A Model for Solar Renewable Energy Certificates:

Shining some light on price dynamics and optimal market design

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(work at Princeton University with Javad Khazaei & Warren Powell)

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Workshop on Electricity, Energy and Commodities Risk Management

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Carbon Market Outlook

Outlook for EU market bleak right now... *(Apr 2013 Economist article)*

ETS, RIP?

The failure to reform Europe's carbon market will reverberate round the world

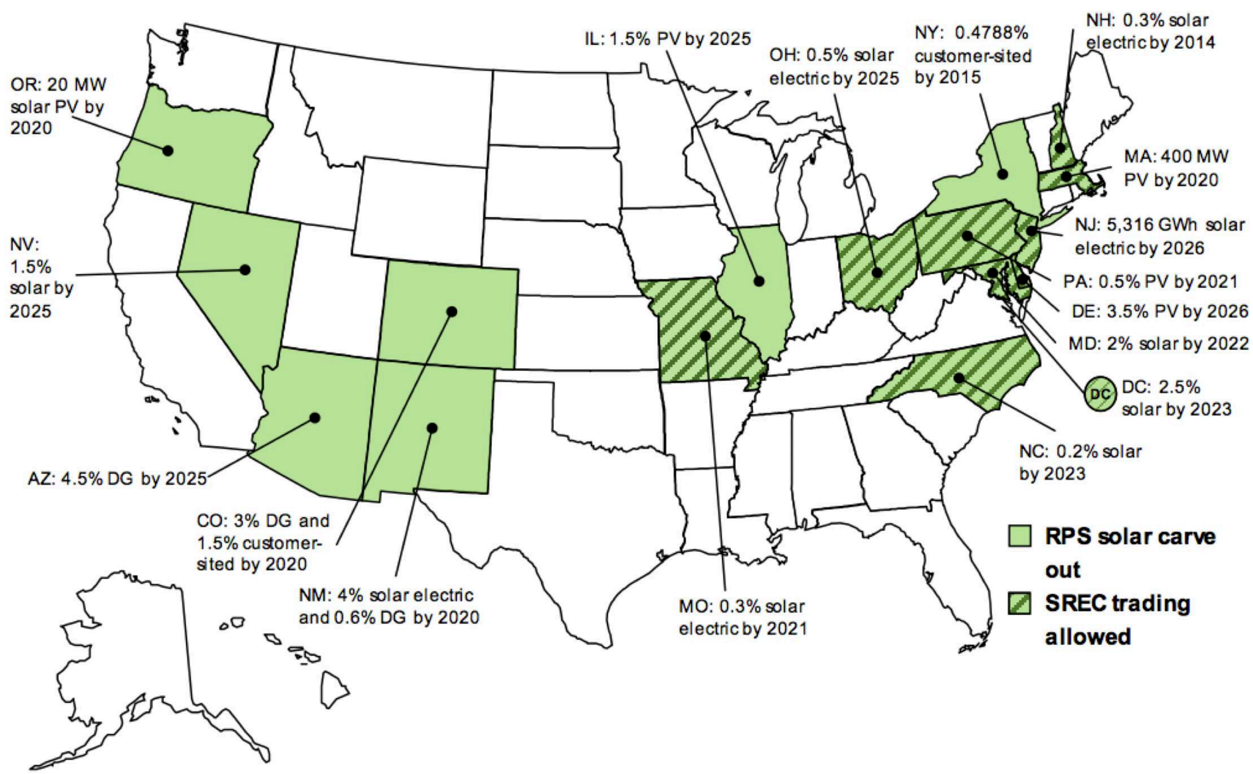
Apr 20th 2013 |From the print edition

On the other hand, other regions are developing (eg, California, China).

Renewable Energy Certificates (RECs)

In the US, about 30 states recently introduced a Renewable Portfolio Standard (RPS). About 10 have set up markets for tradeable certificates called SRECs (or more generally RECs) to achieve these RPS targets.

(map taken from: US DoE-NREL report by Bird, Heeter, Kreycik, 2011)



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A market-based alternative to direct subsidies for clean technologies!
But... if prices are too volatile, it can be very risky for solar investors relying on revenues from selling SRECs, counteracting the goal of the market

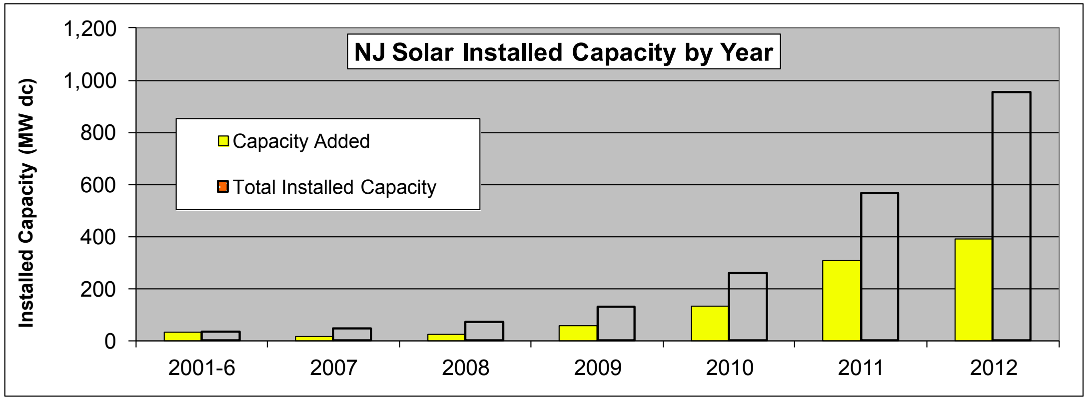
$\Longrightarrow$ Market design very important!

The New Jersey SREC market

The New Jersey SREC market is the biggest in the US (among about 10 states; similar markets for 'green certificates' also exist in Europe and Asia)

- Most ambitious target of over 4% solar energy by 2028.
- Highest recorded prices so far at about $700 per SREC.
- Rapid growth witnessed in solar installations in recent years.

(plot below from NJ Clean Energy)



