of capacity

The following graph shows the evolution of capacity prices in USD per installed kW (there are a lot of extrapolation given we have only two data points in 1998 and 2012. > We need to fix this



Combined pricing-capacity factors

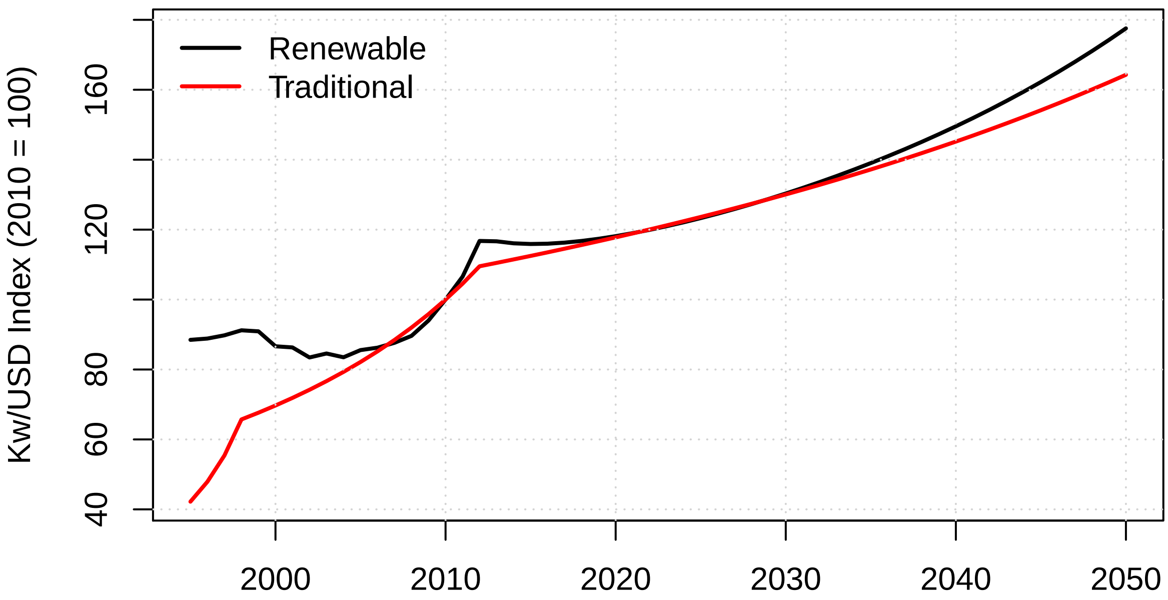
If we combine the two dynamics (capacity factor and pricing), we get the combined available capacity per USD (indexed, 2010 = 100):



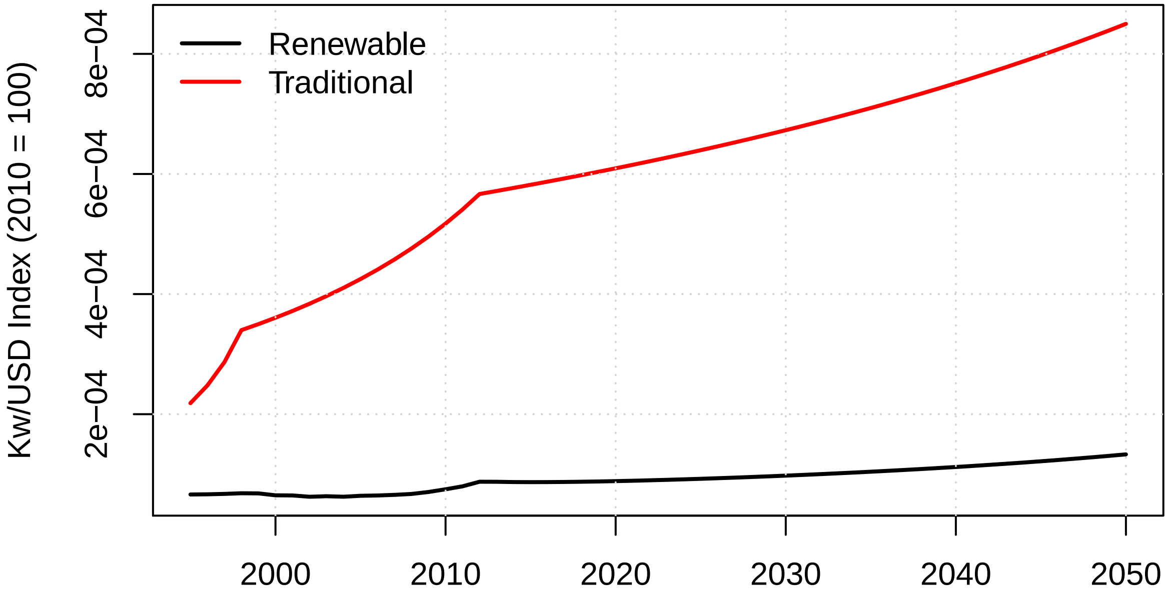
We see that recently the available output per USD has increased drastically in the renewable sector (hence the decrease in price has more than compensated the aggregate decline in capacity factor). The overall increase in the traditional/brown sector has been more sustained (data are to be treated cautiously, there are not many observation points and I've assumed a constant capacity factor).

Forecasting

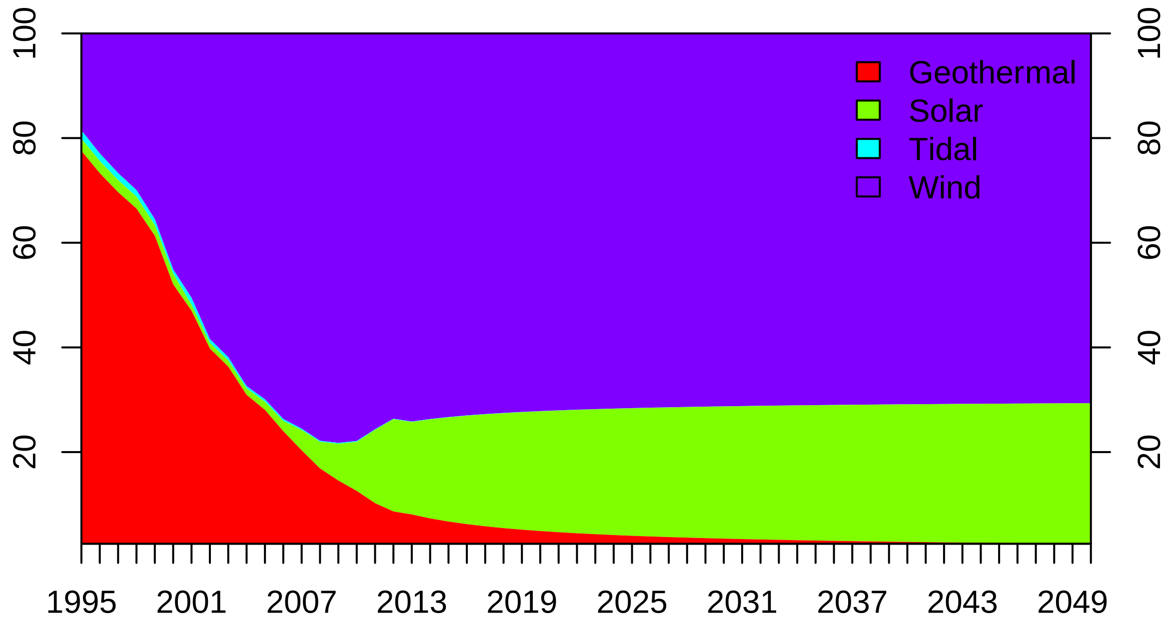
If we are to believe that by 2050, price per kW are the following: USD 2000 for green and USD 1000 for brown, the we have the following dynamics (using hp filters and linear trends and minimum capacity factor of 25% in the green sector).



