Output-based allocations in pollution markets with uncertainty and self-selection

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Motivation

- EU-ETS pillar of the EU Climate Policy (50% EU CO2);
- Carbon markets spreading (California-Quebec-Ontario, RGGI, China, New Zealand);
- Two critical issues for their design:
  - how to allocate permits (auctions, grandfathering, output-based)
  - how to deal with carbon price variations (price corridor, market stability reserve).
- Both issues are linked: Could free allocations be used to deal with price volatility?

Motivation for output based allocations (OBAs)

- OBAs receiving increasing attention: California, EU, New Zealand
- permits are allocated according to firms' output, so
  - they represent a production subsidy, and
  - total number of permits in the market no longer fixed
- two reactions
  - subsidy usually justified by carbon leakage or market power
  - in California the cap is kept fixed (adjust grandfathered or auctioned allocations)

Main results (plan of the talk)

- OBA need only be justified on demand and cost uncertainty (no need of leakage or market power)

- the overall permits cap should be flexible

- optimal OBA design solves a trade-off between output inefficiency and cap flexibility (keeping the permit price closer to marginal harm)

- the optimal OBA rate is increasing in sector (demand/supply) volatility

- self-selection problem: room for lobby and misreporting, but can solved with menus of lump-sum permits and OBA rates

- numerical simulations: gains from optimal OBA can be substantial

Literature

- prices vs quantities: Weitzman (1974), Roberts and Spence (1976)

- indexed (e.g., to GDP) allocation: Newell and Pizer (2008), Branger and Quirion (2014)

- intertemporal trading: Rubin (1996), Ellerman and Montero (2007)

- OBA and leakage: Fischer and Fox (2007, 2012), Monjon and Quirion (2011), Meunier et al. (2014)

- OBA and market power: Fischer (2011), Fowlie et al. (2015)

- pollution regulation under asymmetric information: Spulber (1988), Montero (2008), Martimort and Sand-Zantman (2016)

Model - One sector

- consumers demand output q according to $P(q,\theta) = S'(q,\theta)$, where θ is a demand shock

- output is supplied by a sector with a large number of price-taking firms

- sector produces output q and pollution e according to $C(q,e,\eta)$, where η is a supply shock

- environmental harm is $D(e)$, so welfare in a given state θ and η is

$$W(q,e,\theta,\eta) = S(q,\theta) - C(q,e,\eta) - D(e)$$

- q and e are equilibrium variables that depends on the environmental policy

OBA regulation and equilibrium

- An OBA scheme is defined as $\{\bar{e}, \alpha\}$, where

- $\bar{e}$ is the number of permits to be auctioned off and α is the OBA rate, so total emissions (the cap) are

$$e = \bar{e} + \alpha q$$

- Timing: (1) the regulator picks $\bar{e}$ and α, (2) shocks θ and η are realized, and (3) firms choose q and e so as to maximize

$$\pi = pq - C(q, e, \eta) - re + \alpha rq$$

where r is the permits price and $p = P(q, \theta)$ the output price

- in equilibrium

$$p = C_q - \alpha r \text{ and } r = -C_e$$

Proposition 1

- Consider a permits market with $\alpha = 0$ and $\bar{e}$ such that $D'(\bar{e}) = \mathbb{E}[r]$. If in that market we observe a positive correlation between permit prices and output, then it is optimal to introduce a positive OBA rate, $\alpha > 0$.

- More precisely, the optimal OBA scheme $\{\bar{e}, \alpha\}$ in that case satisfies the pair of equations

$$\mathbb{E}[r - D'(e)] = \alpha \mathbb{E}[D'(e) q_{\bar{e}}]$$
$$\text{cov}\left(\frac{\partial W}{\partial \bar{e}}, q\right) = \alpha \mathbb{E}\left[D'(e) \frac{-C_e}{\delta_2}\right]$$

where $\delta_2 = -P_q + C_{qq} + 2\alpha C_{qe} + \alpha^2 C_{ee} > 0$.

Intuition for Proposition 1

- Suppose the regulator sets $\alpha = 0$, it is optimal to set $\mathbb{E}[r] = D'(\bar{e})$ and let permit prices move around $D'(\bar{e})$...

- the impact on (expected) welfare of introducing a very small OBA rate $\alpha \approx 0$

$$\tilde{W}_\alpha(\bar{e}, \alpha) = \mathbb{E}[-\alpha r q_\alpha + (r - D'(e))e_\alpha]$$

- the first term is the subsidy effect (always negative) and the second term is the flexibility effect

- since $e = \bar{e} + \alpha q$, $e_\alpha = q + \alpha q_\alpha$, so when $\alpha \approx 0$

$$\tilde{W}_\alpha(\bar{e}, \alpha = 0) = \mathbb{E}[(r - D'(\bar{e}))q] = \text{cov}(r, q)$$

- when cov$(r, q) > 0$:

- the gains from increasing pollution when prices are high (r_H) is greater than the losses of increasing pollution when prices are low (r_L), or

$$(r_H - D'(\bar{e}))q_H > (D'(\bar{e}) - r_L)q_L$$

(recall that $e_\alpha = q$)

- the result in Proposition 1 is very general
  - it still applies if the regulator implements a hybrid permit scheme with a price floor and ceiling
  - and it applies more so if we have multiple sectors

OBA in a hybrid scheme?

