Understanding volatility dynamics in the EU-ETS Market

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Motivation

- Agents enter the market on a regular basis (short run) to optimize their allowances holdings:
  1. Authority must know how market **regulation** affects the **short-run price** (and volatility) dynamics.
     - Particularly relevant after EC's publication of the intension of creating a "market stability reserve" to stabilize price (Pizer, 2002).
  2. Firms need an accurate **measurement** of market risk as a key factor for portfolio management and hedging:
     - allow firms to realize efficient **trading** strategies and to take informed **investment** decisions.
- Tradable emission permit markets were created based on the principle that they make it possible to achieve the pollution control target cost-efficiently (Montgomery, 1972):
  - analysis refers to equilibrium prices (long run) and the way these are determined by market regulation.

Data and Modelling Strategy

- **Data**: we analyze Phase II and III short term price and volatility dynamics
  1. Before 01/08: daily December 2008 EUA futures prices traded in ICE since Apr 22, 2005.
  2. After 01/08: using front contract price (December) until May 31, 2013- the **underlying contract** can be used for compliance.
- Benchmark **model**: model returns within a standard ARMA-GARCH framework (fundamentals: Brent, NGas, Coal, Electricity, extreme temp).
  - Failure of the implied standard Gaussianity assumption (Pearson goodness-of-fit test rejected).
    - **Problem**: excess kurtosis (and skewness) due to the presence of a number of level and volatility outliers, i.e. extremely large returns.

Stylized facts and Related Literature

- EUA returns cannot be modeled with the standard approach:
  - Paolella and Taschini (2006) use three-regime mixture of normals (mutually exclusive);
  - Benz and Trück (2009) use a Markov switching model.
- Using Doornik and Ooms (2005) we detect jumps in EUA returns and volatility
  - Conservative technique that detects few outliers but allows us to realize that jumps may be caused by:

  1. the daily relative change in volume;
  2. changes in the regulatory environment due to EC's announcements regarding:
     - Phase II NAPs;
     - Phase III global cap;
     - Auction regulation.
- Our approach -> Bernoulli mixture of normals: extremely flexible, parsimonious and relatively simple model & Provides insights on the occurrence and economic interpretation of jumps.

Bernoulli Mixture

The procedure is based on the use of a GARCH-type model with mixed innovations to fit an **underlying price process** combined with an **additive jump component** (occurs w/a certain **probability** λ).

$$\begin{array}{ll} r_t = \mu_t + \sigma_t z_t & \text{with probability } 1-\lambda \\ r_t = \underbrace{\mu_t + \sigma_t z_t}_{\textit{continuous comp.}} + \underbrace{\boldsymbol{\tau} + \delta z_t^*}_{\textit{additive jump comp.}} & \text{with probability } \lambda \end{array}$$

that is

$$\begin{array}{rcl} r_t & = & \mu_t + \lambda\boldsymbol{\tau} + \varepsilon_t; \\ \varepsilon_t & \mid & \Omega_{t-1} \sim (1-\lambda)N(-\lambda\tau, \sigma_t^2) + \lambda N(\tau - \lambda\tau, \sigma_t^2 + \delta^2); \\ \lambda & = & 1 - (1 + \exp(\gamma_0 + \Sigma_i \gamma_i x_{it-1}))^{-1} \end{array}$$

- μ_t and σ_t^2 represent the mean and variance of the process;
- τ and δ^2 mean and variance of the jump component;
- z_t and z_t^* are *iid* $N(0,1)$;
- Each distribution in the mixture represents a regime & the mixing law gives the probability of each regime.

ARMAX-GARCH

- Given the ARMAX-GARCH the mean and variance in the previous mixture are:

$$
\begin{aligned}
\mu_t &= \beta X_{t-1} + \sum_{i=1}^{m} \varphi_i r_{i-1} + \sum_{i=1}^{n} \psi_i \varepsilon_{t-1}; \\
\sigma_t^2 &= \mathbf{c} + \sum_{i=1}^{p} \mathbf{a}_i \varepsilon_{t-1}^2 + \sum_{j=1}^{q} \mathbf{b}_j \sigma_{t-j}^2 .
\end{aligned}
$$

- We consider lagged values of the exogenous variables to make the model completely forecastable.

