Mandates and the Incentive for Environmental Innovation*

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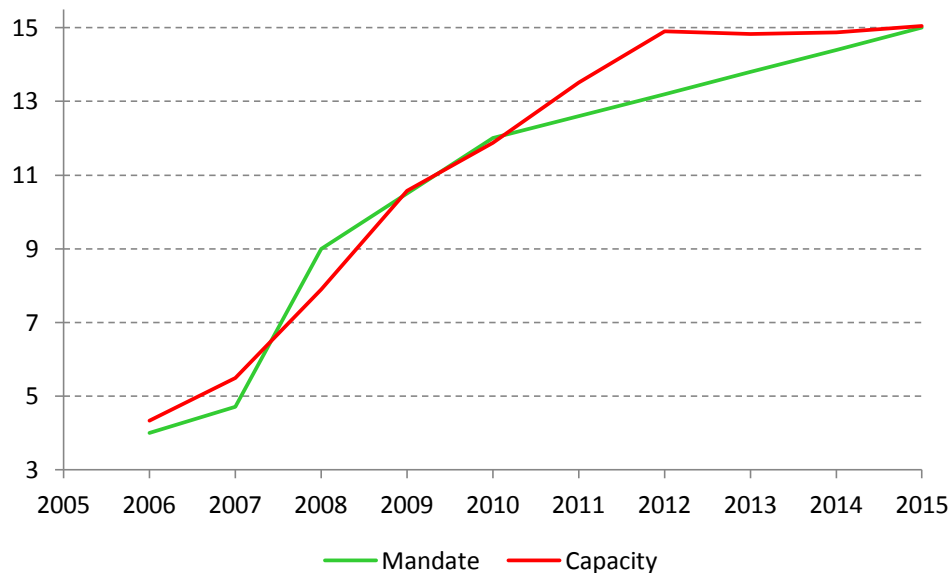
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* **Full paper** available at: **http://www.card.iastate.edu/publications/dbs/pdffiles/15wp557.pdf**
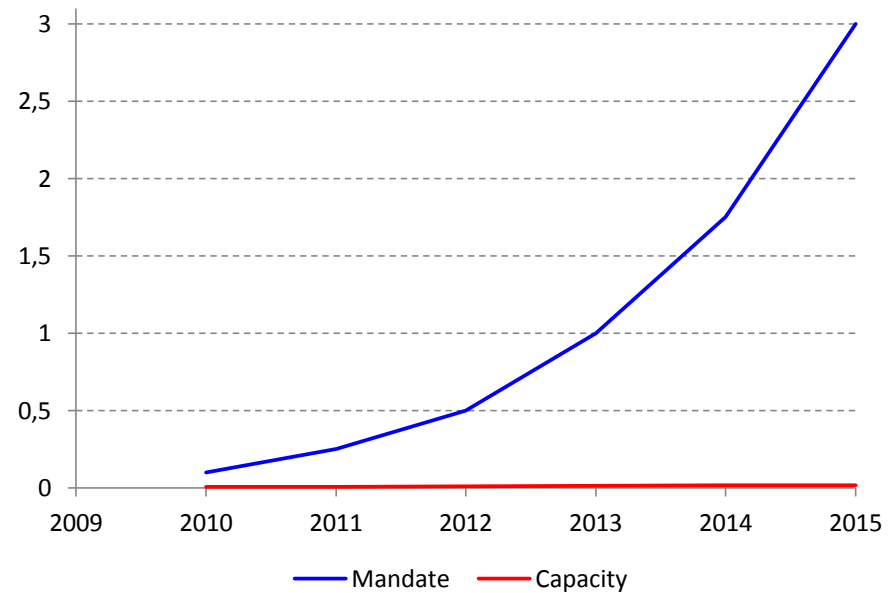
A tale of two mandates