- Suppose the regulator follows Roberts and Spence (1976) auctions $\bar{e}$ and in addition:
  - let firms to buy extra permits at the price ceiling $\bar{r}$, and
  - is ready to buy permits from firms at the price floor $\underline{r}$
- this implies that $r(\theta, \eta) \in [\underline{r}, \bar{r}]$ for all θ, η
- is OBA still worth implementing, $\alpha > 0$, given that $\bar{e}$, $\bar{r}$ and $\underline{r}$ are optimally set?
- for simplicity, consider only demand shocks $\theta \in [\theta_{\text{min}}, \theta_{\text{max}}]$ which are distributed according to the cdf $F(\theta)$

- ...and ask the same question: does it pay to introduce a positive but arbitrarily small OBA rate?

- proceeding as before, the benefit of introducing an arbitrarily small OBA rate (**Proposition 2**)

$$\begin{aligned}\tilde{W}_\alpha(\alpha &= 0) = \int_{\theta_{\text{min}}}^{\underline{\theta}} (\underline{r} - D'(\theta))e_\alpha dF \\ &+ \int_{\underline{\theta}}^{\bar{\theta}} (r - D'(\bar{e}))q dF + \int_{\bar{\theta}}^{\theta_{\text{max}}} (\bar{r} - D'(\theta))e_\alpha dF\end{aligned}$$

- when demand and marginal costs are linear, $e_{\alpha\theta} = e_{\bar{r}\theta} = e_{\underline{r}\theta} = 0$, so we are left with the middle term, and

- ....$\tilde{W}_\alpha(\alpha = 0) > 0$ iff cov$(r, q) > 0$

Multiple sectors: A two-sector example

- two sectors $i = 1, 2$ (more precisely: many sectors of either type in equal proportions)

- large number of firms in each sector

- sectors take the permit price r as given

- linear marginal costs: $C(q) = q^2/2$

- no abatement technology: $e = q$

- environmental harm: $D(e) = he$

- linear demand and sector 2 more volatile than sector 1:

$$P_1 = a - q_1 + \theta_1$$
$$P_2 = a - q_2 + \theta_2$$

where

$$\mathbb{E}[\theta_i] = \mathbb{E}[\theta_i \theta_j] = 0$$
$$\mathbb{E}[\theta_i^2] = \sigma_i^2 > 0 \text{ and } \sigma_2 > \sigma_1$$

What is the optimal OBA design (Propositions 3 and 4)?

- the sector with higher volatility (sector 2) gets a larger OBA rate. The optimal OBA scheme $\{\bar{e}, \alpha_1, \alpha_2\}$ is given by

$$\alpha_1 \in [0, 1)$$
$$\frac{\alpha_2 - \alpha_1}{1 - \alpha_1} = 1 - \left[(\Delta^2 + 1)^{1/2} - \Delta\right] > 0$$
$$\bar{e} = \frac{1}{2}(a - h)(2 - \alpha_1 - \alpha_2)$$

  where $\Delta = [\sigma_2^2 - \sigma_1^2]/2h^2 > 0$.

- **intuition.** suppose $\alpha_1 = \alpha_2 = 0$: total output is fixed, $q_1 + q_2 = \bar{e}$, but it splits across sectors according to shocks

- this output adjustment leads to changes in permit prices r and, ultimately, to a covariance between permit prices and output in each individual sector

Self-selection problem

- Since sector profit is increasing in the OBA rate, sector 1 may pretend to be sector 2 (adverse selection problem) or lobby for the OBA rate of sector 2

- regulator can solve this self-selection problem with a menu of permit-allocation options:

$$\{\alpha_1, \hat{e}_1\} \text{ and } \{\alpha_2, \hat{e}_2\}$$

  where α_j is the OBA rate in option $j = 1, 2$ and $\hat{e}_j$ is the number of free lump-sum permits

- implementation of the optimal OBA scheme requires to satisfy

  1. budget balance: $\hat{e}_1 + \hat{e}_2 < \bar{e}$ and

2. self-selection:

$$\mathbb{E}[\pi_i(\theta_i, r, \alpha_i) + r\hat{e}_i] \geq \mathbb{E}[\pi_i(\theta_i, r, \alpha_j) + r\hat{e}_j]$$

for both $i = 1{,}2$ and where

$$\pi_i(\theta_i, r, \alpha) = \frac{1}{8}\left[a + \theta_i - (1 - \alpha)r\right]^2$$

is sector i's profit gross of (lump-sum) permit transfers for a given OBA rate α and permit price r

Sorting out sectors

- Which sector, 1 or 2, is willing to pay more for a marginal increase in the OBA rate?

$$\mathbb{E}\left[\frac{\partial \pi_2(\theta_2, r, \alpha)}{\partial \alpha}\right] - \mathbb{E}\left[\frac{\partial \pi_1(\theta_1, r, \alpha)}{\partial \alpha}\right] = \frac{1}{4}\mathbb{E}\left[r(\theta_2 - \theta_1)\right]$$