Results last specification B.01/08

Before 01/08

Param.	Model 4	Param.	Model 4	Param.	Stat	p-val
γ_0	**−2.739**	β_1	**0.117**	*skew*	−0.214	0.02
	(0.370)		(0.043)	*kurt*	0.557	0.00
γ_{vol}	**2.042**	β_{oil}	**0.081**	BDS_{iid}	0.430	0.66
	(0.894)		(0.044)	$P(30)_{gof}$	32.34	0.00
γ_{news}	**0.806**	c	**0.310**			
	(0.392)		(0.107)			
τ	−0.682	a	**0.122**			
	(0.973)		(0.029)			
δ^2	**38.87**	b	**0.771**			
	(6.657)		(0.045)			
β_0	**0.213**	LLF	−1587.9			
	(0.132)					

Notes: Parameters significant at 10% in bold.

Results last specification A.01/08

After 01/08

Param.	Model 4	Param.	Model 4	Param.	Stat	p-val
γ_0	**−4.194**	β_{gas}	**−0.069**	*skew*	−0.078	0.24
	(0.426)		(0.018)	*kurt*	0.258	0.04
γ_{vol}	−0.387	β_{coal}	**−0.061**	BDS_{iid}	1.034	0.34
	(1.137)		(0.026)	$P(30)_{gof}$	25.13	0.02
γ_{news}	**2.292**	c	**0.051**			
	(0.999)		(0.020)			
τ	−1.110	a	**0.088**			
	(2.513)		(0.012)			
δ^2	**107.94**	b	**0.897**			
	(27.02)		(0.013)			
β_1	**0.046**	LLF	−3261.9			
	(0.024)					

Notes: Parameters significant at 10% in bold.