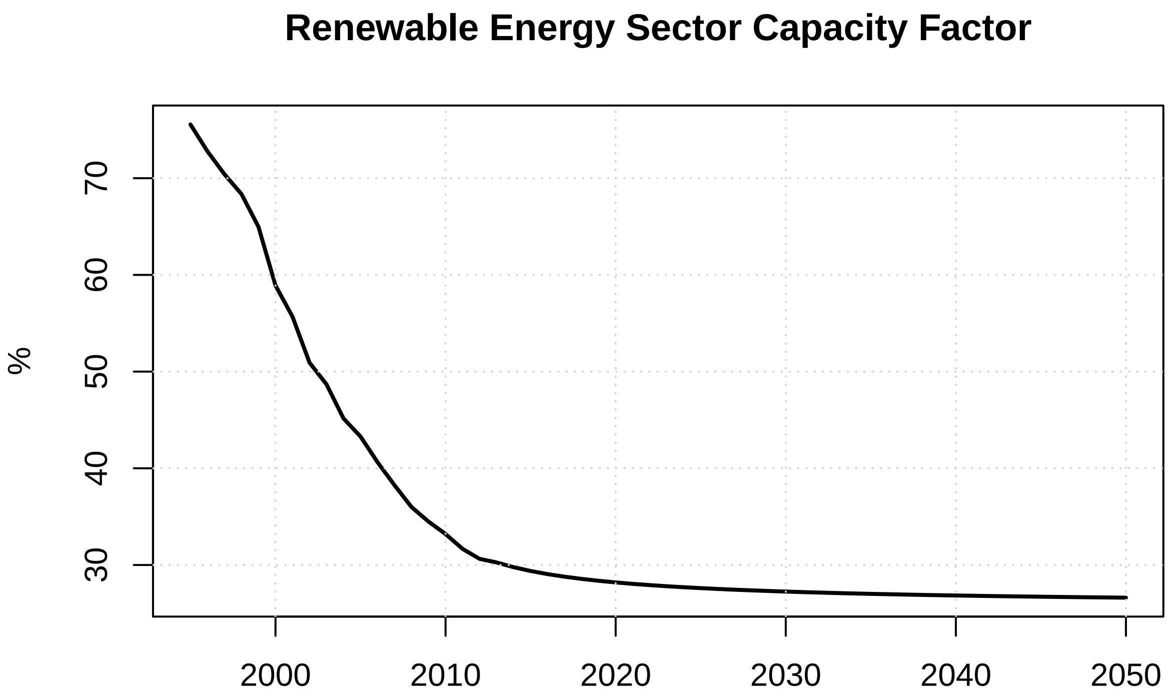
And the forecast in levels:



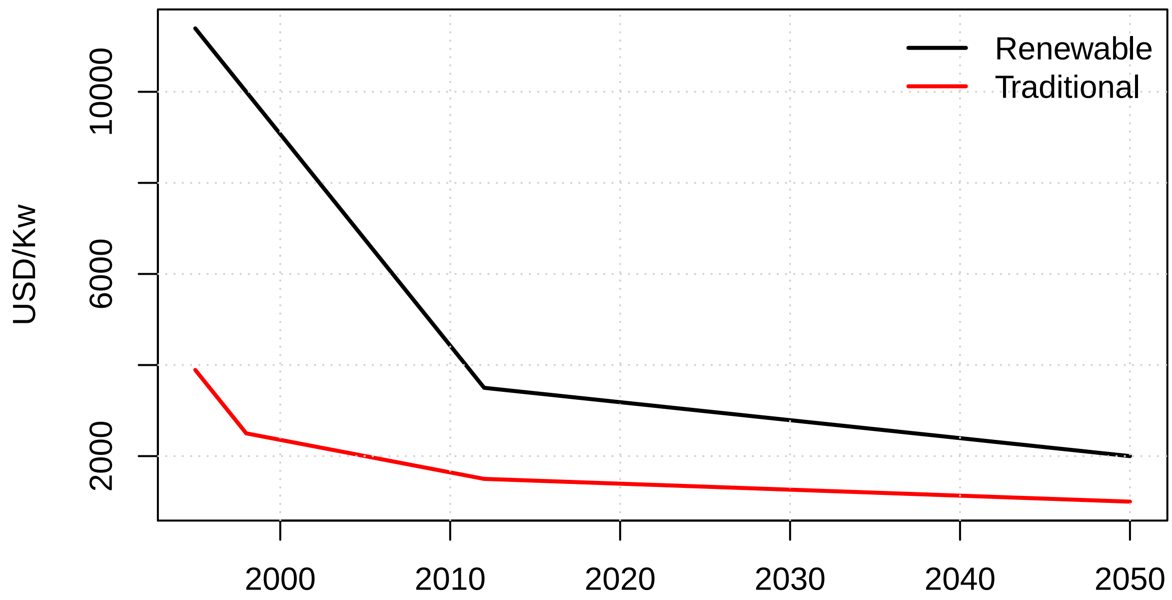
FYI, here are the HP forecast output share by renewable source:



The predicted capacity factor:

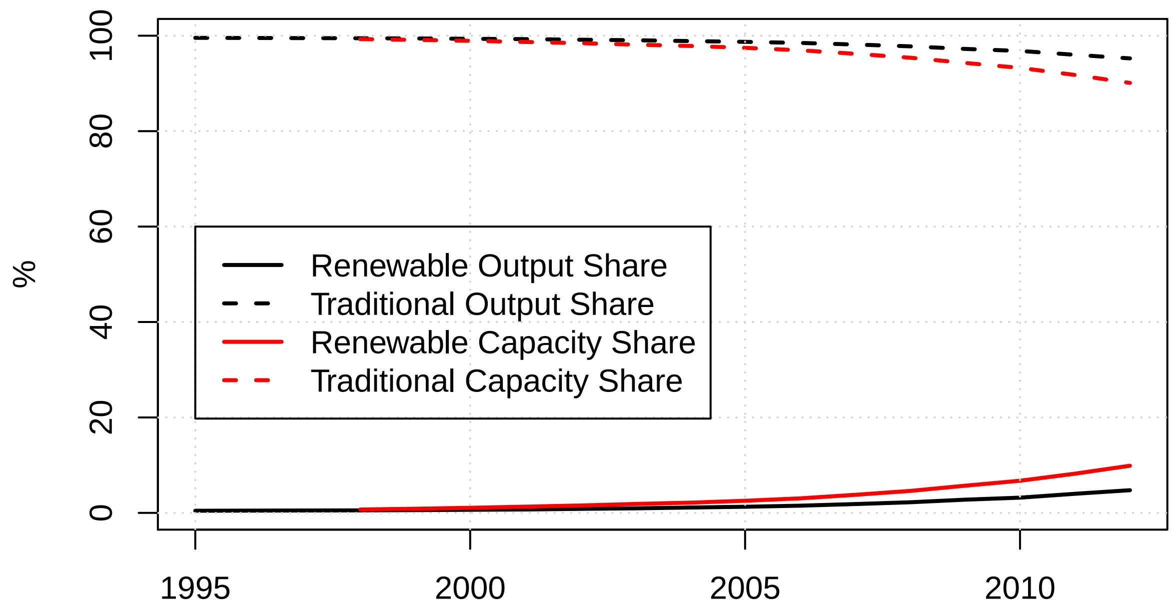


And finally the prices:



Capacity Building and Output Share

One final note regards the distinction between capacity building (i.e. installed capacity) and market share (i.e. output share) between green and brown capital. The following graph shows that capacity share has grown faster than market share.



Proposed calibration

The goal of the procedure is to calibrate the values for β_0 and β_1 entering in the investment decision of the consumption sector (see the Investment Decision Document):

The share of investment going to brown ($i^y_{c,k}$) or green capital ($i^y_{c,i}$) is then determined using a linear expenditure system, modified to account for productivities:

$$i^y_{c,i} = \beta \frac{i^y_{c,\mathrm{tot}}}{pr_i} \tag{1}$$

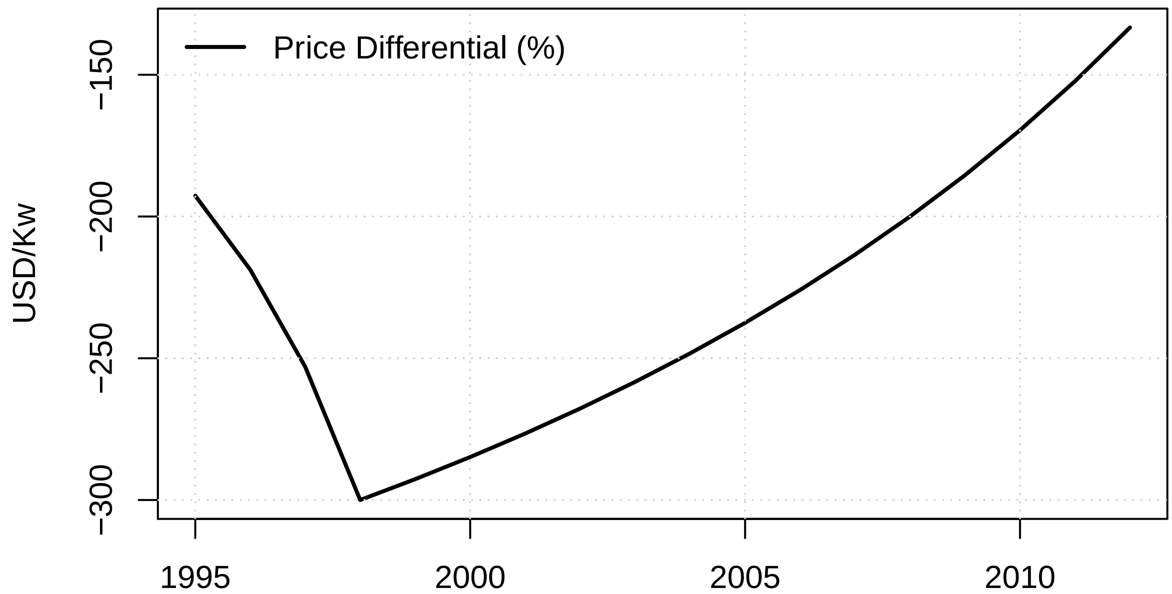
$$i^y_{c,k} = (1-\beta)\frac{i^y_{c,\mathrm{tot}}}{pr_k} \tag{2}$$

The preference parameter (β) is endogenous and determined depending on the relative total unit costs:

$$\beta = \frac{1}{e^{\beta_0+\beta_1 \frac{tuc_{k,c}-tuc_{i,c}}{tuc_{k,c}}}}$$

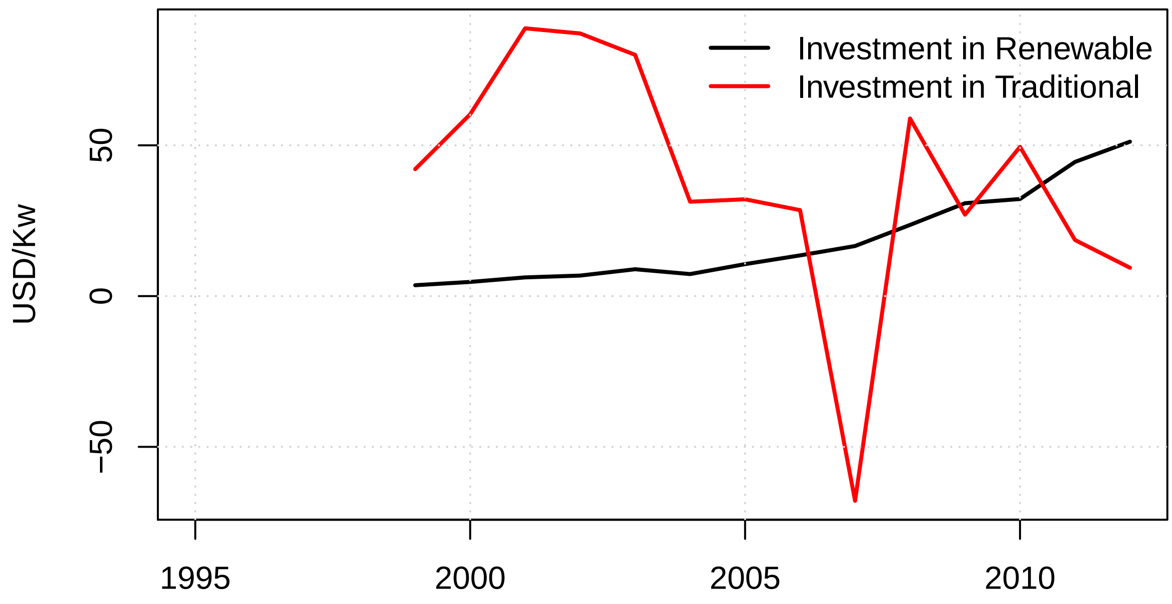
Price differential

If we assume away the difference in capacity factor (and hence the productivity differential for each installed Kw per type of capital), lifetime, and labor-capital ratio, and if we assume that all the investment done in capaciy installation has been done by the consumption sector, we then have that the total unit cost difference boils down to a price difference: $tuc_{x,c} = \frac{W_c}{pr_x * l_x} + \frac{p_x}{\delta_x * pr_x}$ where W_c, pr_x, l_x, and δ_x are assumed to be identical for the two types of capital. We now thus have that $\frac{tuc_{k,c}-tuc_{i,c}}{tuc_{k,c}} = \frac{p_k-p_i}{p_k}$. This is how it looks like in the data:

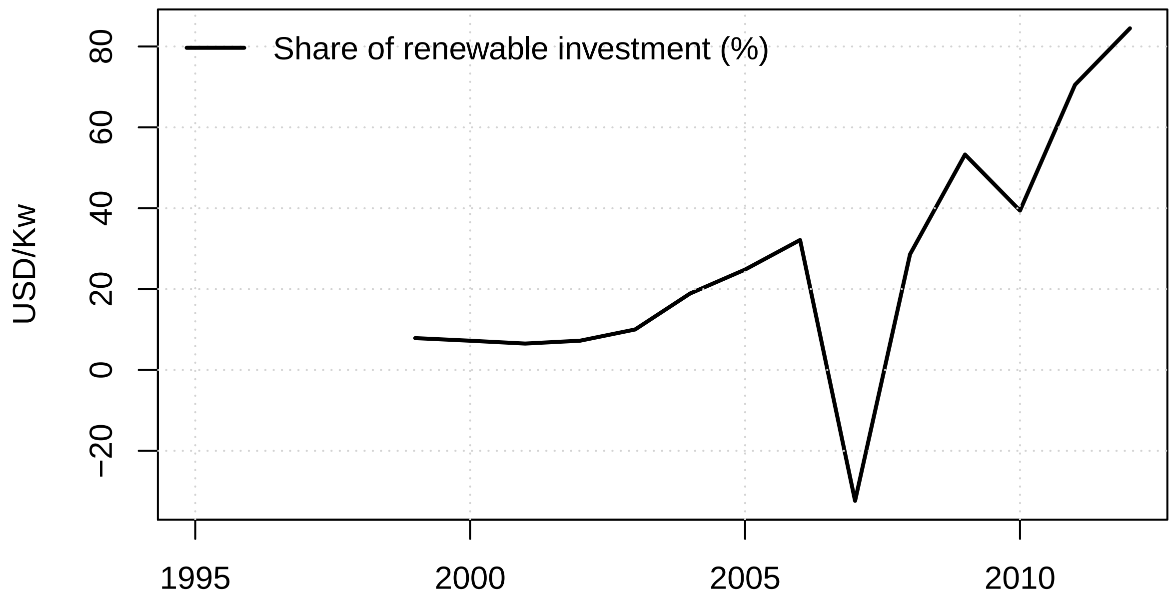


Investment share calibration

In order to be able to calibrate, we also need to look at the investment share for each type of capital. This can be computed by looking at the difference in installed capacity of each type of capital:



Note that in 2007, there was a negative investmemnt decision while investment in renewable was positive. The corresponding β for this investment pattern is the following:



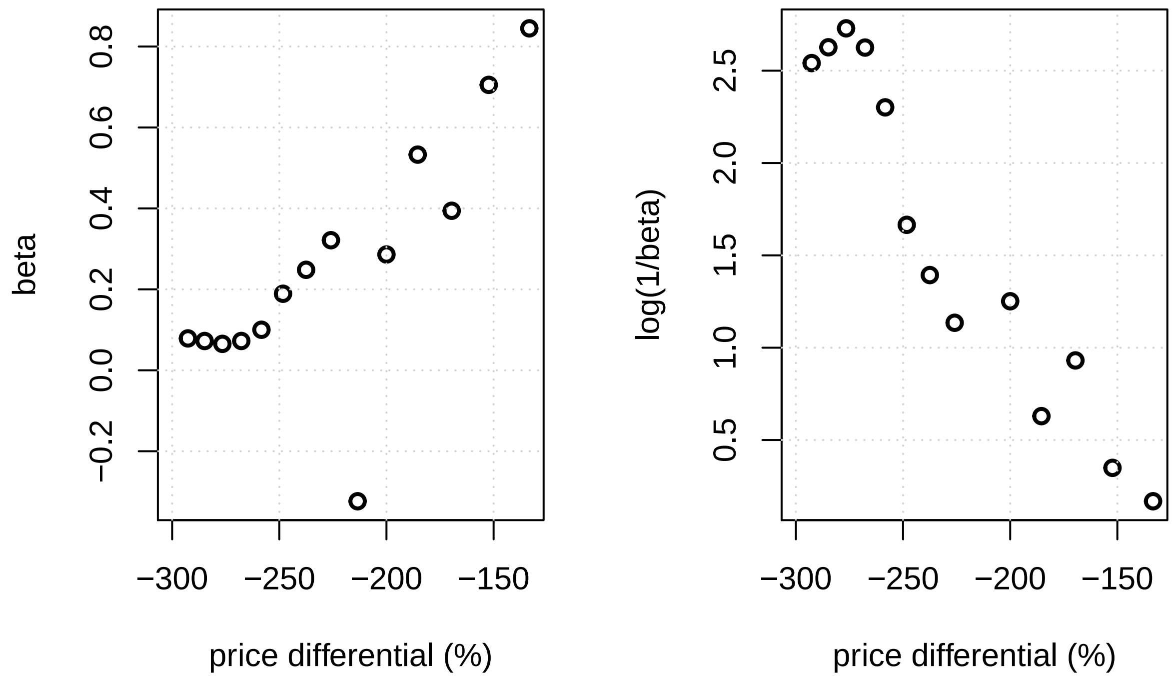
Obviously the 2007 point is again an outlier (due to the negative investment in traditional capital).

Specification 1

Starting from the β euqation here above, we can show that:

$$log(\frac{1}{\beta}) = log(\beta_0) + \beta_1 \frac{p_k - p_i}{p_k}$$

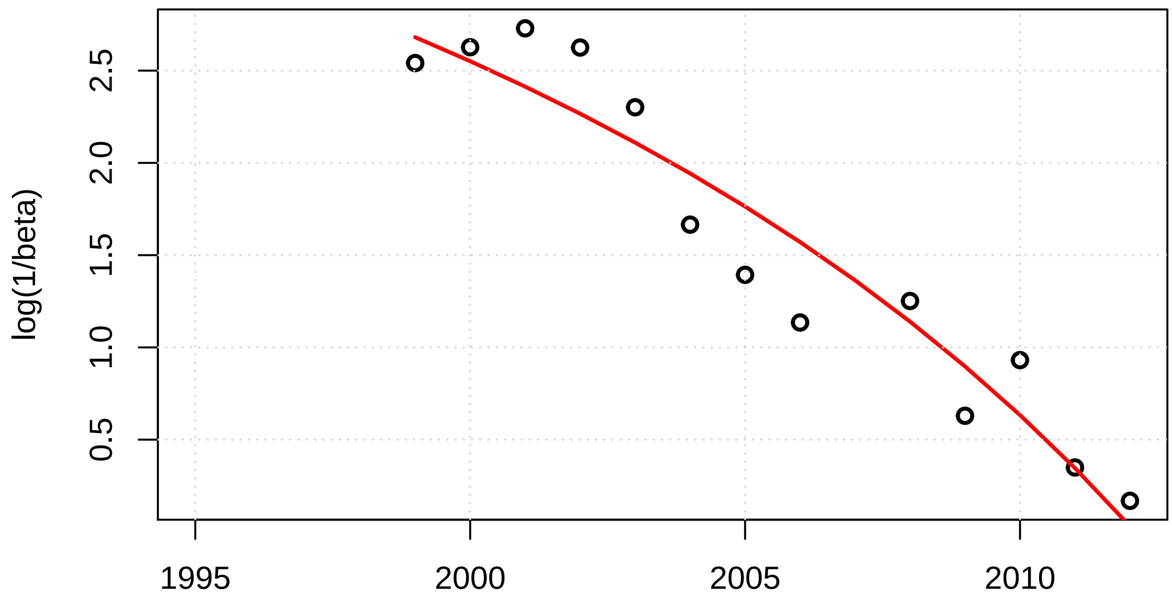
Before regressing the model, let's have a look at the data:



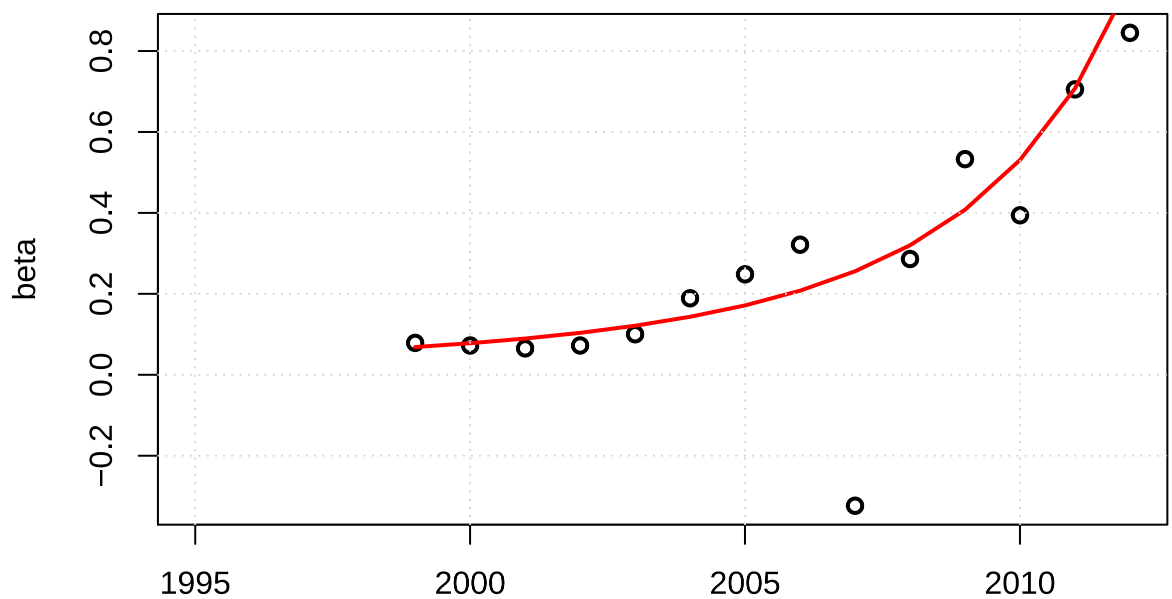
It is thus possible to regress that equation, these are the results.

```
##
## Call:
## lm(formula = log1beta ~ priceDiff, data = energyData)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.43613 -0.26776  0.07553  0.19125  0.35859
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -2.1872     0.3590  -6.092 7.83e-05 ***
## priceDiff    -1.6635     0.1553 -10.712 3.70e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2838 on 11 degrees of freedom
##   (5 observations deleted due to missingness)
## Multiple R-squared:  0.9125, Adjusted R-squared:  0.9046
## F-statistic: 114.7 on 1 and 11 DF,  p-value: 3.704e-07
```

The regression line is:



Or, transforming everything into the β space:



Which shows a fairly good fit.The only issue regards the fact that this formulation is not bounded at 1 and indeed if the price differential is at -1 in 2050 (as predicted by most institutes), the share of investment above green capital would be above 1.In fact the maximum differential value it can take is -1.3148013.

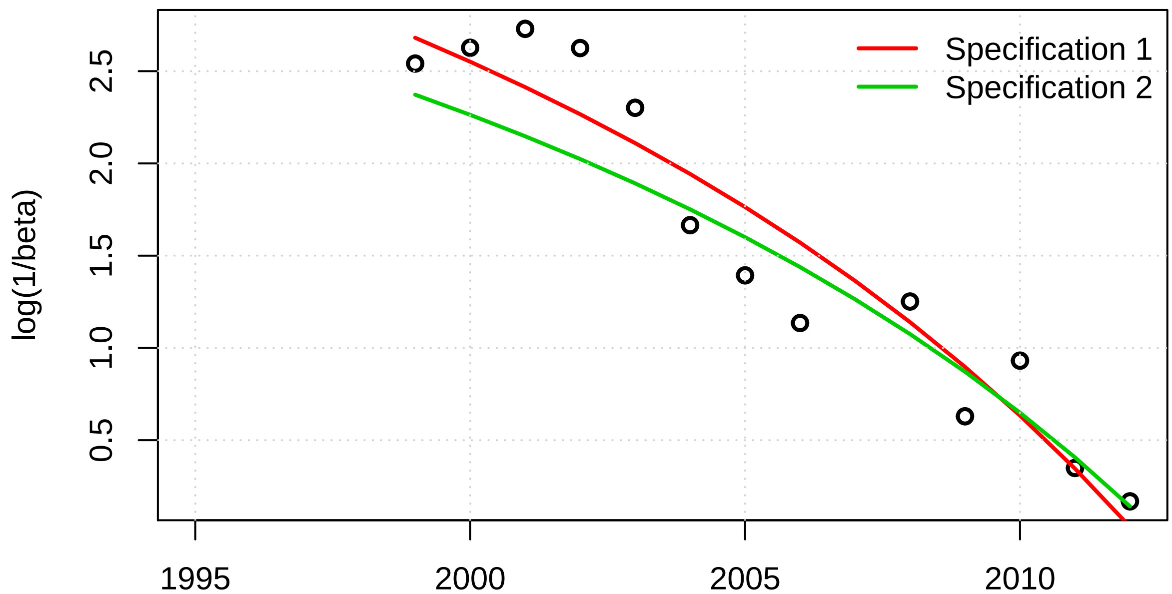
Specification 2

Let's add a slope dummy the first three observations of beta and regress again the equation, these are the results.