- Since sectors are price takers, using the equilibrium price when all other sectors are taking their equilibrium options

$$r = \frac{(1-\alpha_1)(a+\theta_1) + (1-\alpha_2)(a+\theta_2) - 2\bar{e}}{(1-\alpha_1)^2 + (1-\alpha_2)^2}$$

- for sector 2 to be willing to pay more:

$$\mathbb{E}\left[r(\theta_2 - \theta_1)\right] > 0 \Leftrightarrow (1-\alpha_2)\sigma_2^2 > (1-\alpha_1)\sigma_1^2$$

- this is not a standard "single-crossing property", as it depends on the regulatory design:
  - in the absence of OBA, more volatile sectors have a greater influence on permit price variations
  - but as these more volatile sectors get assigned higher OBA rates, their volatility is reduced, and hence, their influence on permit price variations
  - it is required then that the optimal OBA rates don't increase too fast
  - how likely? very much (**Proposition 5**)

$$a/3 > h > \sigma_1$$

Numerical exercises

- evaluate (welfare) gains from implementing OBA, three scenarios
  - fixed cap & no OBA (standard permit market)
  - fixed cap & OBA (EU-ETS proposal)
  - OBA and flexible cap (our proposal)
- illustrate the self-selection problem
- what if we add leakage?

Two-sector numerical exercise

- parameter values: $a = 1$, $h = 1/4$, $\sigma_1 = 0$ and $\sigma_2 \in [0, 1/2)$.

- first-best is to tax emissions (not feasible), so

$$r = h = 1/4$$

- (optimal) fixed-cap

$$\bar{e} = a - h = 3/4$$

so

$$\mathbb{E}[r] = \mathbb{E}\left[\frac{2a + \theta_2 - 2\bar{e}}{2}\right] = h = 1/4$$