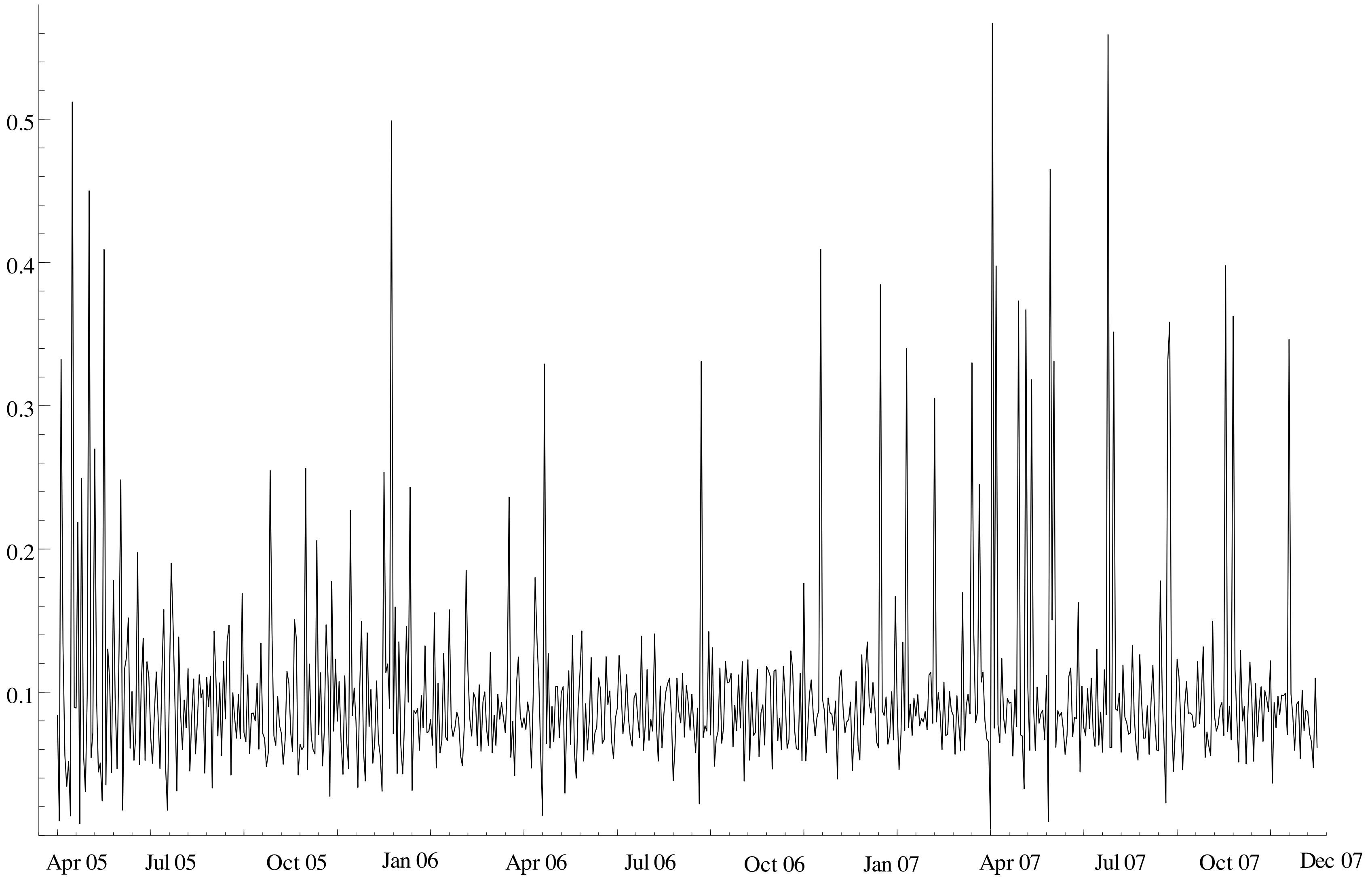
Jump determinants: Volume

- Before 01/08 we detect a destabilizing effect of large incoming volumes, which translate into sudden volatility movements on prices (this is captured by the large value of δ^2 which is 38.87).
- Possible causes:
  - **concentration** of the EU-ETS market among few leading players, the relatively low number of market transactions, the lack of transparency and discontinuous flow of information (Benz and Hengelbrock, 2008);
  - Gabaix et al. (2006): spikes in returns can be motivated by trades placed by large investors in relatively **illiquid markets**, even in the absence of important news about fundamentals.
- No longer significant After 01/08: the market has developed.