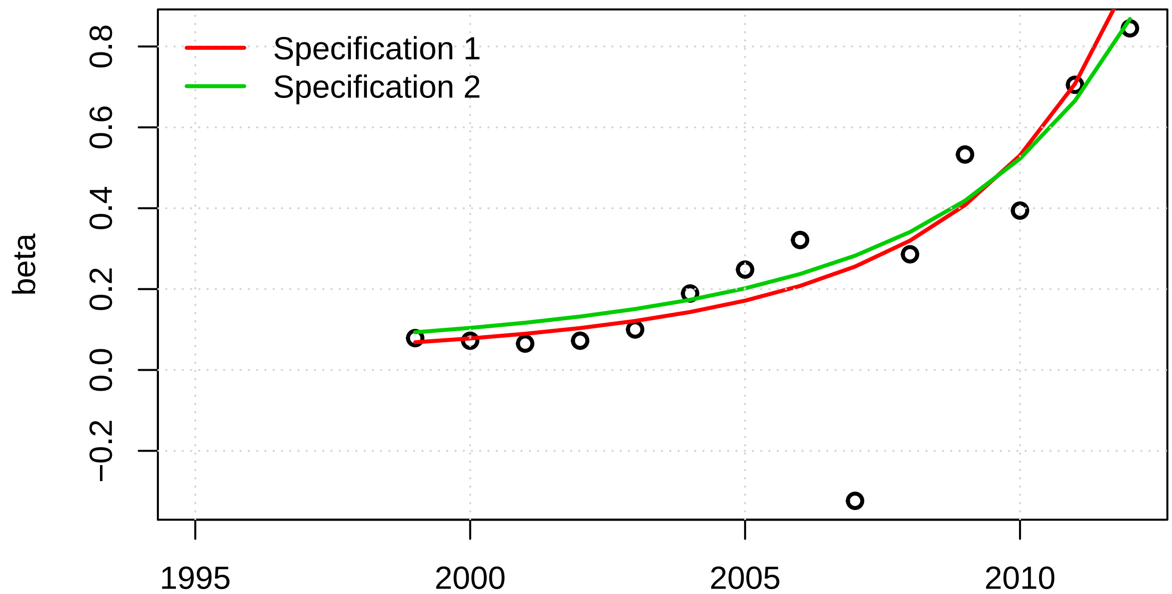
```
##
## Call:
## lm(formula = log1betamod ~ priceDiff, data = energyData)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.30323 -0.20694 -0.05755  0.17641  0.40943
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -1.7256     0.4312  -4.002 0.005177 **
## priceDiff    -1.4004     0.2099  -6.673 0.000285 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2626 on 7 degrees of freedom
##   (9 observations deleted due to missingness)
```

```
## Multiple R-squared:  0.8641, Adjusted R-squared:  0.8447
## F-statistic: 44.52 on 1 and 7 DF,  p-value: 0.0002845
```

The regression line is:



Or, transforming everything into the β space:



Which improves slightly the fit towards the end of the regressions but still has the same problem, now the maximum value the price differential can take is -1.2322475.

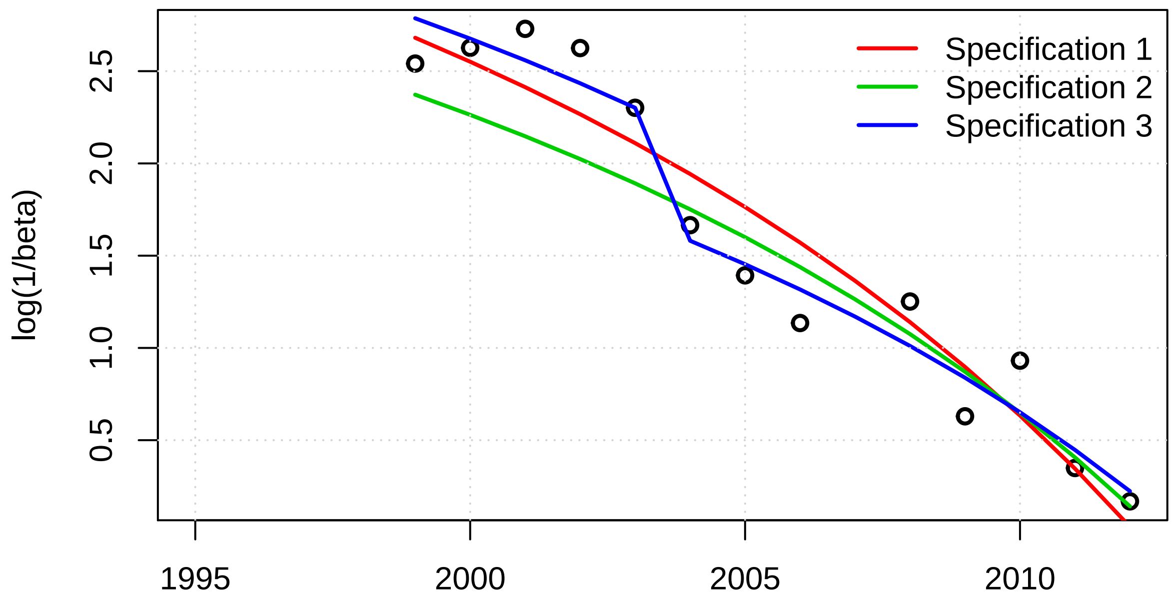
Specification 3

Let's add a slope dummy the first five observations of beta and regress again the equation, these are the results.

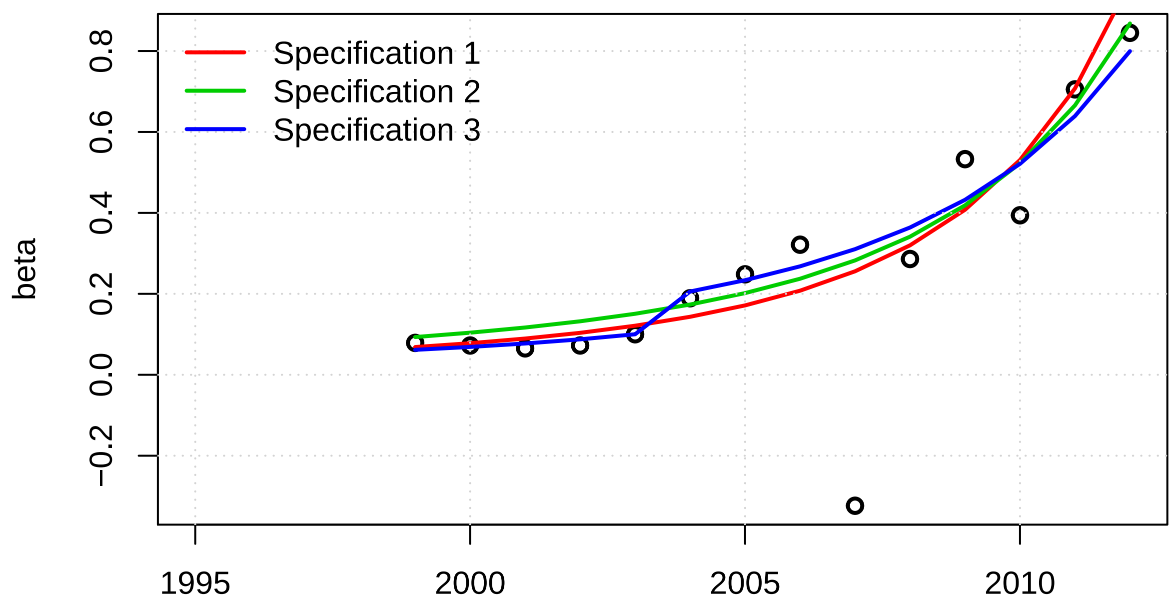
```
##
## Call:
## lm(formula = log1betamod ~ priceDiff + priceDiffDum, data = energyData)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.20920 -0.09810 -0.05515  0.08450  0.27958
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -1.35062    0.35875  -3.765 0.009346 **
## priceDiff    -1.18074    0.18132  -6.512 0.000625 ***
## priceDiffDum -0.23297    0.09316  -2.501 0.046487 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1985 on 6 degrees of freedom
##   (9 observations deleted due to missingness)
```

```
## Multiple R-squared:  0.9335, Adjusted R-squared:  0.9113
## F-statistic:  42.1 on 2 and 6 DF,  p-value: 0.0002944
```