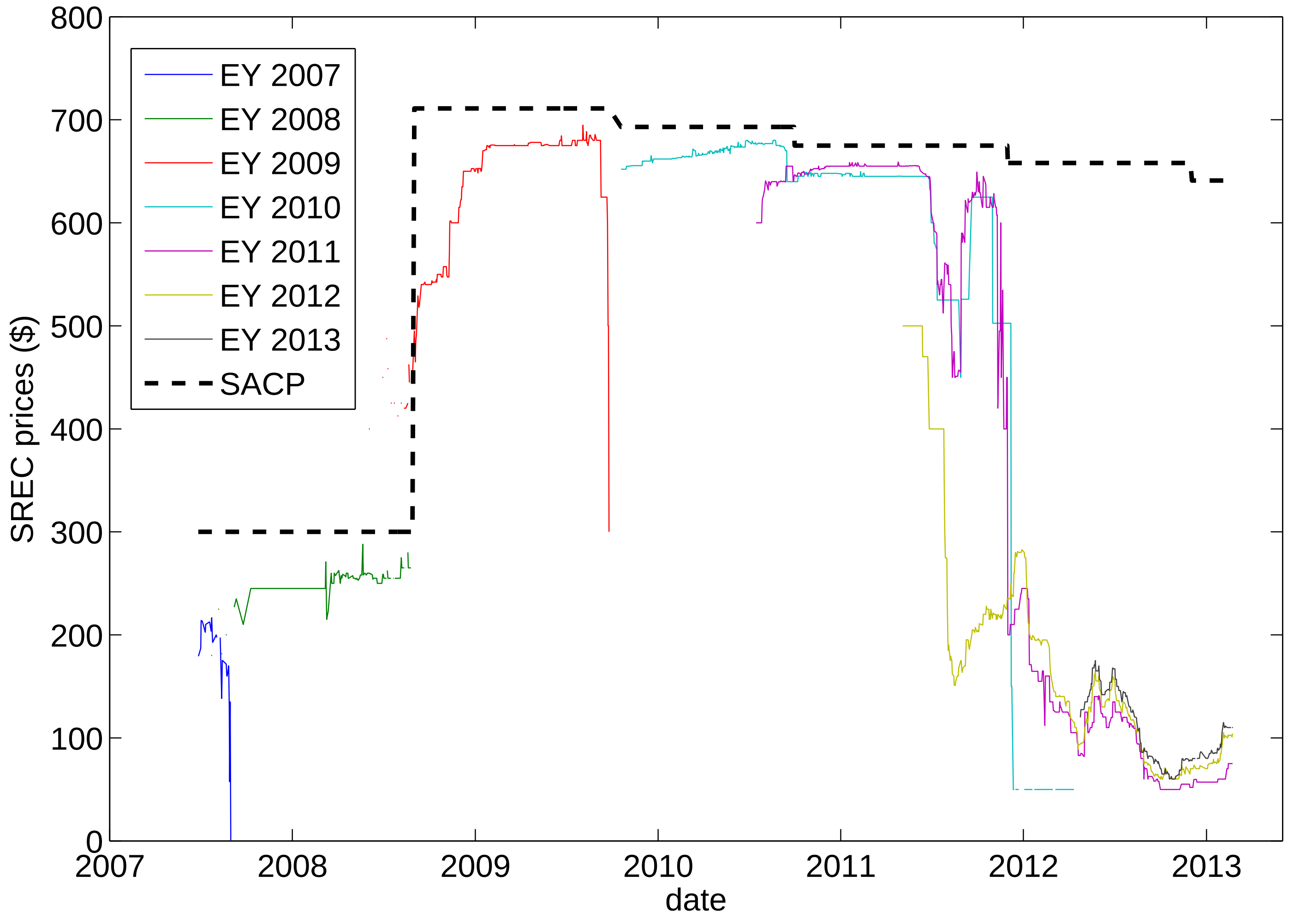
The New Jersey SREC market

The rules of the NJ market have been changed many times. Just a summary:

Energy Year	True-up Period	Oldest Rules *(no banking)* R	π	2008 change *(3-year life)* R	π	2012 change *(5-year life)* R	π
2007	3 mon	32,743	300				
2008	3 mon	65,384	300				
2009	4 mon	130,266	300	130,266	711		
2010	4 mon	195,000	300	195,000	693		
2011	6 mon			306,000	675		
2012	6 mon			442,000	658	442,000	658
2013	6 mon			596,000	641	596,000	641
2014	6 mon			772,000	625	1,707,931	339
2015	6 mon			965,000	609	2,071,803	331
2016	6 mon			115,0000	594	2,360,376	323
2017	6 mon					2,613,580	315
2018	6 mon					2,829,636	308

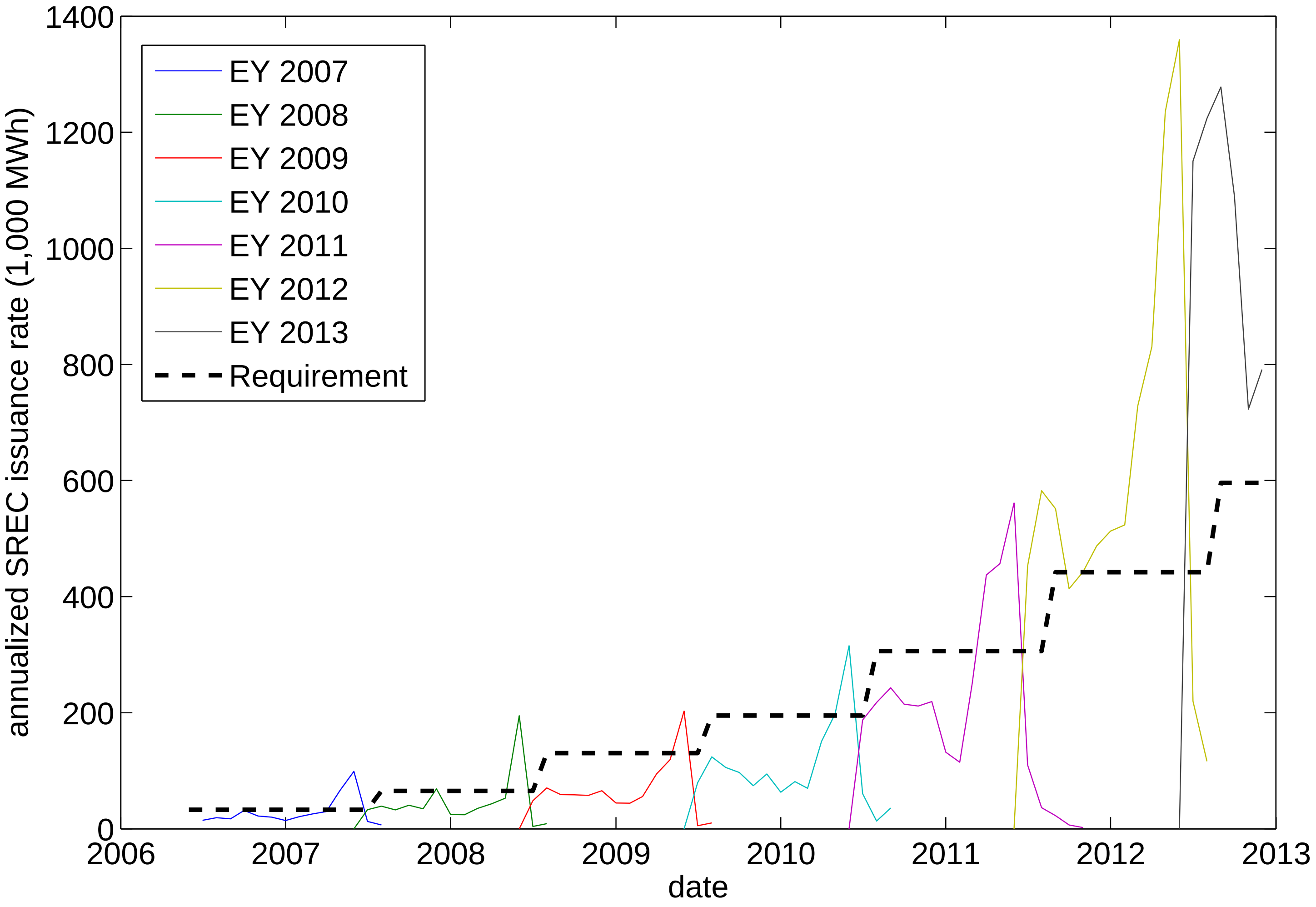
The New Jersey SREC market

What about historical prices? Very high (near π) until very recently...



The New Jersey SREC market

Historical (monthly) issuance data easily available online. Solar generation is growing fast (faster than R), with clear seasonality... will the trend continue?



Stochastic models for SREC prices

How can we model an SREC price p_t^y (for vintage year $y \in \mathbb{N}$)?

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Consider a single-year case $t \in [y-1, y]$ (no banking). Like carbon,

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Therefore, for $t \in [y-1, y]$,

$$
\begin{aligned}
p_t^y &= e^{-r(y-t)} \pi_t^y \mathbb{E}_t \left[1_{\{\int_{y-1}^y g_u \mathrm{d}u < R_t^y\}} \right], \\
&= e^{-r(y-t)} \pi_t^y \mathbb{P} \left\{ \int_t^y g_u \mathrm{d}u < R_t^y - \int_{y-1}^t g_u \mathrm{d}u \right\},
\end{aligned}
$$

where g_t is the annualized solar generation rate (ie, SREC issuance rate).