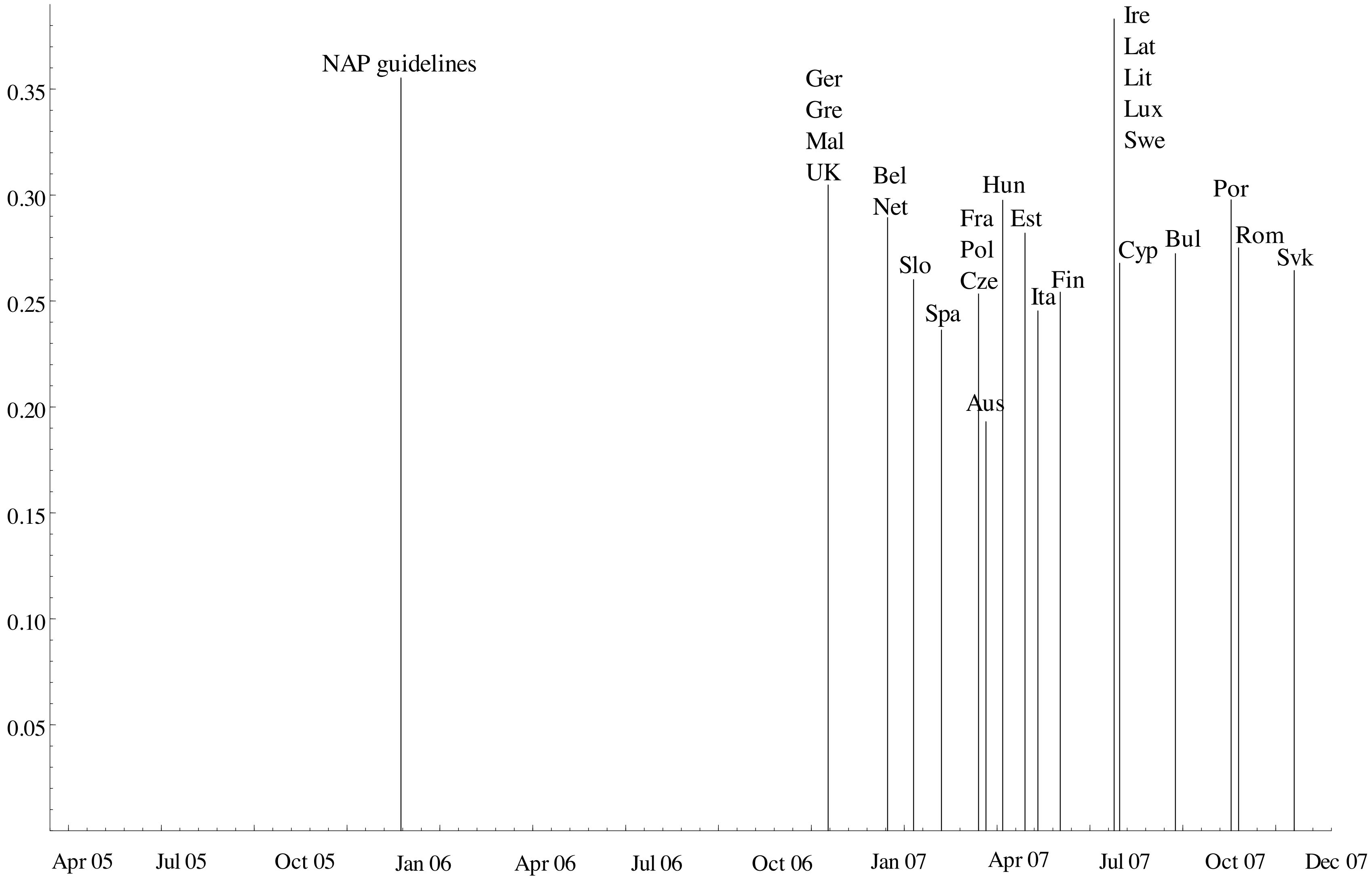
Jump determinants: EC announcements

- Before 01/08 announcements concerning the NAPs for Phase II induce jumps and tend to increase volatility.
    - Interpretation? Unexpected relative **scarcity** of EUA for Phase II (adopted NAPs sensibly more restrictive than the target proposed by member States)
    - Probability of being in the high volatility regime varies between 0.57 and 0.005 with an average jump probability of 0.06.
    - **Average marginal contribution** of announcements to the jump probability is **24%**.
- After 01/08 announcements concerning auction's regulation as well as the global cap for Phase III still induce jumps and tend to increase volatility.
    - Interpretation? Still some **uncertainty** on how the market will evolve.
    - Probability of being in the high volatility regime varies between 0.19 and 0 with an average jump probability of 0.15.
    - Average marginal contribution of announcements to the jump probability is just **14%**.

Time varying jump probability B.01/08



Announcement's marginal contribution to jump probability B.01/08



Concluding Remarks

- We provide a way to adequately represent EUA return and volatility dynamics.
- We model outliers in a non standard and parsimonious way and we detect that:
  - EC announcements increase the probability of being in the high volatility regime;
  - Before Jan. 08 large incoming volumes have a destabilizing effect and translate into sudden and large volatility movements but no longer the case After Jan. 08.

A highly volatile market would fail to give the right incentives for environmental innovation and pollution reduction: our result suggests that the authority faces a trade off between providing information effectively and promoting market efficiency.

Assessing the Implementation of the Market Stability Reserve

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Motivation: what is the MSR?

- Regulatory response to low expectations regarding the future scarcity of permits:
  - **Economic crisis**, depressed output and therefore demand for emission permits. As an example, production in the **steel industry declined by 28% from 2008 to 2009** (Eurostat, 2013).
  - Free allocated allowances banked.
- 24th February 2015 the European Parliament´s Environment Committee supported by 57 to 10 the proposal put forward last February by the European Commission to annually remove ¨permits in circulation¨ based on certain trigger thresholds as from December 2018.
- Additionally, the 900 million tons being withheld during 2014-2016 (backloading) could be kept in the Reserve.