The regression line is:



Or, transforming everything into the β space:

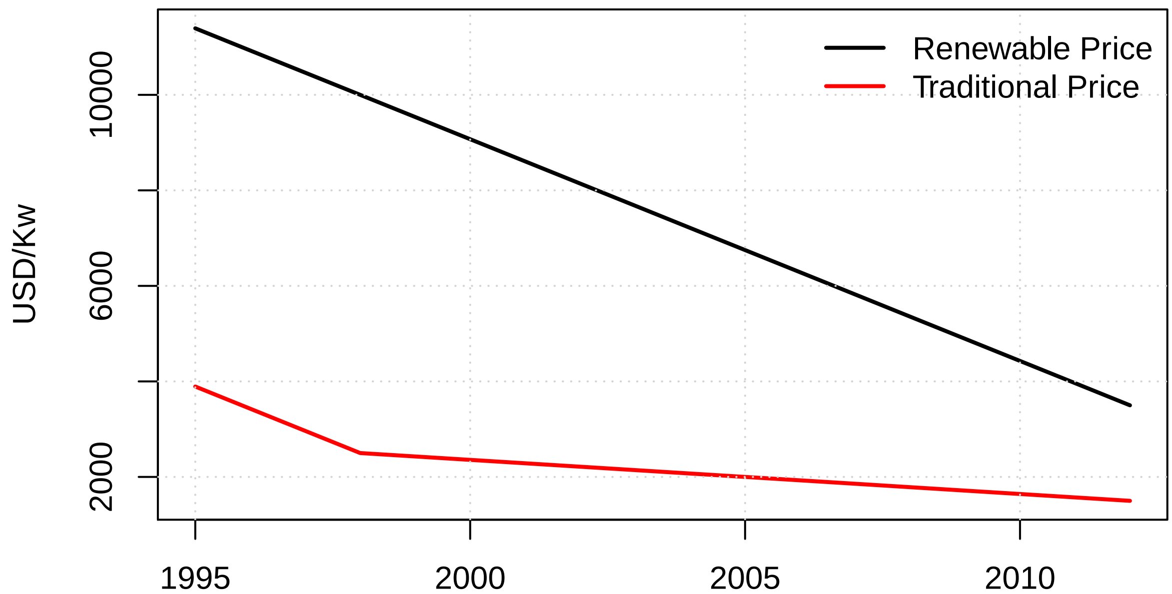


Which improves still the fit towards the end of the regressions but still has the same problem, now the maximum value the price differential can take is -1.1438711.

I suggest we keep this 3rd specification and max out the value beta can take to 1.

Pricing calibration

The following graph shows the evolution of capacity prices in USD per installed kW (there are a lot of extrapolation given we have only two data points in 1998 and 2012. > We need to fix this



In order to try to calibrate the pricing parameters, we need to simplify a bit the pricing equations. Prices are set via a target-return markup. Given a markup ϕ_x in sector x and smoothed expected unit costs NUC_x, the price is given by

$$p_x = p_{x,-1} + \zeta * [(1 + \phi_x) * \mathrm{NUC}_x - p_{x,-1}]$$

In this economy, unit costs are labor costs, computed as the ratio of the nominal wage bill to total output. If we assume only one type of capital per sector (we are interested to calibrate the prices for both capital producers and we assume away the residuals of the initial investment in brown capital from the green sector), the unit costs equation reduces to $UC_x = \frac{W_x}{pr_x l_x}$ where we can safely assume that wages are constants and equal in each sector and where we assume that the capital productiviy is constant and equal in each sector. We are thus left with the labor to capital ratio that needs to be calibrated. Note that we assume away, for the calibration, the smoothening process of expected unit costs and use instead the actual unit costs.

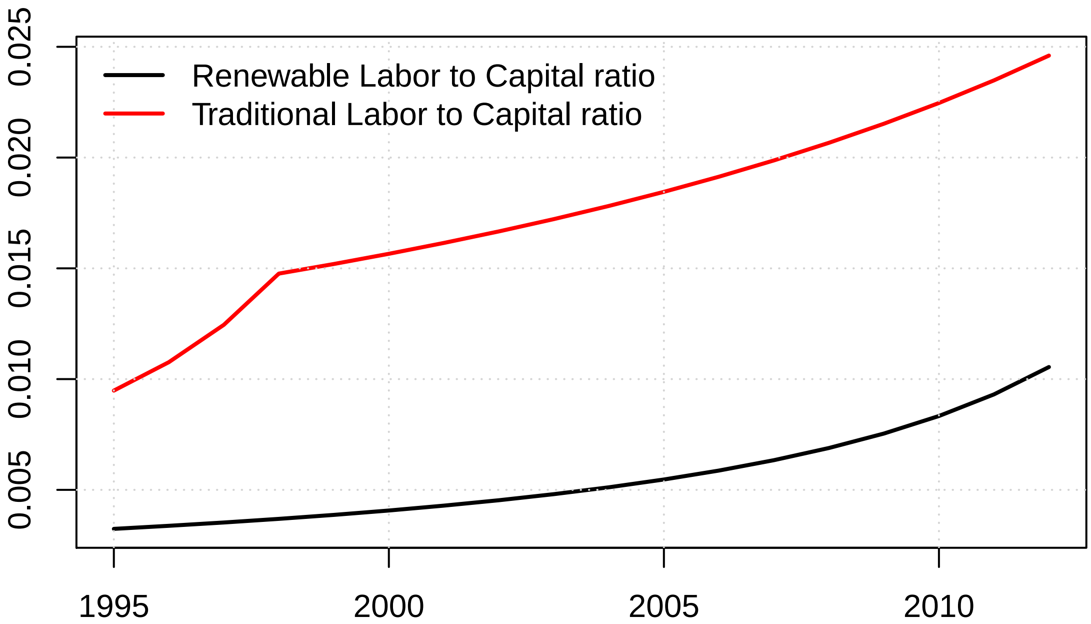
Markups ϕ_x are set to achieve a target return on capital. For sector x this is denoted r_x^T (or `rxT` in the code). The generic expression is $\phi_x = r_x^T \frac{p_{k,-1}k_{x,-1}+p_{i,-1}i_{x,-1}}{\mathrm{NUC}_x y_x^e}$. Again this can be simplified if we assume only one type of capital and a targeted level of utilisation u_x^T. We can show that the markup ϕ_x is a function of the targeted return rate and the targeted utilisation rate: $\phi_x = fracr_x^T r_x^T + u_x^T$.

Assuming that these targeted rate of return or utilisation are equal and constant for both sector, we are thus left only with the labor to capital ratio to explain the price movements: $p_x = (1 + fracr_x^T r_x^T + u_x^T) \frac{W_x}{pr_x l_x}$. Using the following values for the various parameters, we can then compute the capital to labor ratio that explains the price movement and then determine a calibrated equation to forecast future prices.