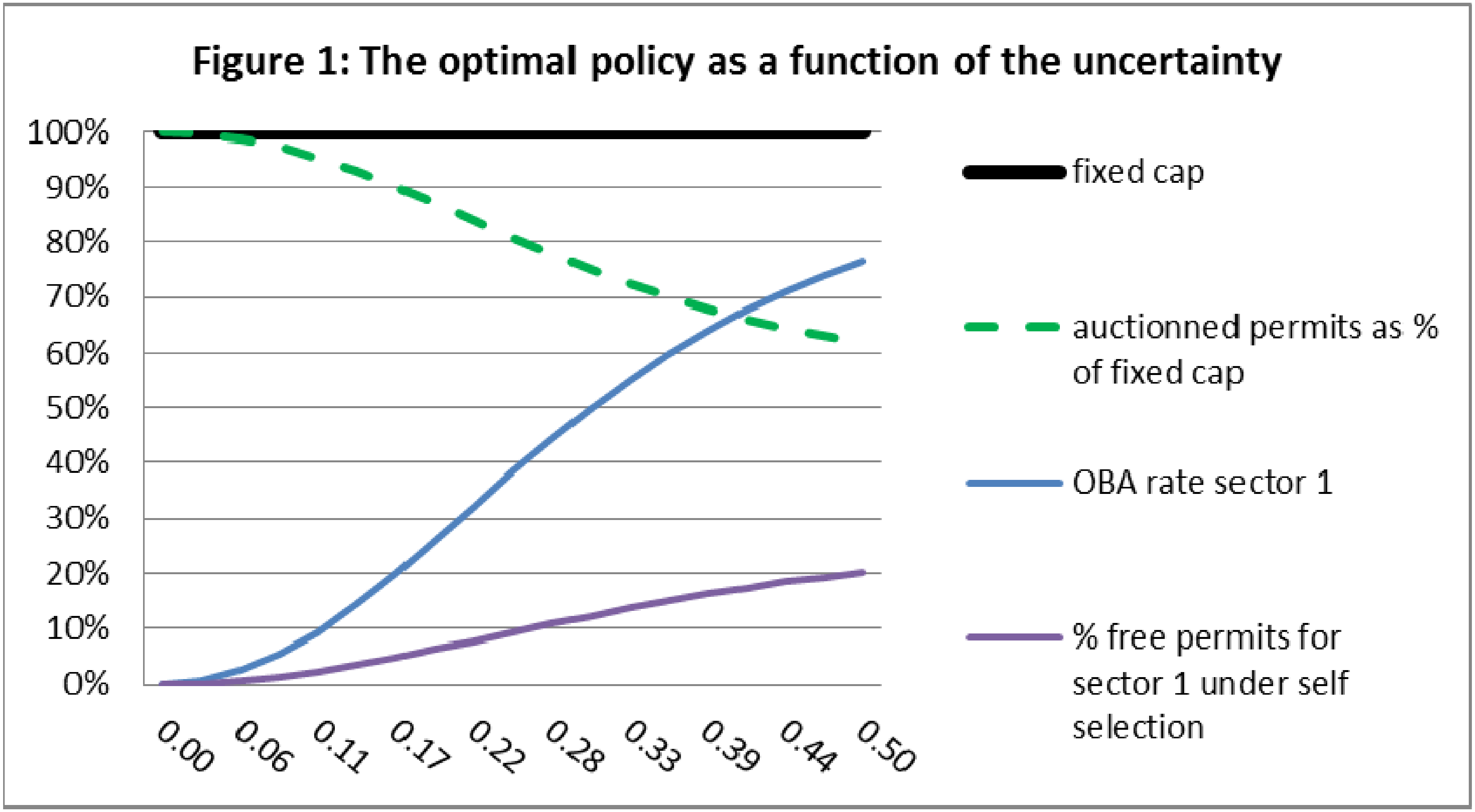


Figure 1: The optimal policy as a function of the uncertainty
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.00
0.06
0.11
0.17
0.22
0.28
0.33
0.39
0.44
0.50
fixed cap
auctionned permits as % of fixed cap
OBA rate sector 1
% free permits for sector 1 under self selection

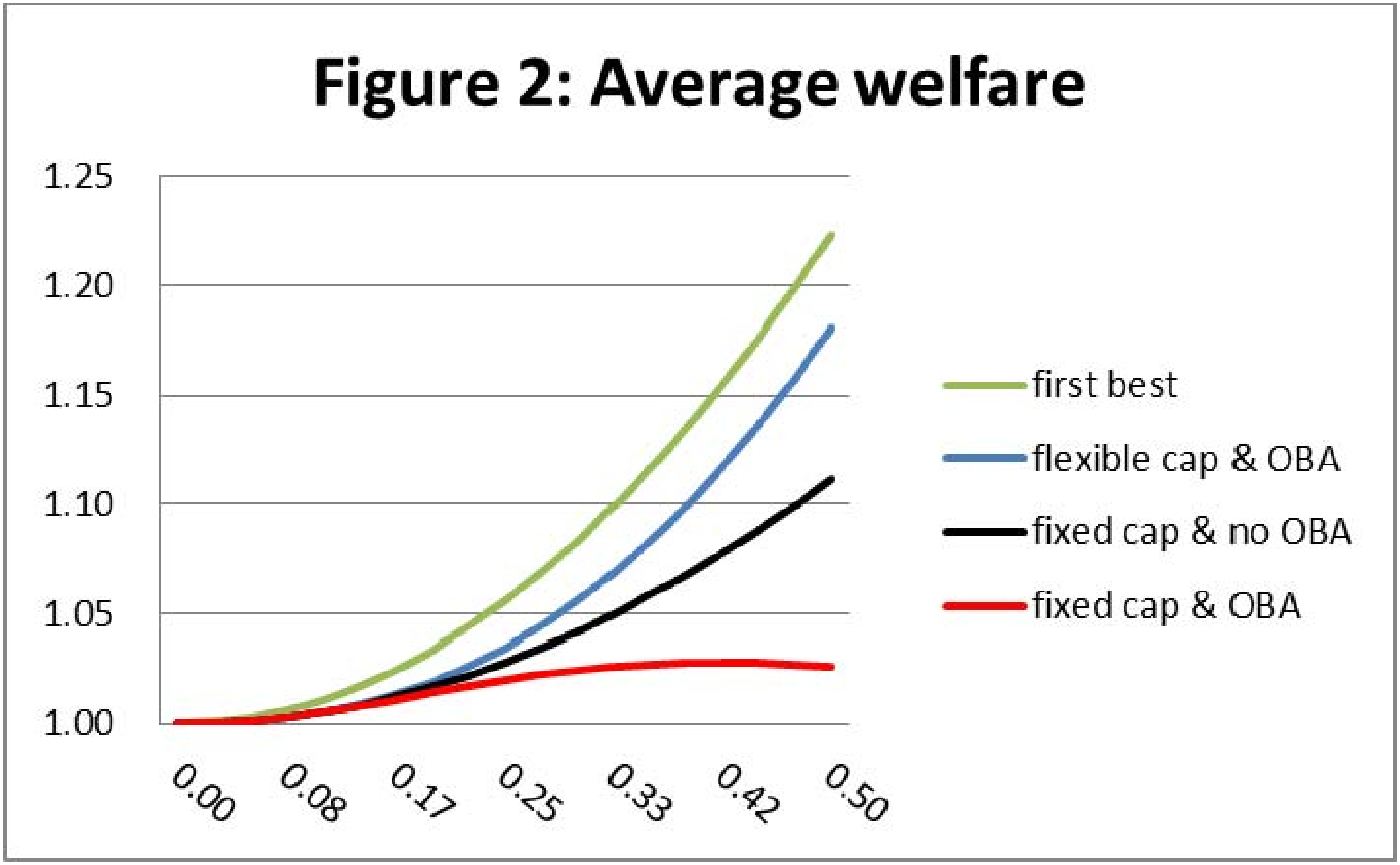


Figure 2: Average welfare
1.25
1.20
1.15
1.10
1.05
1.00
0.00
0.08
0.17
0.25
0.33
0.42
0.50
first best
flexible cap & OBA
fixed cap & no OBA
fixed cap & OBA