Assessment of the MSR design

- We build a microeconomic model (including the polluting output market) that captures the actual design of the MSR:
    - **Endogenous withdrawal rule**: if permits in circulation higher than a threshold a portion is placed in the reserve (starting in Dec 2018 if allowances in circulation per year are $\geqslant$ 833 million, 12% are placed in the reserve)
    - **Exogenous rule**: MSR reinjection (if the allowances in circulation are below 400 million, 100 million are released from the reserve) or like backloading (i.e. withdrawal of a fixed amount).
        - allowances in circulation: allowances issued minus total emissions from 2008 until the year in question (and minus the number of allowances already in the stability reserve) i.e. banking.

Related literature and other experiences

- **"Safety valve"**, initially suggested by Roberts and Spence (1976) and later developed in the context of climate policy by Pizer (2002): a cap-and-trade system is coupled with a price ceiling.
  - As long as the allowance price is below the safety-valve price, this hybrid system acts like cap-and-trade, with emissions fixed but the price left to adjust. Instead, **when the safety-valve price is reached the system behaves like a tax**, fixing the price but leaving emissions to adjust.
  - Philibert (2008) and Burtraw, et al. (2009): symmetric safety valve, also known as a **price collar**, which would limit price volatility on both the upside and the downside.
  - Fell and Moregerstern (2010) introduce **uncertainty** and couples the collar mechanisms to restrictions on banking and borrowing: a price collar can achieve costs almost as low as a tax but with less emissions variation.
- Cost Containment Reserve (CCR) introduced in RGGI in 2014 & Allowance Price Containment Reserve (APCR) in California-Quebec in 2013 but under the cap.

Benchmark model

- 3-period model, n symmetric firms subject to TEP compete in quantities with profits at each t:

$$\pi_{i,t} = (b_t - d_t \sum_{i=1}^{n} q_{i,t})q_{i,t} - c_t q_{i,t} - \sigma_t \left(e_t q_{i,t} + z_{i,t} - \sum_{1}^{t-1} z_{i,t} \right)$$

$$s.t. \sum_{i=1}^{n} \left(e_t q_{i,t} + z_{i,t} - \sum_{1}^{t-1} z_{i,t} \right) \leq A_t + a$$

where $\left(b_t - d_t \sum_{i=1}^{n} q_{i,t}\right)$ is the inverse demand, c_t is the constant marginal costs, σ_t is the permits price, e_t is the polluting intensity of output, $z_{i,t}$ is private banking, A_t is the amount of permits auctioned by the authority and

$$a = \begin{cases} \underline{a} \text{ if } \sum_{i=1}^{n} \sum_{1}^{t-1} z_{i,t} < \underline{R}, \\ 0 \text{ if } \underline{R} \leq \sum_{i=1}^{n} \sum_{1}^{t-1} z_{i,t} \leq \overline{R}, \\ -\overline{a} \text{ if } \sum_{i=1}^{n} \sum_{1}^{t-1} z_{i,t} > \overline{R}, \\ \text{or} \\ -\zeta \sum_{i=1}^{n} \sum_{1}^{t-1} z_{i,t} \quad \text{if } \sum_{i=1}^{n} \sum_{1}^{t-1} z_{i,t} > \overline{R}. \end{cases}$$

Restrictions in the case of permits withdrawal

Last two cases in the constraint i.e.:

$$\sum_{i=1}^{n}\left(e_t q_{i,t} + z_{i,t} - \sum_{1}^{t-1} z_{i,t}\right) \leq A_t + a$$

$$a = \begin{cases} -\overline{a} \text{ if } \sum_{i=1}^{n}\sum_{1}^{t-1} z_{i,t} > \overline{R} \text{ (exogenous)} \\ -\zeta \sum_{i=1}^{n}\sum_{1}^{t-1} z_{i,t} \quad \text{if } \sum_{i=1}^{n}\sum_{1}^{t-1} z_{i,t} > \overline{R} \text{ (endogenous)} \end{cases}$$