Structural model for SREC prices

Next step: Include k years of banking, such that a vintage year y SREC is valid for compliance at times

$$t \in \{y, y+1, \ldots, y+k\}$$

Then the price today is a max over all future shortage probabilities:

$$p_t^y = \max_{v \in \{\lceil t \rceil, \lceil t \rceil + 1, \ldots, y+k\}} e^{-r(v-t)} \pi_t^v \mathbb{E}_t \left[1_{\{b_v = 0\}} \right]$$

where b_t is the accumulated SREC supply (this year's plus banked):

$$b_t = \begin{cases} \max\left(0, b_{t-1} + \int_{t-1}^{t} g_u \mathrm{d}u - R_t^t\right) & t \in \mathbb{N}, \\ b_{\lceil t \rceil - 1} + \int_{\lceil t \rceil - 1}^{t} g_u \mathrm{d}u & t \notin \mathbb{N}. \end{cases}$$

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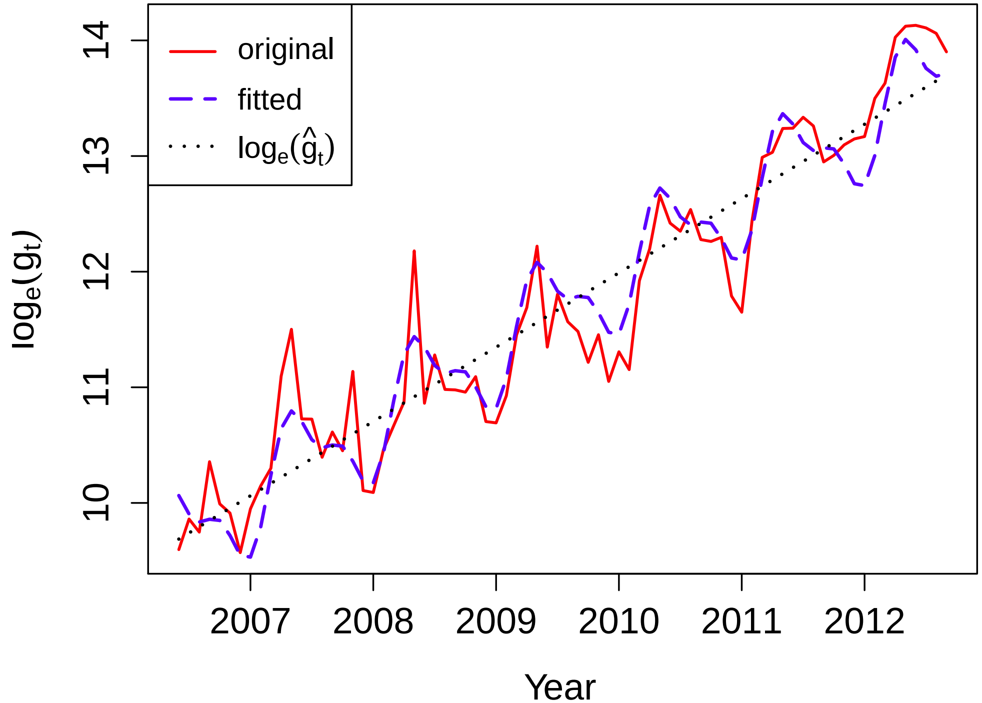
Final step: A stochastic model for solar generation rate g_t?

NJ SREC issuance data

Log plot of total monthly issuance shows some noise but also a clear trend (slope = 0.64) and seasonality:



Like for electricity demand, perhaps model g_t with an OU process plus a trend and cosines? Anything missing?

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$$g_t = \hat{g}_t(p) \exp\left(a_1 \sin(4\pi t) + a_2 \cos(4\pi t) + a_3 \sin(2\pi t) + a_4 \cos(2\pi t) + \varepsilon_t\right),$$

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- We then assume that the average annual generation rate $\hat{g}_t$ grows as:

$$\frac{\ln(\hat{g}_{t+\Delta t}) - \ln(\hat{g}_t)}{\Delta t} = a_5 + a_6 \bar{p}_t, \qquad \text{for } a_5 \in \mathbb{R}, a_6 > 0,$$

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This completes the model. We can now solve by dynamic programming.
(Between years $p_t^y = \mathrm{e}^{-r\Delta t}\mathbb{E}_t^{\mathbb{Q}}[p_{t+\Delta t}^y]$, while jumps can occur at $t \in \mathbb{N}$.)

Summary of the Algorithm

Recall: Firstly the price today as a maximum over expected payoffs:

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Analogously for carbon (emissions E_t, allowance price A_t), the FBSDE:

$$dE_t = \mu_E(A_t, \cdot) dt, \qquad E_0 = 0,$$

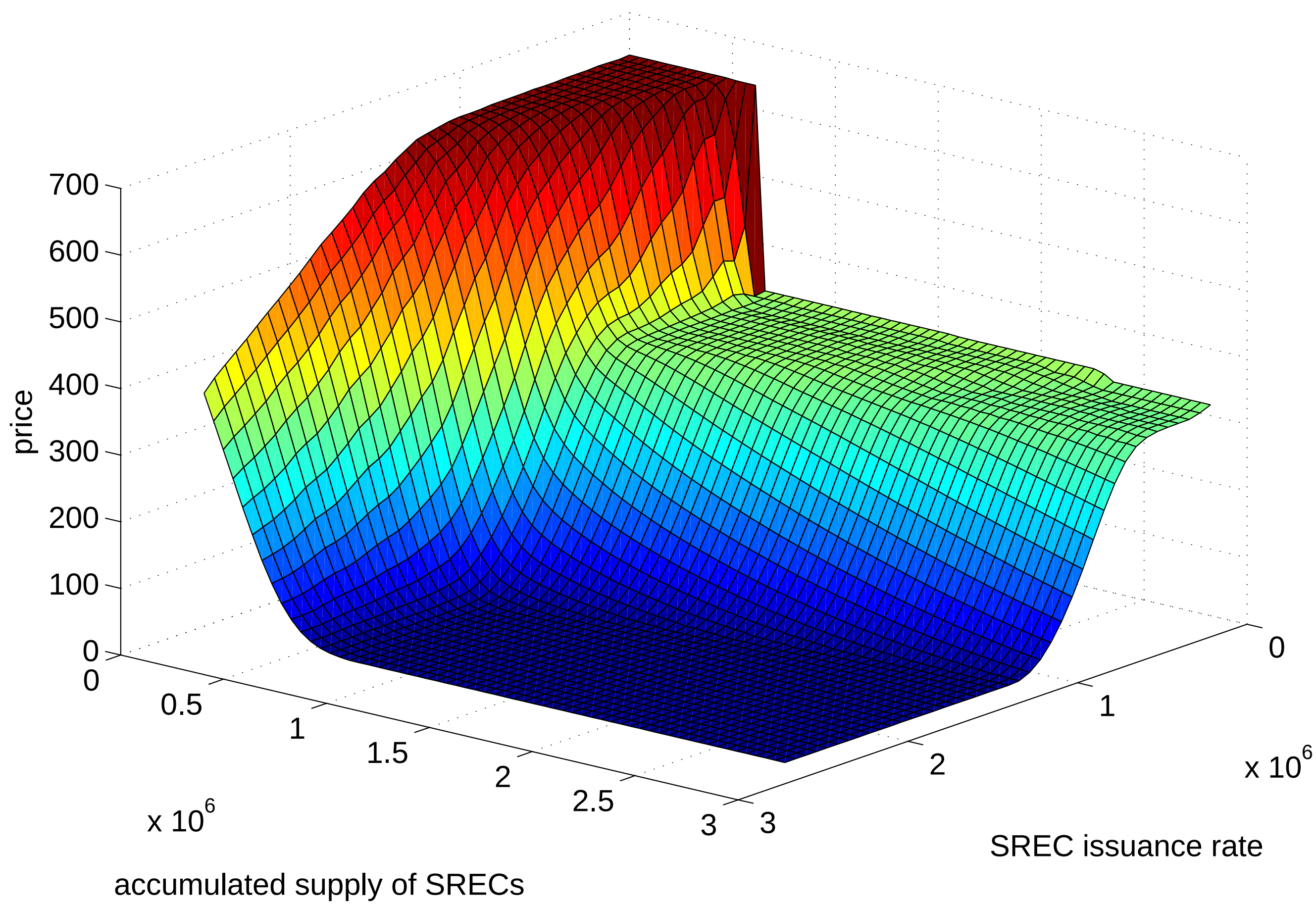
$$dA_t = r A_t dt + Z_t dW_t \qquad A_T = \pi 1_{\{E_T \geq \kappa\}},$$

where the emissions drift $\mu_E(A_t, \cdot)$ is decreasing in A_t.