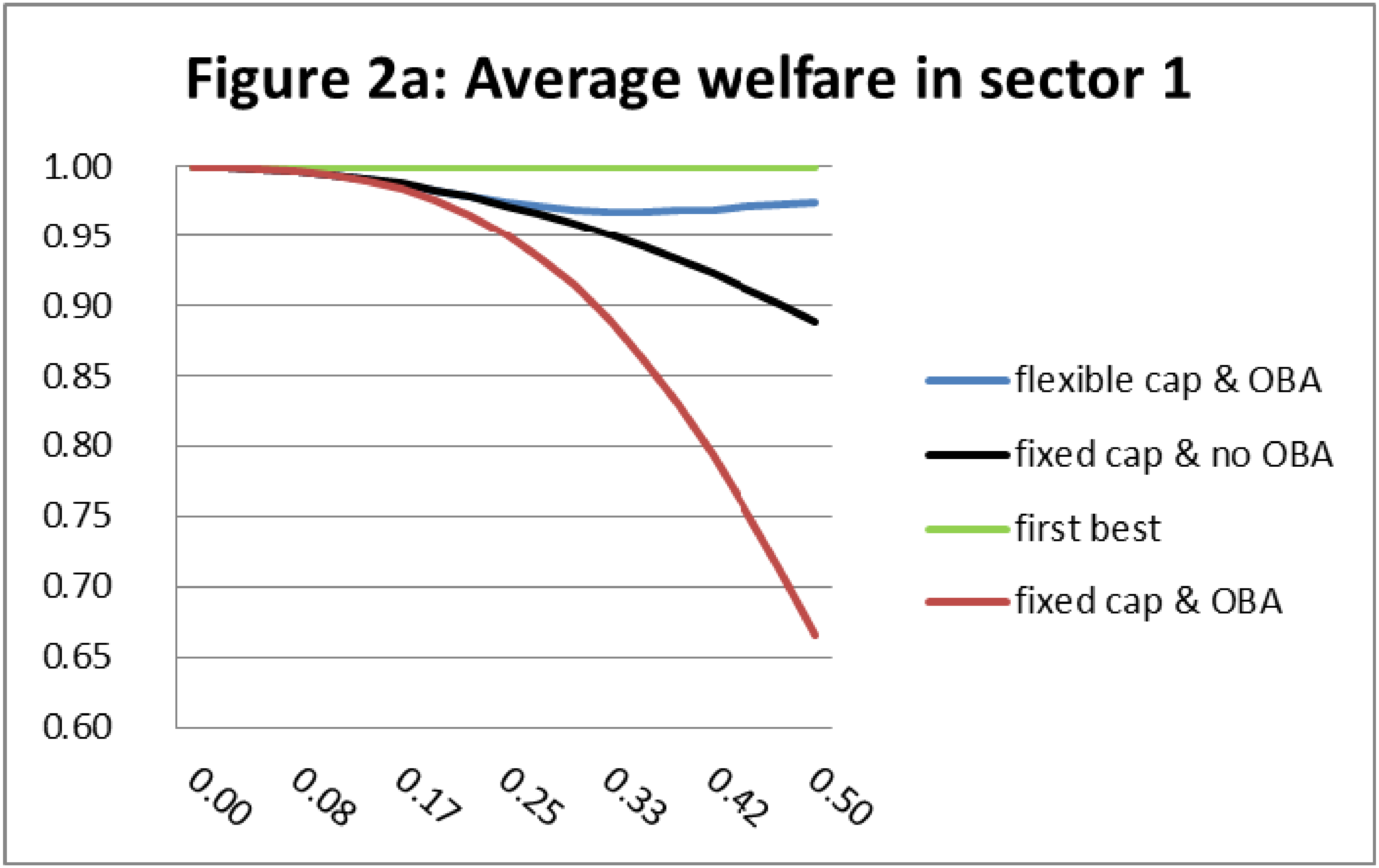


Figure 2a: Average welfare in sector 1
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.00
0.08
0.17
0.25
0.33
0.42
0.50
flexible cap & OBA
fixed cap & no OBA
first best
fixed cap & OBA