$$\begin{array}{cc} t & \textit{Exogenous} \\ 1 & \sum_{i=1}^{n}\left(e_1 q_{i,1} + z_{i,1}\right) \leq A_1 \\ 2 & \sum_{i=1}^{n}\left(e_2 q_{i,2} + z_{i,2} - z_{i,1}\right) \leq A_2 - \overline{a} \\ 3 & \sum_{i=1}^{n}\left(e_3 q_{i,3} + z_{i,3} - z_{i,2} - z_{i,1}\right) \leq A_3 - \overline{a} \end{array}$$

$$\begin{array}{cc} t & \textit{Endogenous} \\ 1 & = \\ 2 & \sum_{i=1}^{n}\left(e_2 q_{i,2} + z_{i,2} - z_{i,1}\right) \leq A_2 - \zeta \sum_{i=1}^{n} z_{i,1} \\ 3 & \sum_{i=1}^{n}\left(e_3 q_{i,3} + z_{i,3} - z_{i,2} - z_{i,1}\right) \leq A_3 - \zeta \sum_{i=1}^{n}\left(z_{i,2} + z_{i,1}\right)) \end{array}$$

with $z_{i,3} = z_{i,2} + z_{i,1}\ \forall i$.

Solving the model

- Firms maximize intertemporal profits (Cournot competition):

$$\Pi_i = \sum_{1}^{3} \frac{\pi_t}{(1+r)^{t-1}}$$

- Two-step-solution:

1. We find the symmetric Nash equilibrium in quantities for each period;
2. We find optimal banking strategies from maximizing intertemporal profits, i.e. $\frac{\partial \Pi_i}{\partial z_{i,1}} = 0$, which gives intertemporal arbitrage:

$$\sigma_1 = \frac{\sigma_2}{(1+r)} = \frac{\sigma_3}{(1+r)^2}$$

This can be done since firms are non-strategic in the permits market.

- We check ex post positivity constraints and threshold restrictions that define the functioning of the MSR.

Equilibrium exogenous rule

(with parameters constant over time and withdrawal case)

$$\begin{aligned}
q^*_{1,\overline{a}} &= \frac{2\left(A-\overline{a}\right)}{ne\left(1+r\right)^2}+\frac{\left(r^2+2r-1\right)\left(b-c\right)}{\left(n+1\right)d\left(1+r\right)^2}, \\
z^*_{1,\overline{a}} &= \frac{\left(r^2+2r-1\right)A+2\overline{a}}{n\left(1+r\right)^2} \\
&\quad -\frac{\left(r^2+2r-1\right)\left(b-c\right)e}{\left(n+1\right)d\left(1+r\right)^2}, \\
\sigma^*_{3,\overline{a}} &= \frac{\left(b-c\right)}{e}-\frac{\left(n+1\right)\left(A-\overline{a}\right)d}{ne^2}
\end{aligned}$$

Discussion exogenous case

- Quantity produced depends on permits availability: clearly seen in $q^*_{3,\overline{a}} = \frac{A-a}{ne}$ or $\sum_{i=1}^{n} eq^*_{3,\overline{a}} = A - a$ but also in each period if we reconstruct the restriction by substituting equilibrium banking and production.
- In the exogenous rule scenario, **the interest rate must be sufficiently low** for firms to be interested in banking. In particular, $z_{2,i}$ and $z_{1,i}$ are positive if and only if $r < \widetilde{r}$ (under our hypothesis of linear demand and costs, $\widetilde{r} \rightsquigarrow 0.28$).
    - Standard result: If the interest rate is low enough firms prefer to be less constraint in the future and bank permits.