Results of structural model

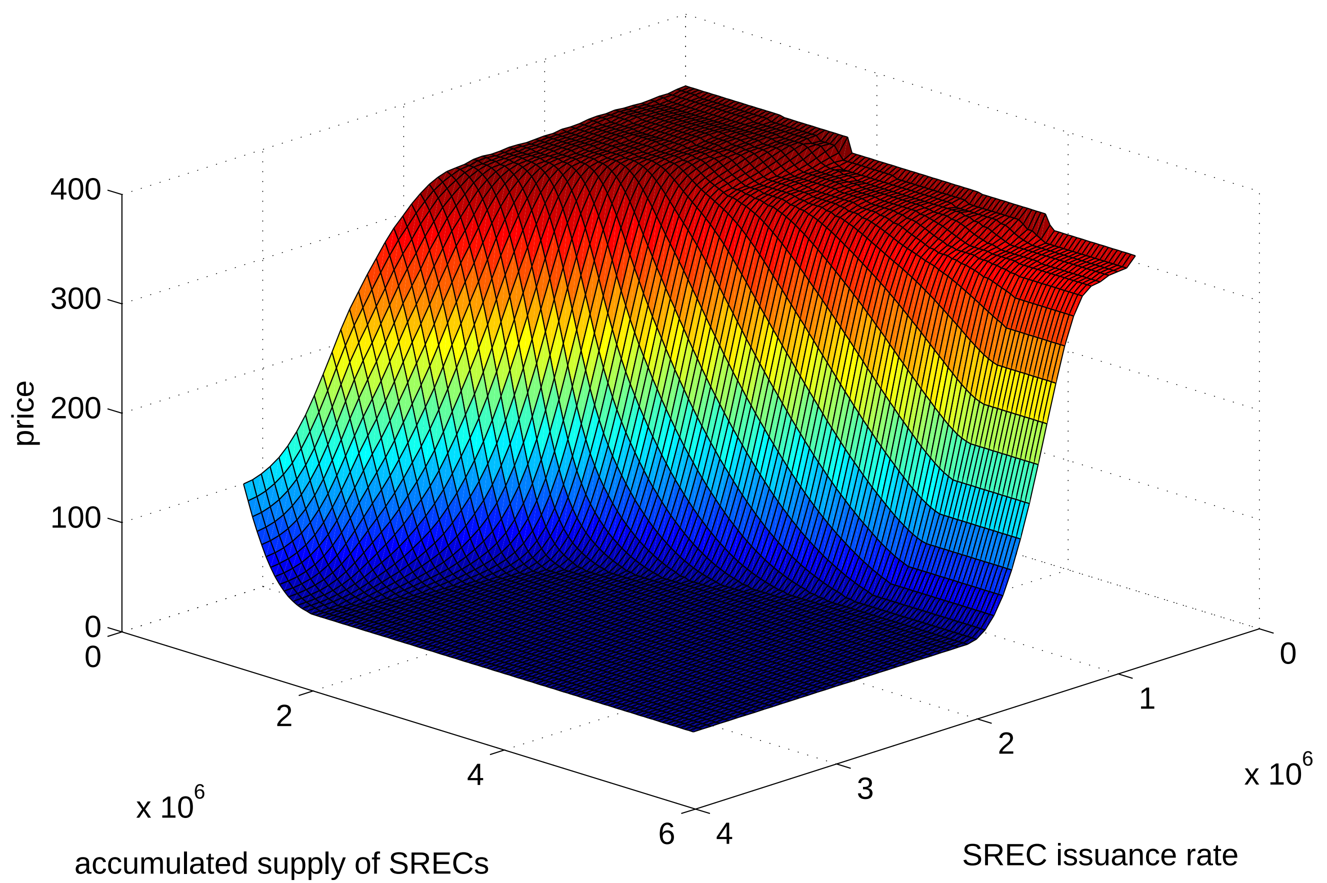
Solving algorithm produces a surface $P_t(b_t, \hat{g}_t)$ for each time.

For 2013 SRECs near the end of the first year:



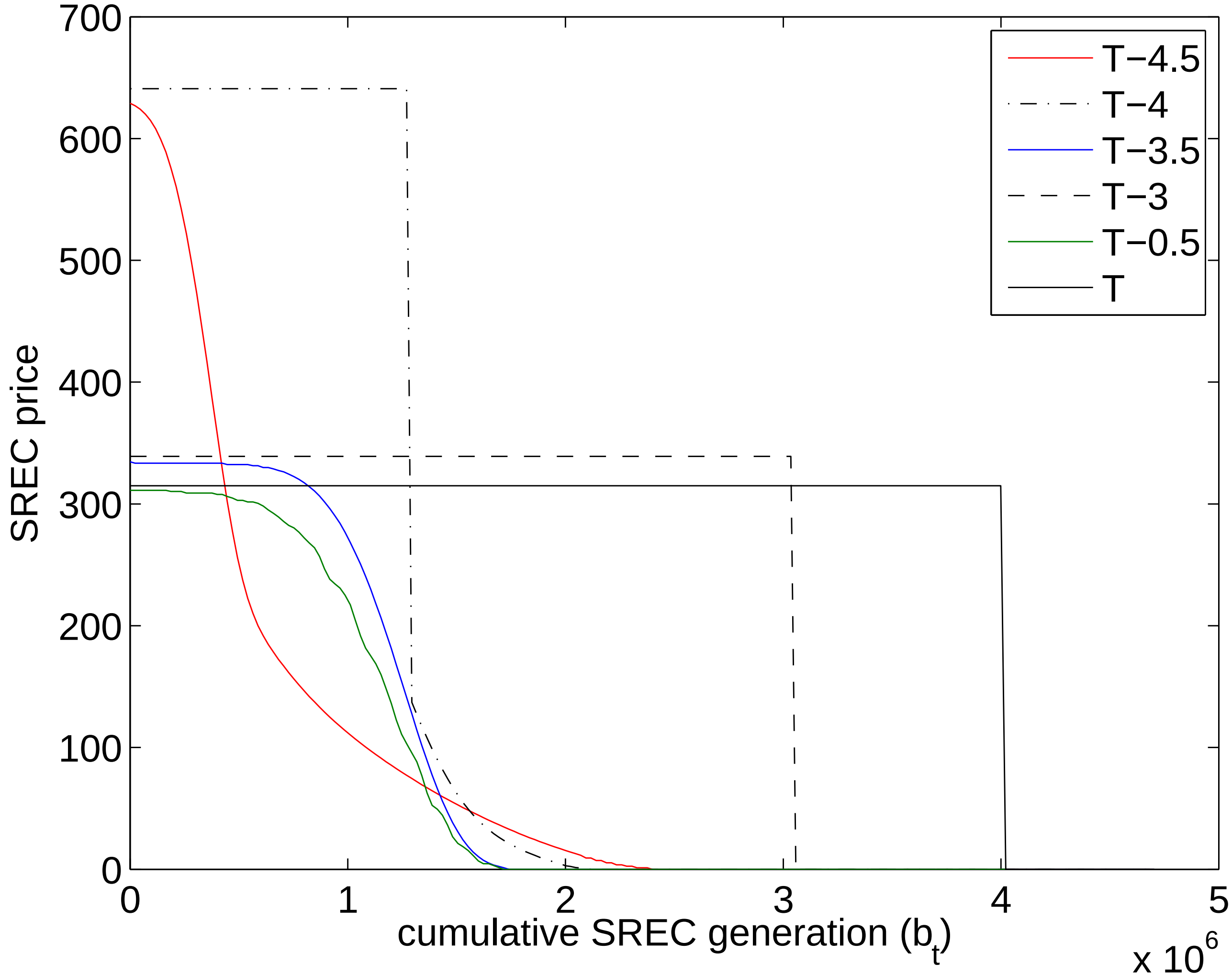
Results of structural model

Same price surface but six months later:



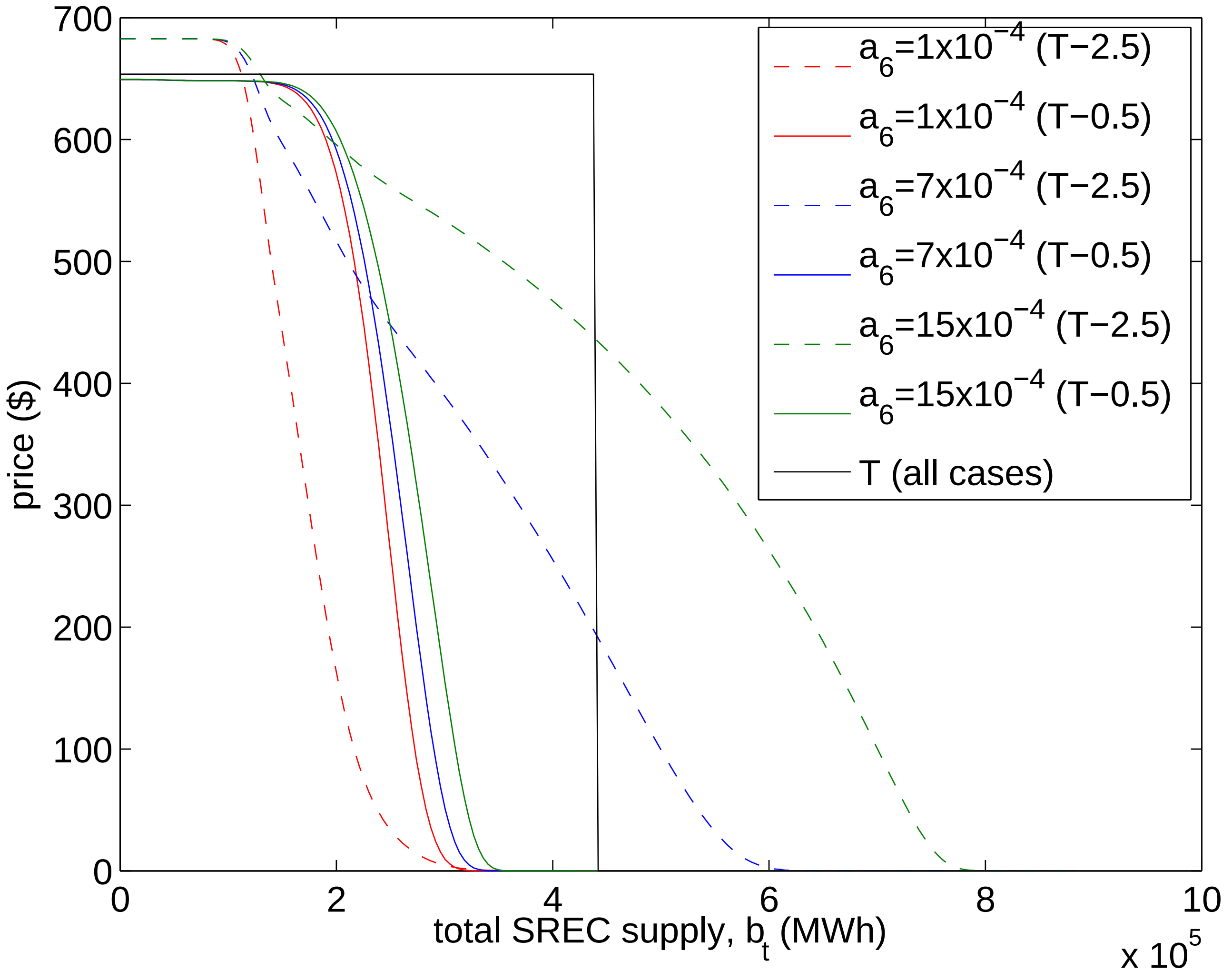
Results of structural model

As with carbon, price surface 'diffuses' from its digital option shape at each compliance date (but not exactly a digital payoff if banking provides value):



Results of structural model

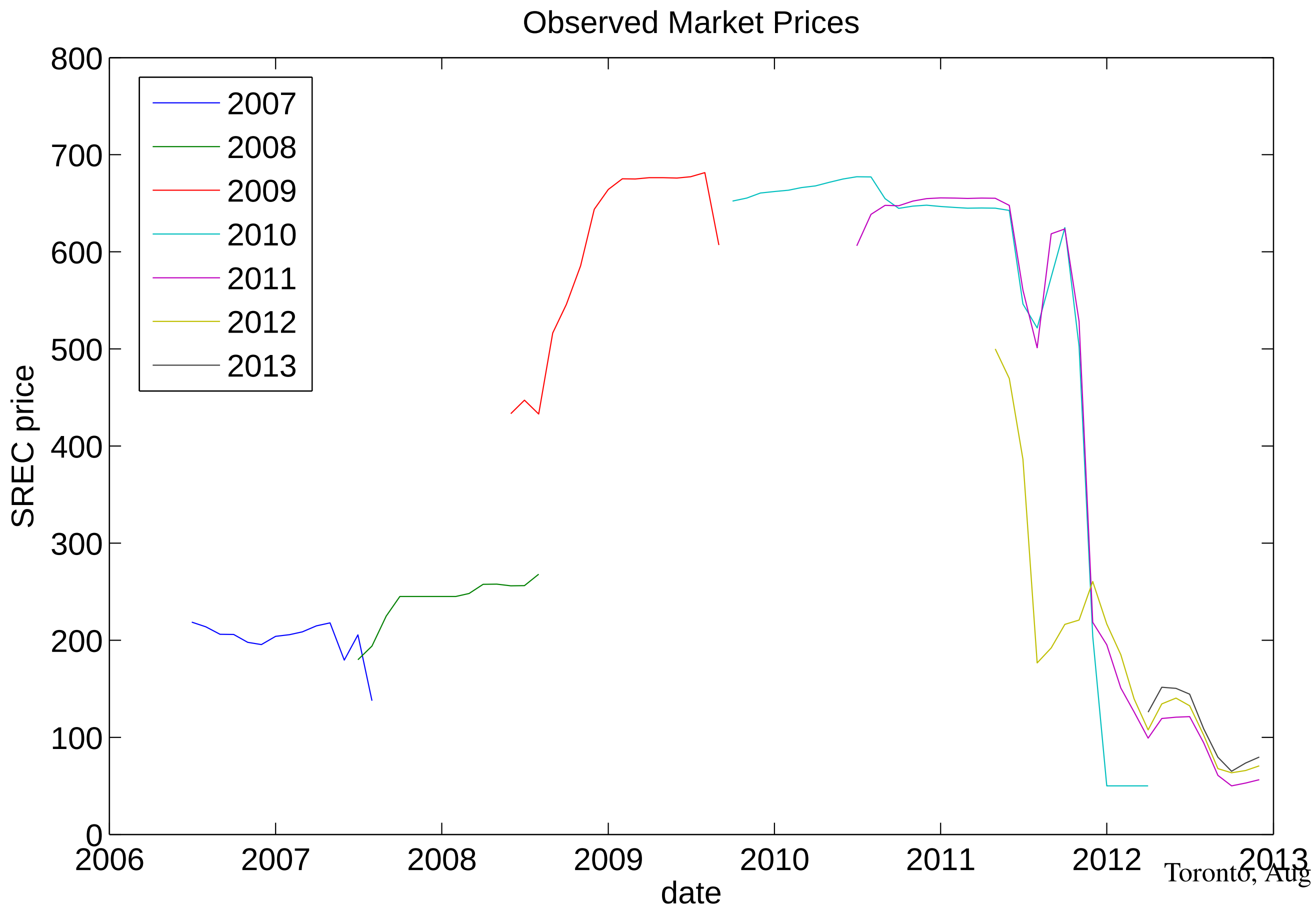
Sensitivity to feedback parameter a_6:



Comparison to history

After fitting parameters, we compare historical market vs model prices:

- Overall price behaviour through history reasonably encouraging
- Also, provides some evidence about the level of feedback in the market