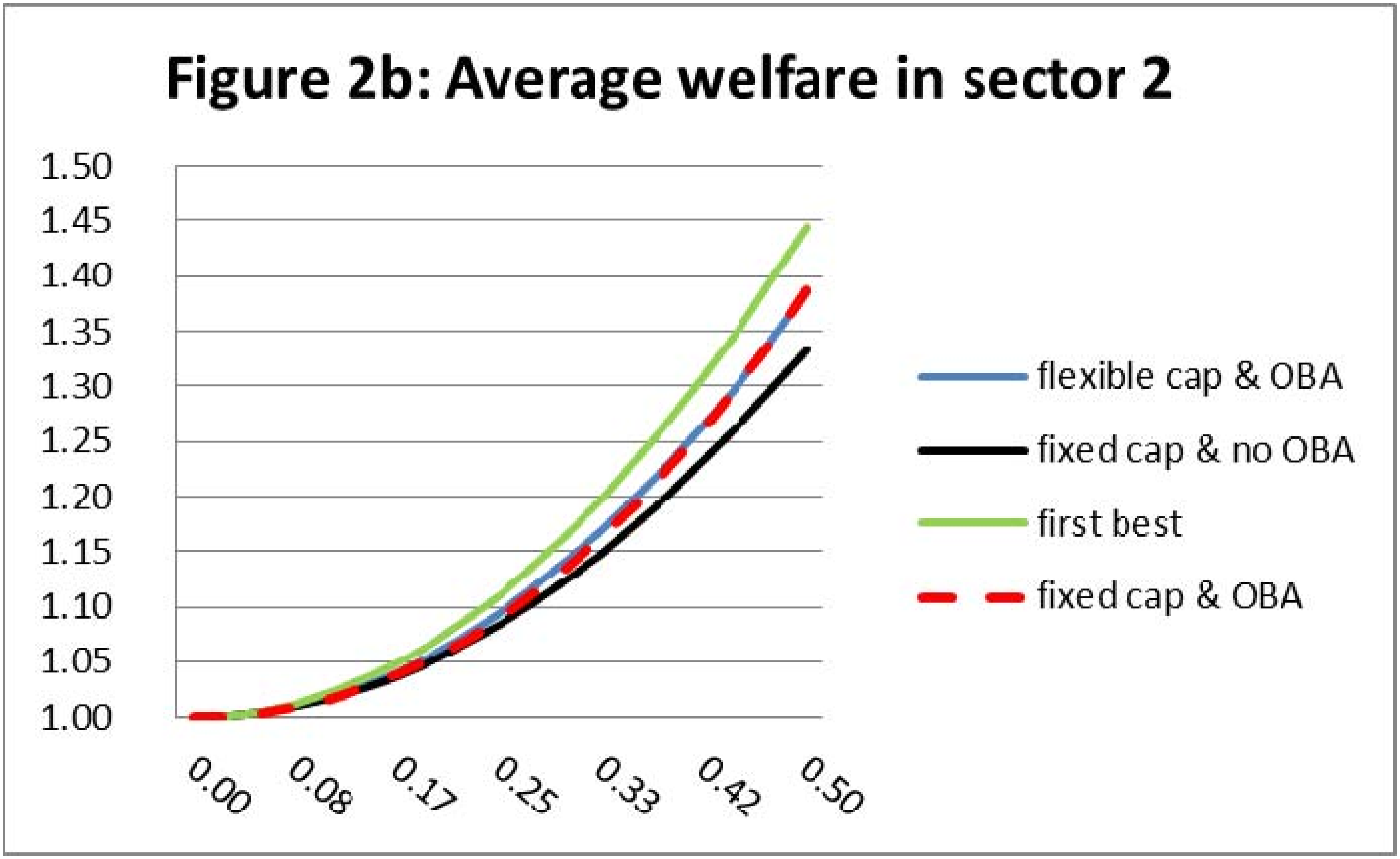


Figure 2b: Average welfare in sector 2
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.00
0.08
0.17
0.25
0.33
0.42
0.50
flexible cap & OBA
fixed cap & no OBA
first best
fixed cap & OBA