Equilibrium endogenous rule

$$
\begin{aligned}
q_{1,\zeta}^{*} &= \frac{2A\left(1-\zeta\left(3-\zeta\right)\right)}{ne\Psi}+\frac{\left(b-c\right)\left(r^{2}+\left(2-\zeta\right)r+\zeta-1\right)}{\left(n+1\right)d\Psi}, \\
z_{1}^{*} &= \frac{A\left(r^{2}+\left(2-\zeta\right)r+1-\zeta+2\alpha\left(\zeta-\alpha\right)\right)}{n\Psi} \\
&\quad -\frac{(b-c)e\left(r^{2}+\left(2-\zeta\right)r-1+\zeta\right)}{\left(n+1\right)d\Psi} \\
\sigma_{3}^{*} &= \frac{\left(1+r\right)^{2}}{e\Psi}\left(\left(\zeta^{2}-3\zeta+1\right)\left(b-c\right)\right) \\
&\quad -\frac{\left(1+r\right)^{2}}{e\Psi}\left(\frac{\left(n+1\right)\left(1-\zeta-\left(\left(2-\zeta\right)\zeta\right)\right)Ad}{e}\right)
\end{aligned}
$$

where

$$\Psi=1-\zeta\left(5-2\zeta\right)+\left(2-\zeta\right)r+r^{2}$$

Discussion endogenous case

- Quantity produced in each period again depends on permits availability, that is on ζ.
- For $0 < \zeta < 1$, there is always a pair (ζ, r) such that firms are interested in banking.
  - INTERPRETATION: the withdrawal rule impacts the **no arbitrage condition** modifies the standard result.
  - This **shows the interaction** between the MSR rule and firm´s valuation of future scarcity.

Introducing uncertainty

- We assume that the demand constant in period 2 is still **b** with **probability** λ or $\mathbf{b_m}$ with a probability $(1-\lambda)$.
- We solve the model by maximizing *expected* discounted profits that in the exogenous case gives:

$$
\begin{aligned}
q^*_{1,\bar{a}} &= \frac{2\left(A-\bar{a}\ \right)}{n\left(1+r\right)^2 e} + \frac{\left(r^2+2r-1\right)\left(\mathbf{b}\boldsymbol{\lambda}+\mathbf{b}_m(\mathbf{1}-\boldsymbol{\lambda})-c\right)}{\left(n+1\right)\left(1+r\right)^2 d}, \\
z^*_{1,\bar{a}} &= \frac{\left(r^2+2r-1\right)A+2\bar{a}}{n\left(1+r\right)^2} - \frac{\left(r^2+2r-1\right)\left(\mathbf{b}\boldsymbol{\lambda}+\mathbf{b}_m(\mathbf{1}-\boldsymbol{\lambda})-c\right)}{\left(n+1\right)\left(1+r\right)^2 d} \\
\sigma^*_{3,\bar{a}} &= \frac{\left(\mathbf{b}\boldsymbol{\lambda}+\mathbf{b}_m(\mathbf{1}-\boldsymbol{\lambda})-c\right)}{e} - \frac{\left(n+1\right)\left(A-\bar{a}\right)d}{ne^2}
\end{aligned}
$$

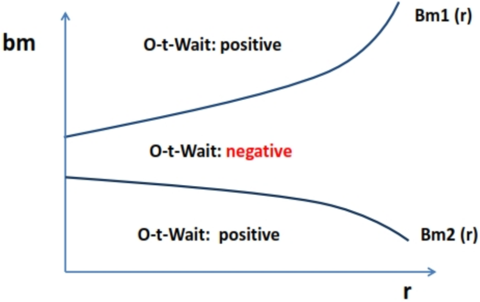
Option to wait

- We consider the decision on banking as a partially reversible investment
  - firms can decide to wait to bank as from period 2

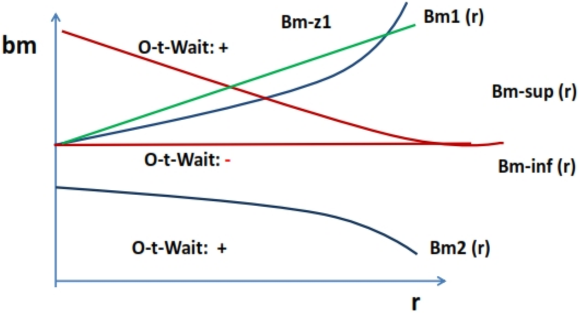
- $OW = E(\Pi / z^{*}_{1,\bar{a}} = 0) - E(\Pi)$
  - Expected discounted profit under the assumption $z^{*}_{1,\bar{a}} = 0$ - expected discounted profit
  - Exogenous case (withdrawal or reinjection) OW_a
  - Endogenous case OW_ζ