Comparison to history

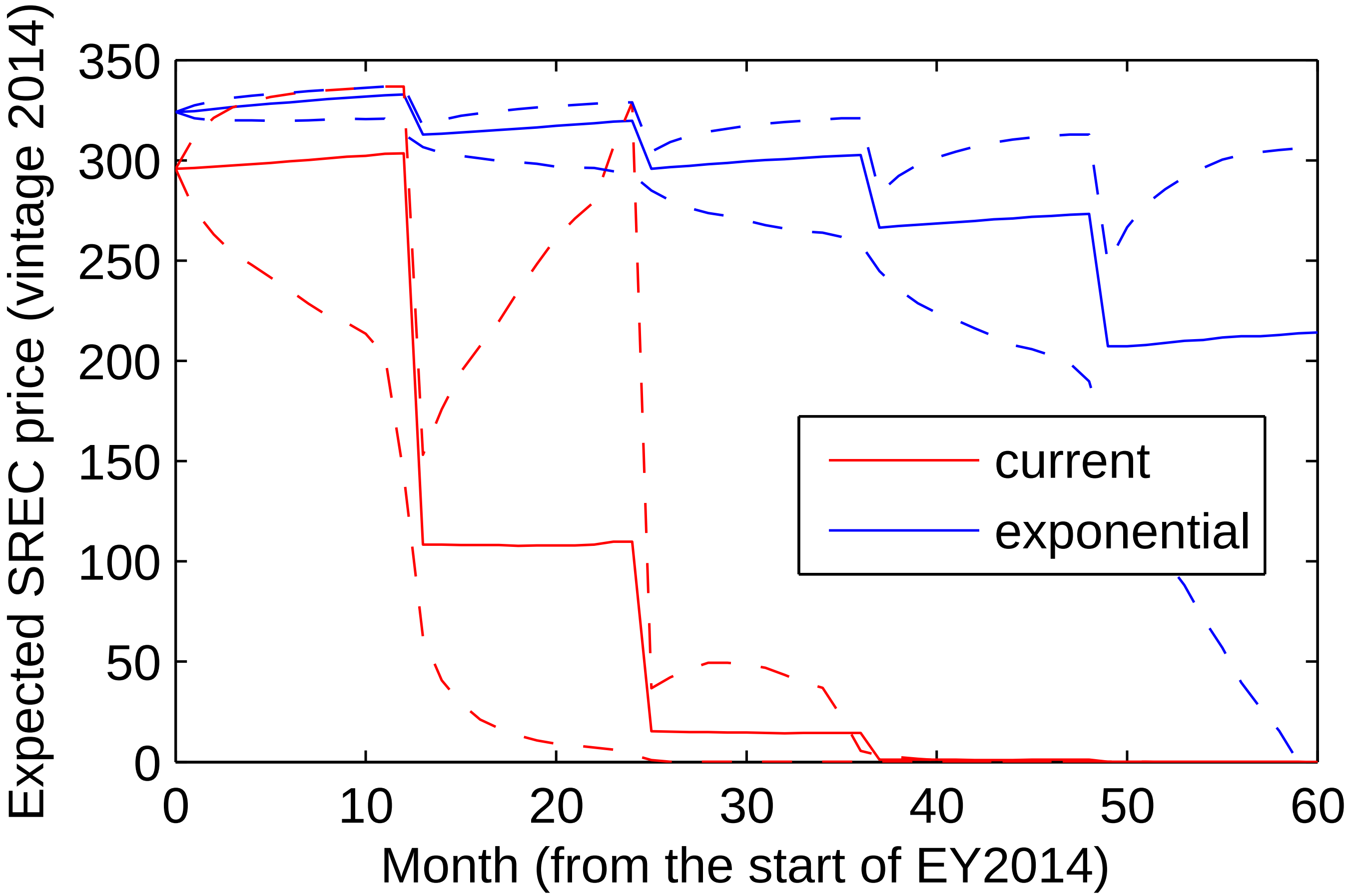
Price elasticity parameter set to $a_6 = 7 \times 10^{-4}$ throughout, except:

- For 2013A line, $a_6 = 5 \times 10^{-4}$ (low feedback)
- For 2013B line, $a_6 = 1 \times 10^{-3}$ (high feedback)

Policy Analysis

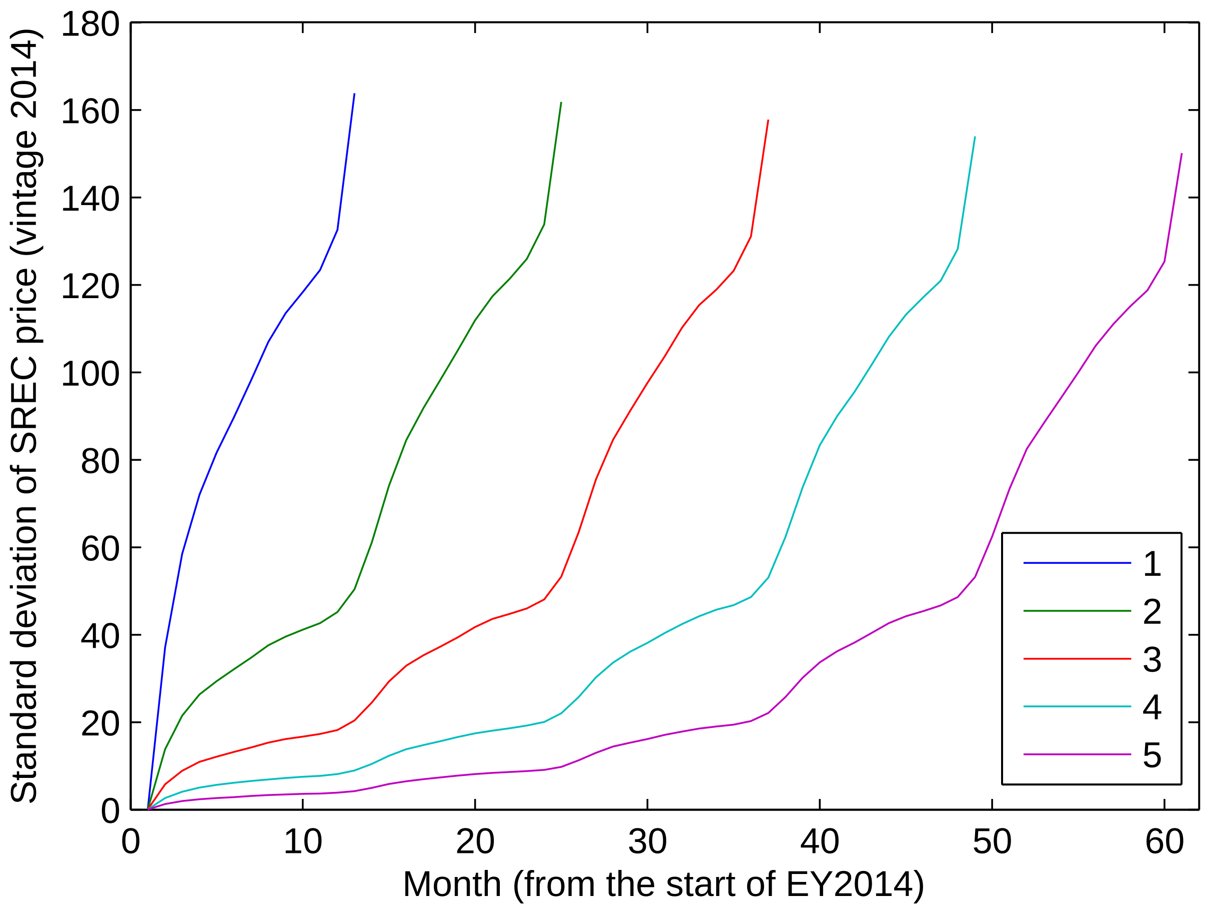
SREC markets (just like cap-and-trade) are very sensitive to market design.