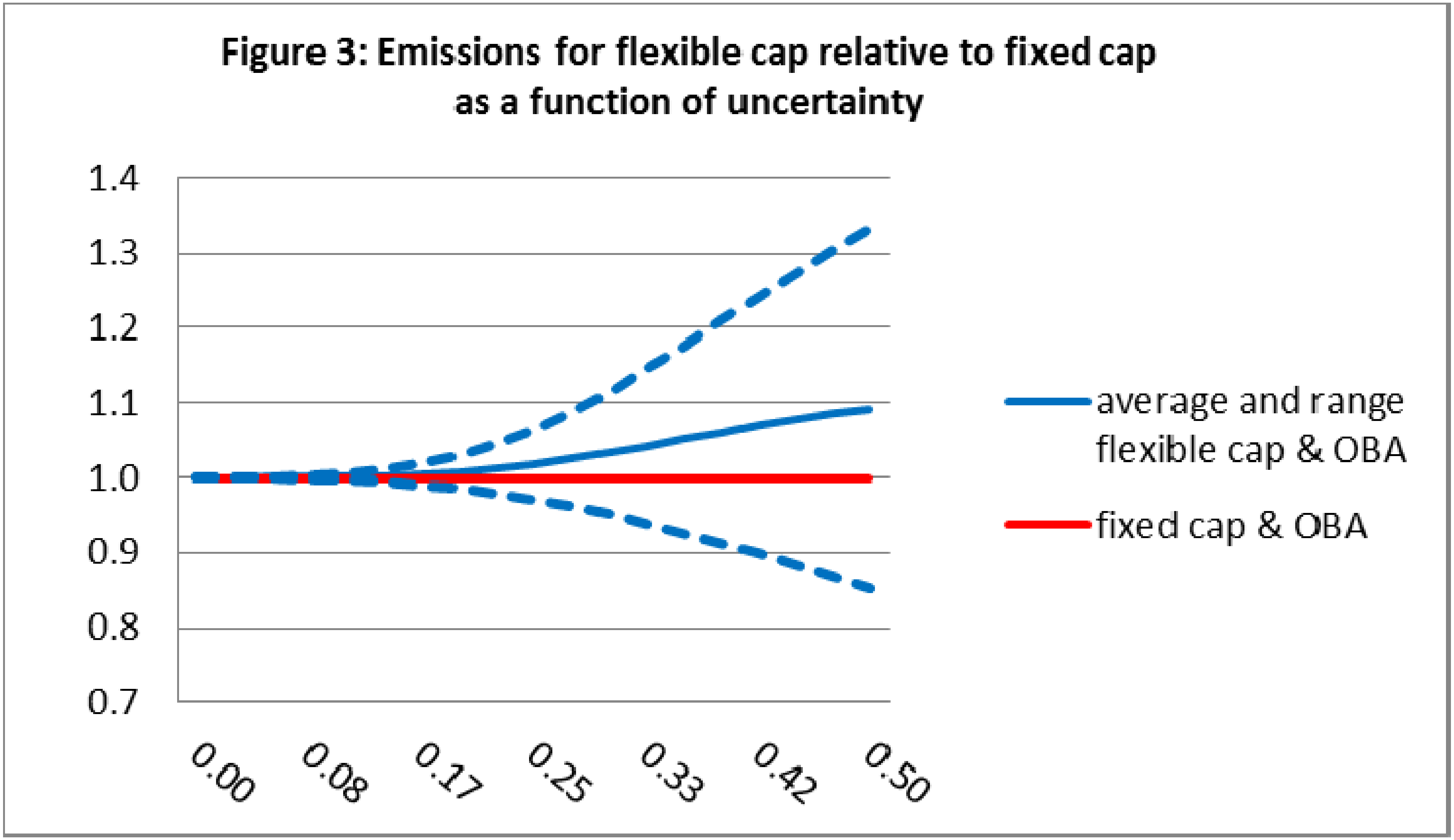
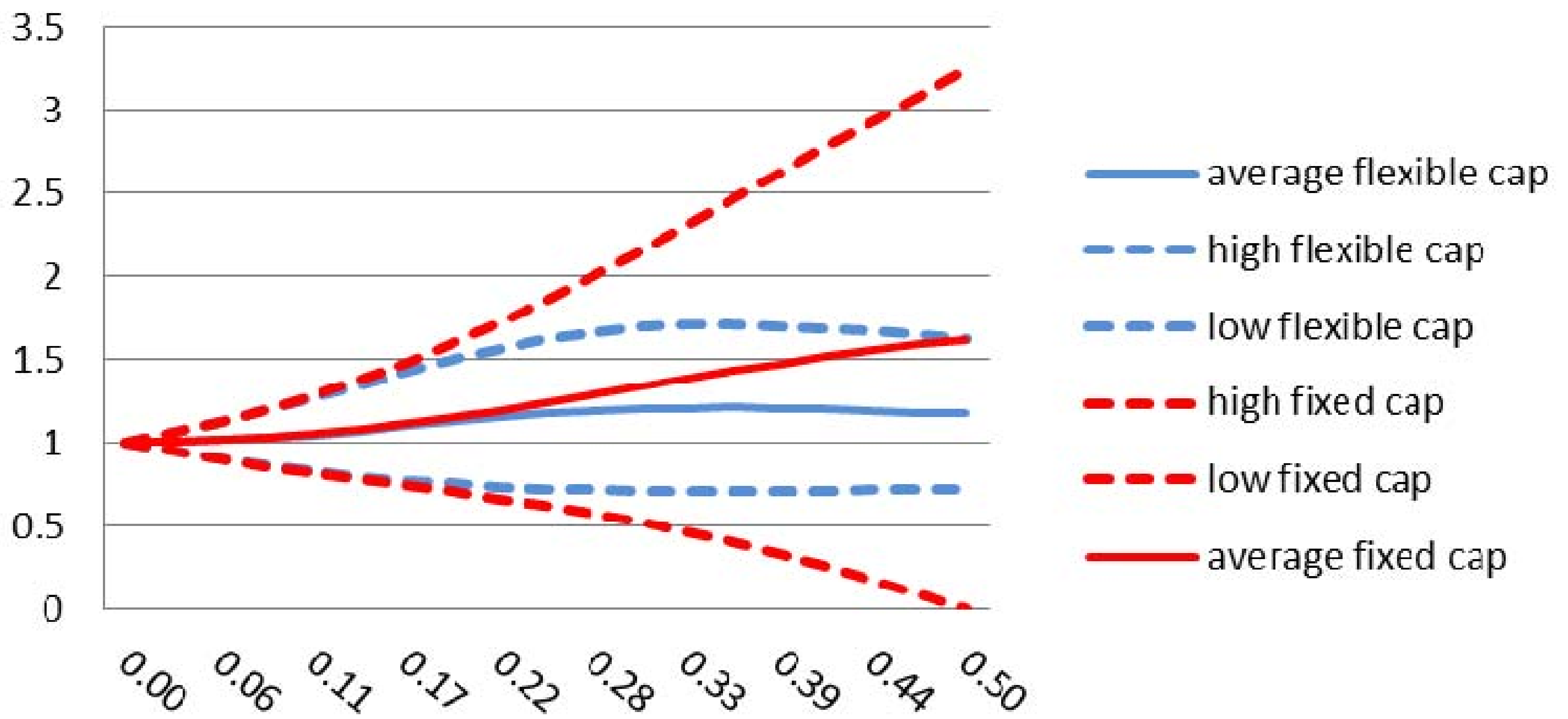