OW: quadratic function of bm (exo & endo)

- Simulation: OW for $b = 2, r = (0, 0.28), bm = (1.8, 3)$



OW: interaction with constraints on the parameters



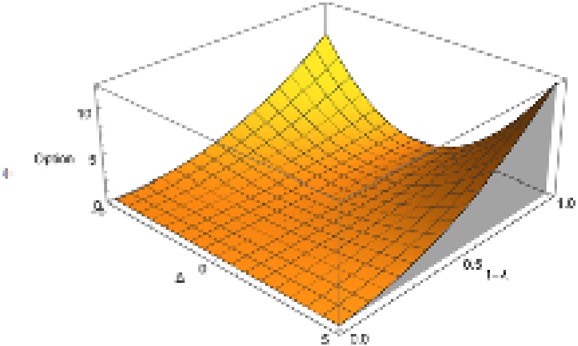
The MSR "generates" an option to wait

- In the exogenous case OW_a is always positive if permits are reinjected in period 2 (not defined for withdrawal).

- In the endogenous case OW_ζ is always positive.
    - There is a profit gain to wait and bank only after knowing the resulting interaction between the MSR and the demand shock.

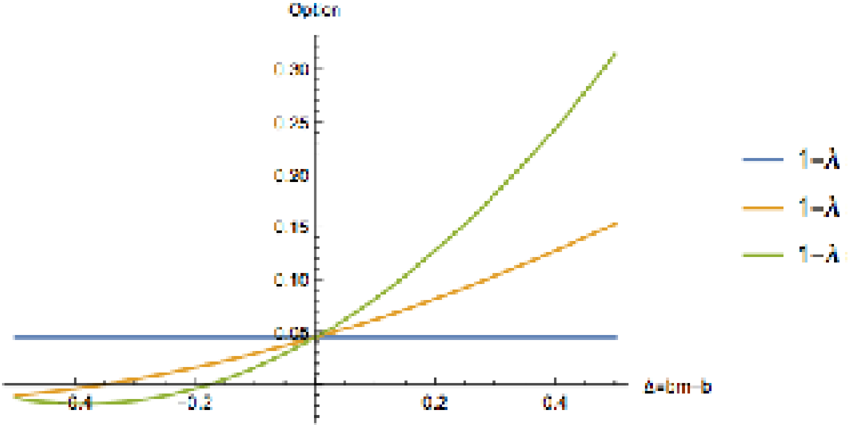
OW: comparative statics in the endogenous case (I)

- as a function of $b_m - b = \Delta$ and the probability of a demand shock of size Δ *i.e.* $(1 - \lambda)$



OW: comparative statics in the endogenous case (II)

- as a function of $b_m - b = \Delta$ and for different values of $(1 - \lambda)$ (1 if blue, 0.5 if yellow, 0 if green)



OW: comparative statics in the endogenous case (III)

- $\frac{\partial OW_\zeta}{\partial(1-\lambda)} > 0$: the higher the uncertainty the higher the incentive to wait but this interacts with the importance of demand shock $b_m - b = \Delta$
    - for $\Delta < 0$ the OW_ζ higher as $(1-\lambda)$ high: waiting is more profitable as the probability of a recession increases
    - for $\Delta > 0$ the OW_ζ higher as $(1-\lambda)$ low: waiting is more profitable as the probability of an economic boom decreases
    - the previous interaction depends on the relative scarcity of permits in period 2 as compared to what the MSR withdraws from what has been banked.

Conclusion

- THE RULE MATTERS: Contrary to what we could expect the fact of considering an endogenous way of withdrawing permits does not simply crowds out private banking but instead interacts with it affecting permit prices and production as well as banking incentives.

- OW ANALYSIS WORTHY: When modeling uncertainty we find that banking can be considered as a partially reversible investment and how the profitability of waiting depends on the MSR mechanism.
  - Further work: investment in abatement technology