For example, choosing an appropriate requirement growth schedule:



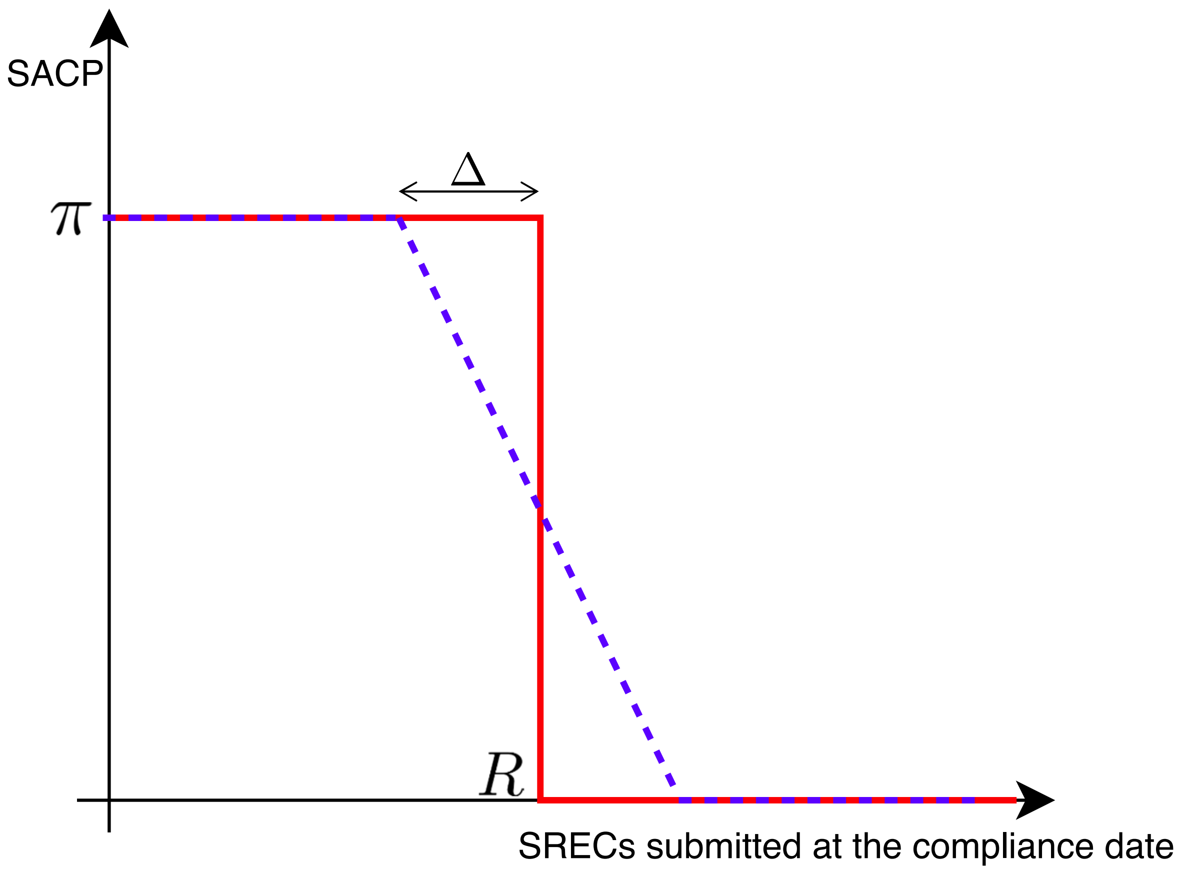
Policy Analysis

A larger number of banking years clearly produces greater price stability:



Policy Analysis - Other Ideas?

Inherent instability (in both REC and carbon markets) is due to the digital payoff functions... why not try something smoother? (eg, the blue line below)

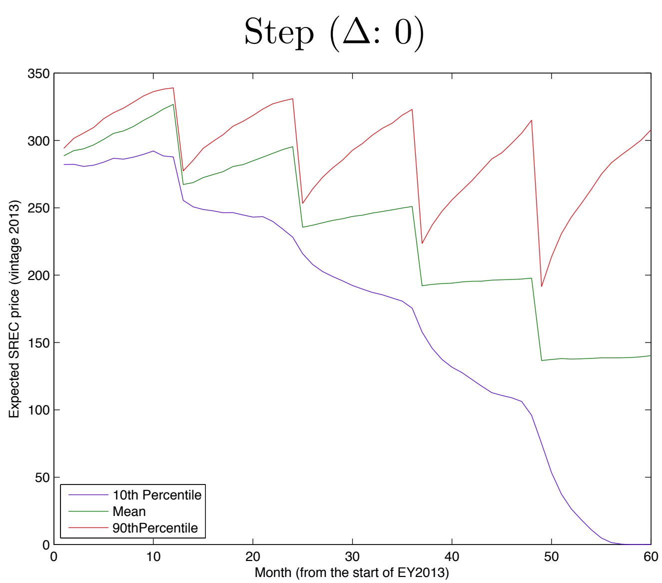


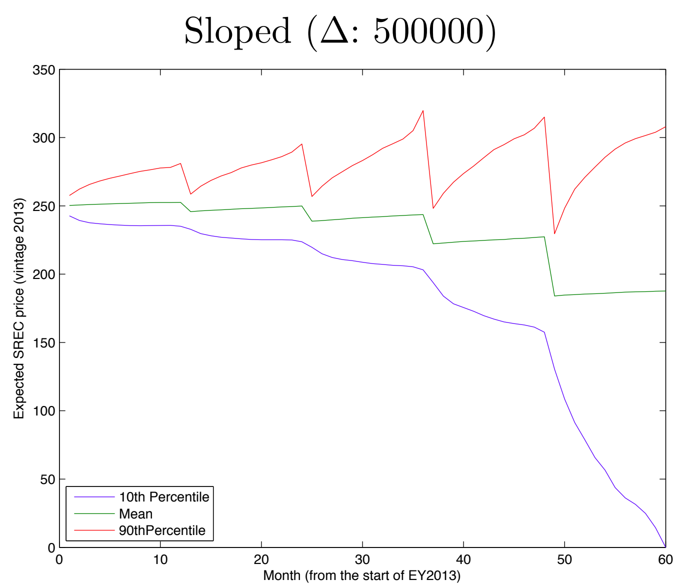
Penalty Function: Step vs Slope

A sloped penalty function implies:

- A non-trivial (model-dependent) banking decision each year
- A resulting threshold analogous to Am. options' 'exercise boundary'

Simulated paths reveal greater stability:





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Long-term simulations of different vintages reveal that with a sloped (graduated) penalty policy:

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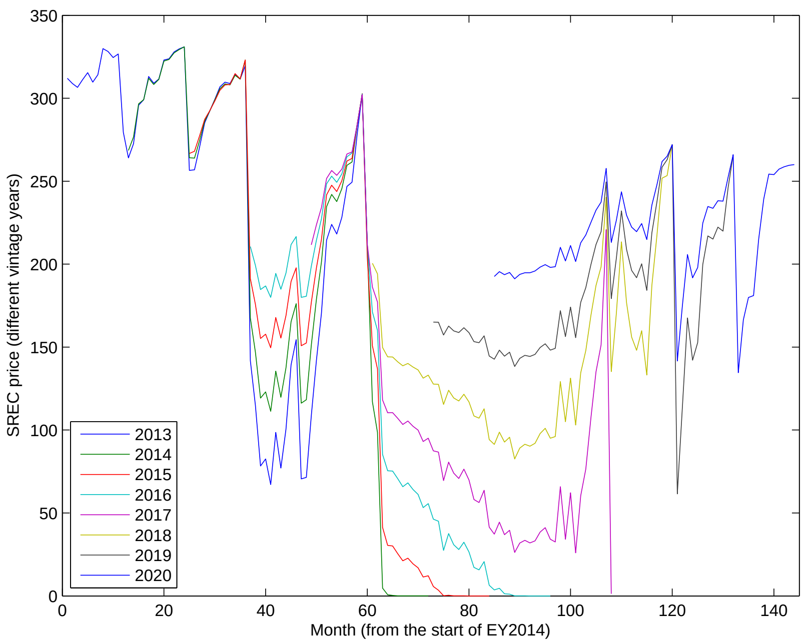
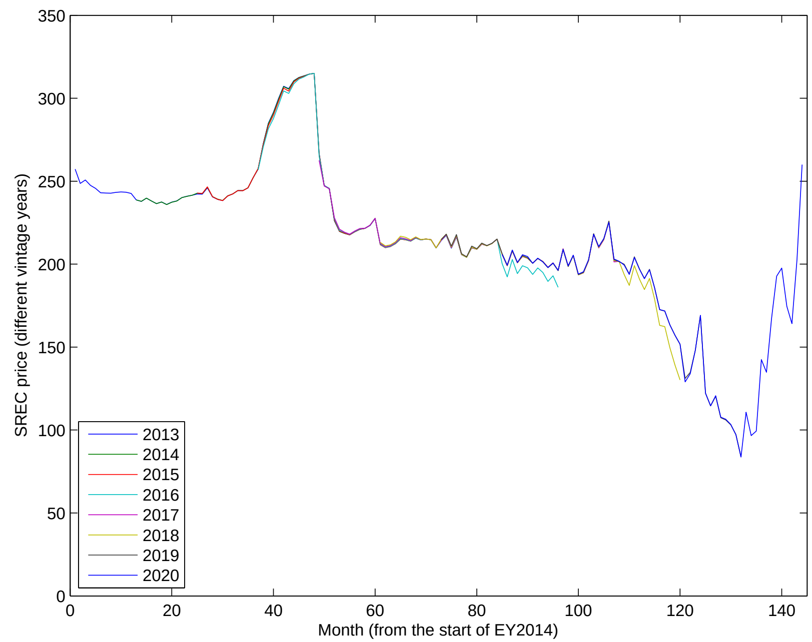
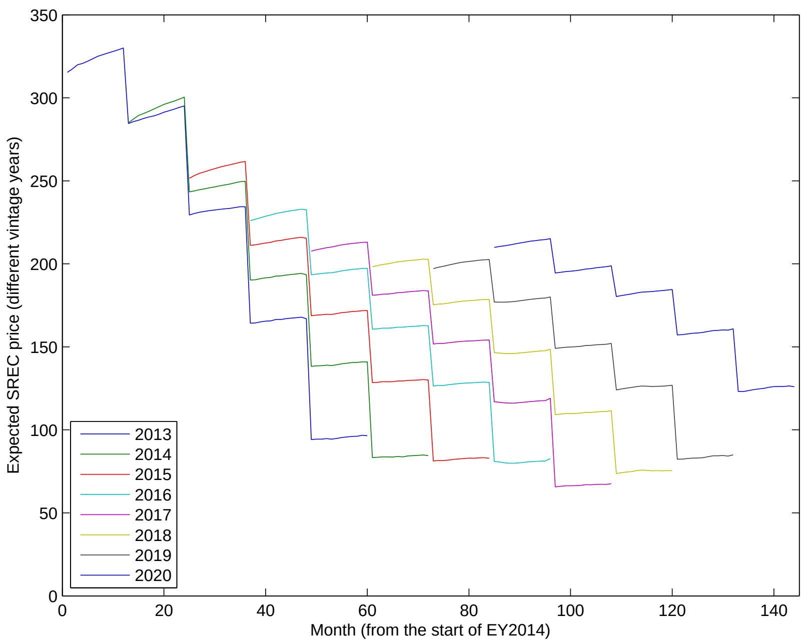