Figure 3: Emissions for flexible cap relative to fixed cap
as a function of uncertainty
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.00
0.08
0.17
0.25
0.33
0.42
0.50
average and range flexible cap & OBA
fixed cap & OBA

Figure 4: Permit prices for flexible cap versus fixed cap



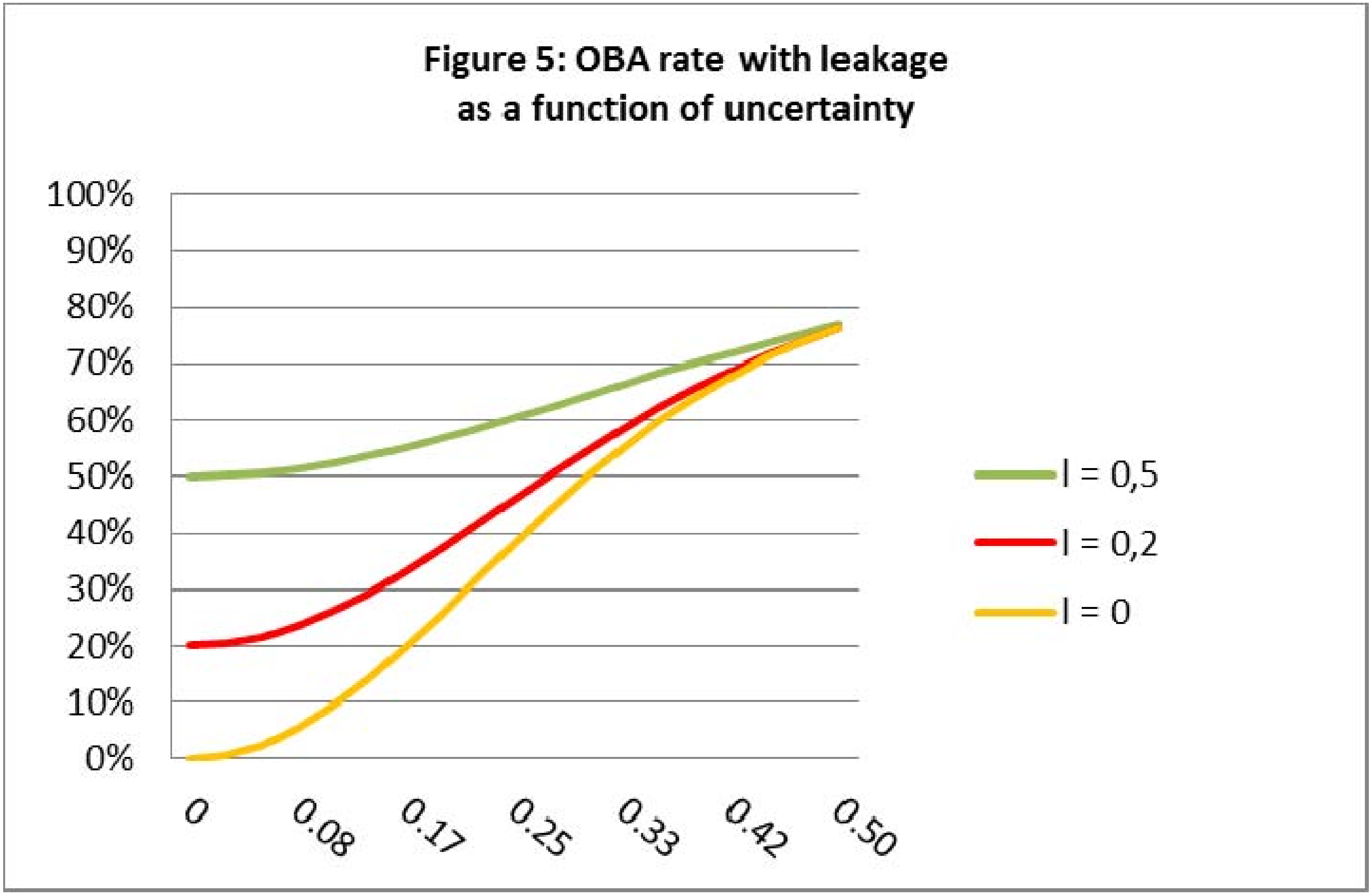


Figure 5: OBA rate with leakage
as a function of uncertainty
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.08
0.17
0.25
0.33
0.42
0.50
l = 0,5
l = 0,2
l = 0

Conclusions

- Output-based allocation schemes can be effective to handle price volatility, but if well designed (i.e., flexible cap)

- Because OBA rates will vary across sectors, regulator must handle a self-selection problem by allocating some permits in a lump-sum fashion

- (future work: explore the best OBA design when either or both budget-balance and self-selection constraints don't hold at the optimal OBA scheme)