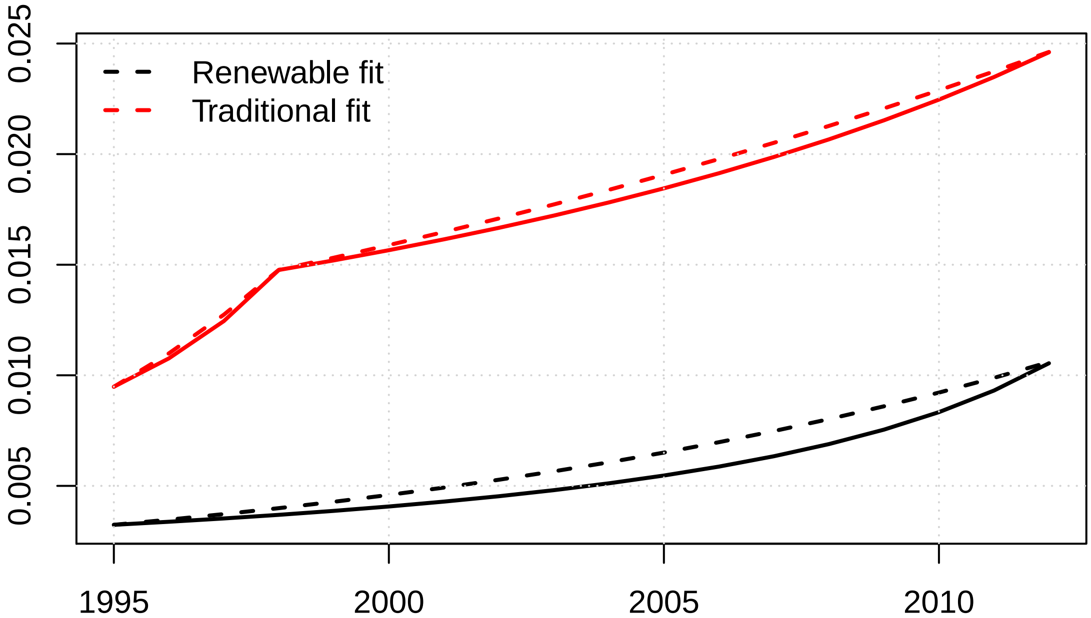
Parameter	Value
u_x^T	0.8
r_x^T	.096

Parameter	Value
W_x	10
pr_x	0.3

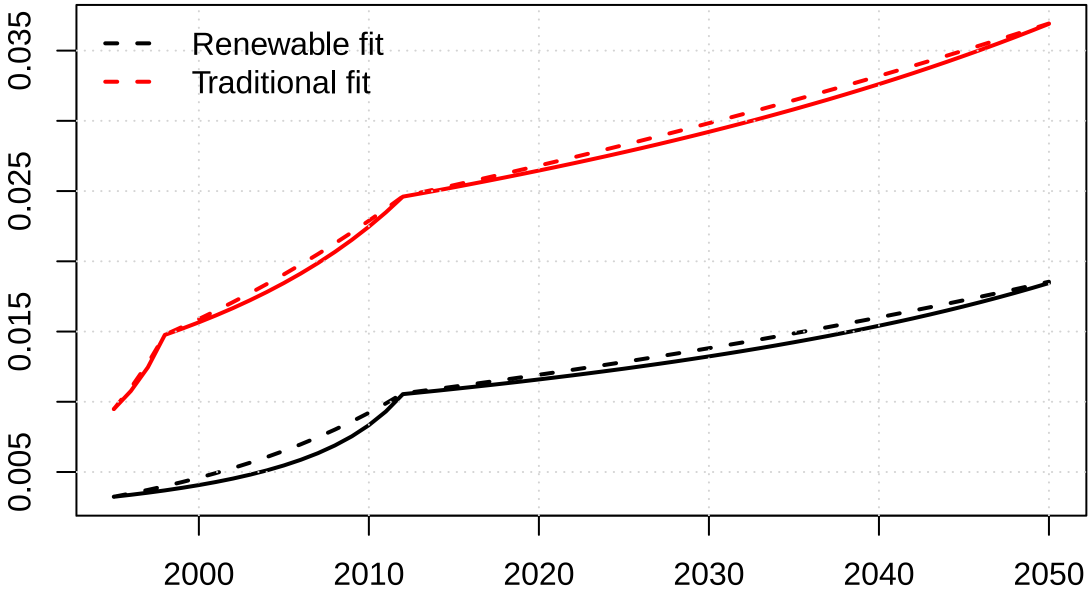
The following graph show the values for both labor to capital ratios:



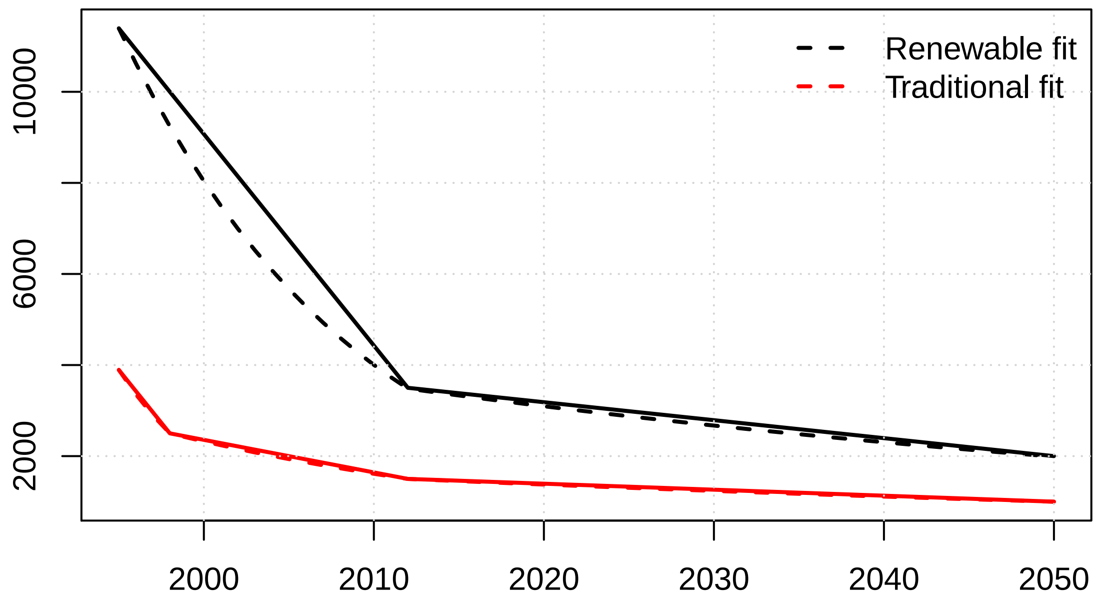
Assuming a constant growth rate (which is not the case), we get:



Now let's look at out of sample data and assuming a structural break in the constant growth:



Prices would then be:


Renewable fit
Traditional fit
10000
6000
2000
2000
2010
2020
2030
2040
2050