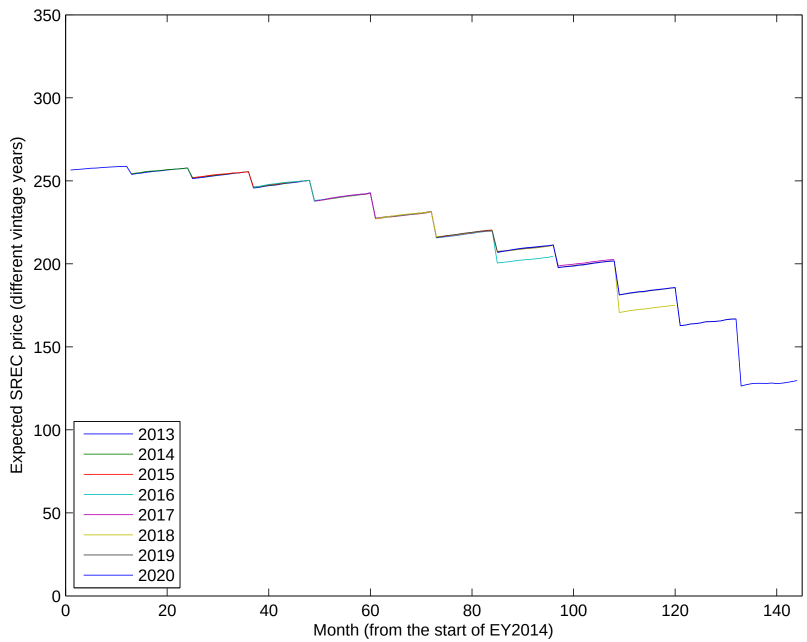


Simulations above use the same set of random numbers but for the step case ($\Delta = 0$) on the left and slope case ($\Delta = 500$ GWh) on the right.

Penalty Function: Step vs Slope

Mean of simulations reveals similar patterns (again $\Delta = 0$ on left, $\Delta = 500$ GWh on right)





Note: Why do the annual drops in mean price not clash with ‘no arbitrage’?

- Expectation is taken over all paths, including those for which banking is not optimal (ie, SRECs should all be used up for compliance)
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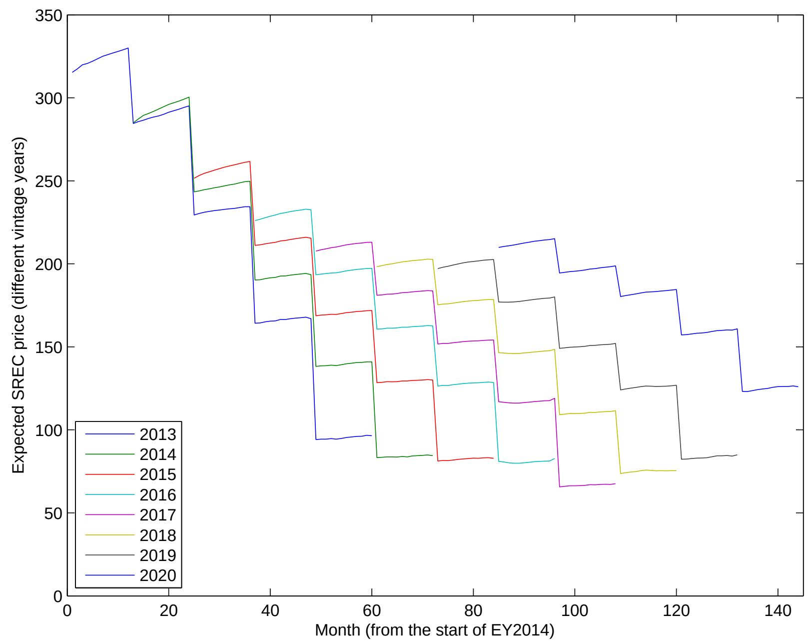

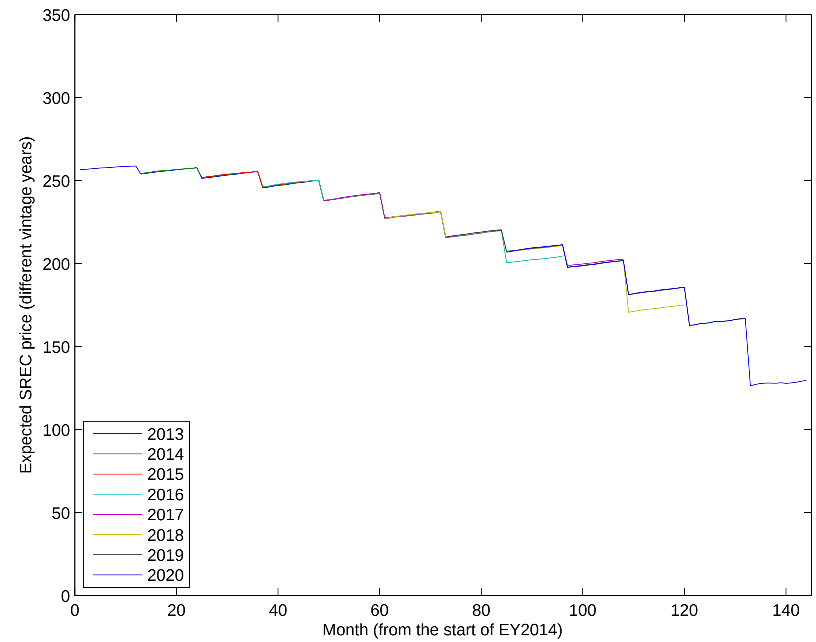

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$$\tilde{R}^y = R^y + \lambda \left(b_{y-1-\epsilon} - R^{y-1} \right), \qquad \lambda \in (0,1).$$

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- Finally, in addition to this formula for R, Mass implements a \$300 fixed-price auction each year, as a form of 'price floor mechanism'.

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Some promising ideas, but details are tricky and more work on understanding and modeling the resulting price dynamics is crucial!