U.S. **Corn-Ethanol Mandate** and
Nameplate Capacity, billions of gallons

U.S**. Cellulosic Ethanol Mandate** and
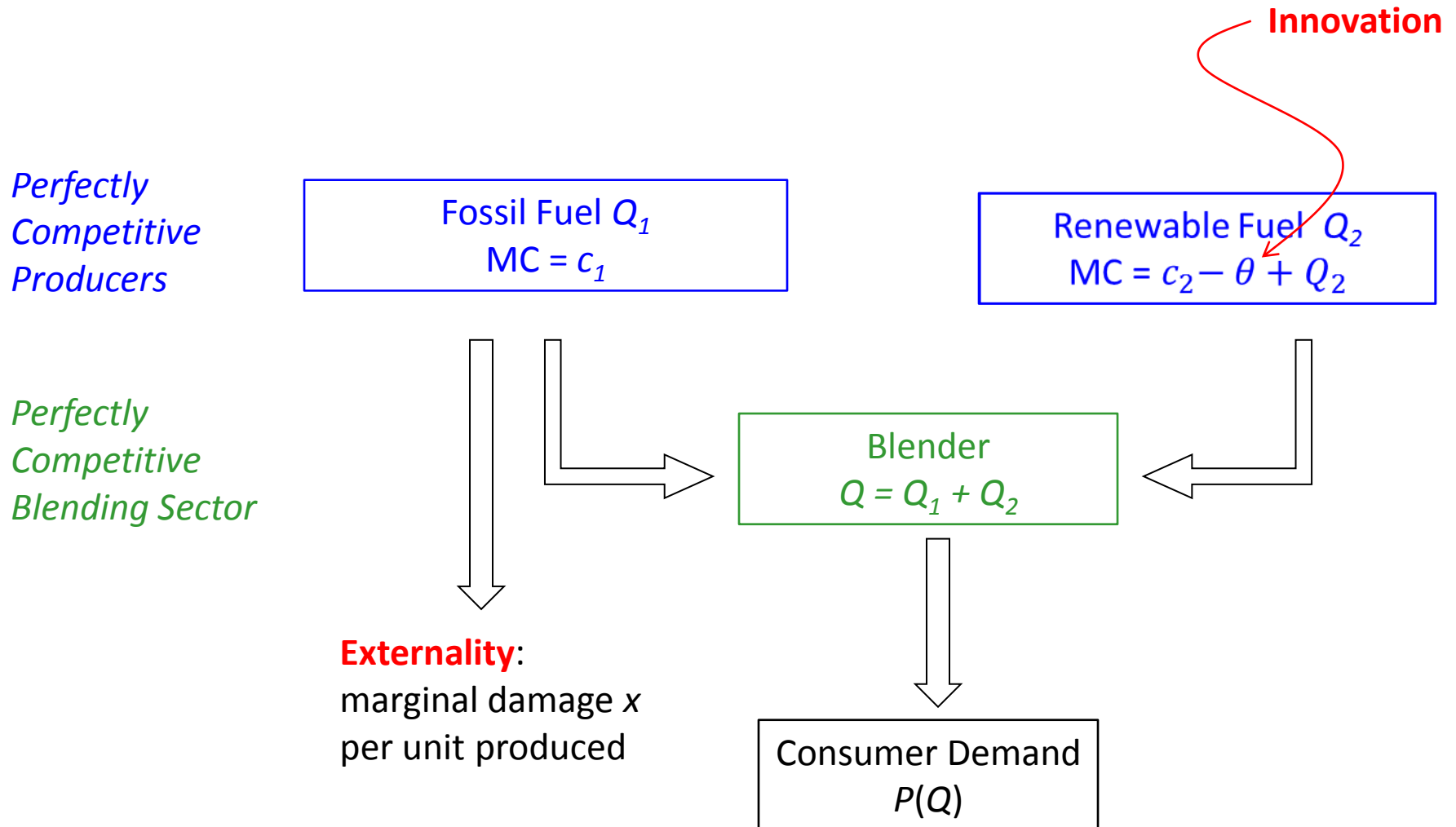Production Capacity, billions of gallons

- Key difference:
  - **corn ethanol** was a mature technology, mandate served to catalyze **investment in physical plants**
  - **cellulosic ethanol** requires new technologies to make it commercially viable and scalable
    - **R&D is key**, this is an **innovation challenge**
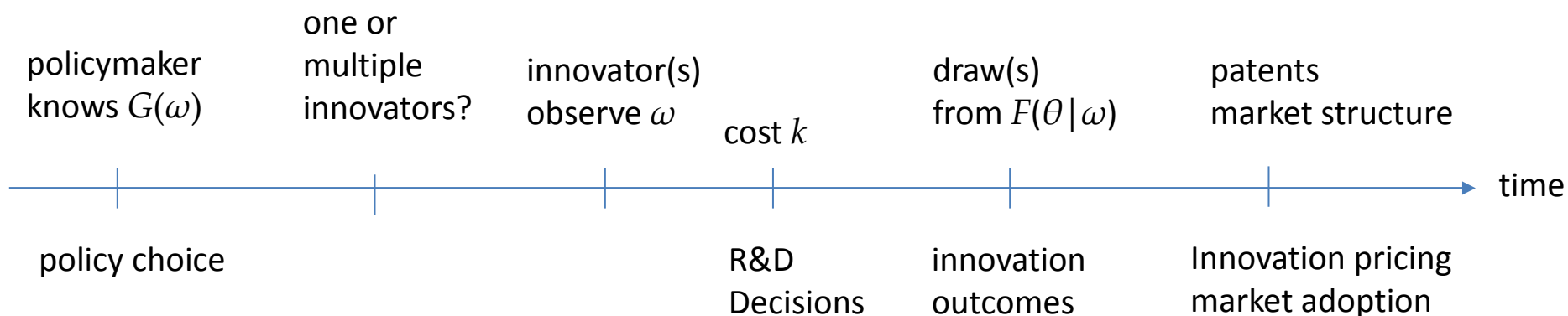
"Mandates" as a policy tool

- Two effects of renewable energy policies (Jaffe, Newell & Stavins 2003; Popp, Newell & Jaffe 2010)
    - ameliorate pollution **externality**
        - — substitute cleaner energy for fossil fuel
    - promote **innovation**

- Impact on innovation arguably more important   (Jaffe, Newell & Stavins 2005; Popp 2010)
    - twin market failures → pervasive innovation **under-provision**

- Two families of policy tools (Parry, 1995; Denicolo, 1999; Scotchmer, 2010; …)
    - **price** instruments – e.g., **carbon tax**
    - **quantity** instruments – e.g., (tradable) **pollution permits**

- Ranking of policy instruments **inconclusive** (Fischer, Parry & Pizer 2003)
    - review of evidence may favor price-based policies (Requate 2005)

- Where do renewable energy "mandates" fit in?
    - what is the impact of **mandates** on **innovation**?
    - how do mandates **perform**, compared with **other policy tools**?

Our Paper

Innovation and market for renewable energy

Innovation

Perfectly Competitive Producers

Fossil Fuel Q_1
MC = c_1

Renewable Fuel Q_2
MC = $c_2 - \theta + Q_2$

Perfectly Competitive Blending Sector

Blender
$Q = Q_1 + Q_2$

Externality:
marginal damage x per unit produced

Consumer Demand
$P(Q)$

A model of stochastic innovation

policymaker knows $G(\omega)$

one or multiple innovators?

innovator(s) observe ω

cost k

draw(s) from $F(\theta|\omega)$

patents market structure

time
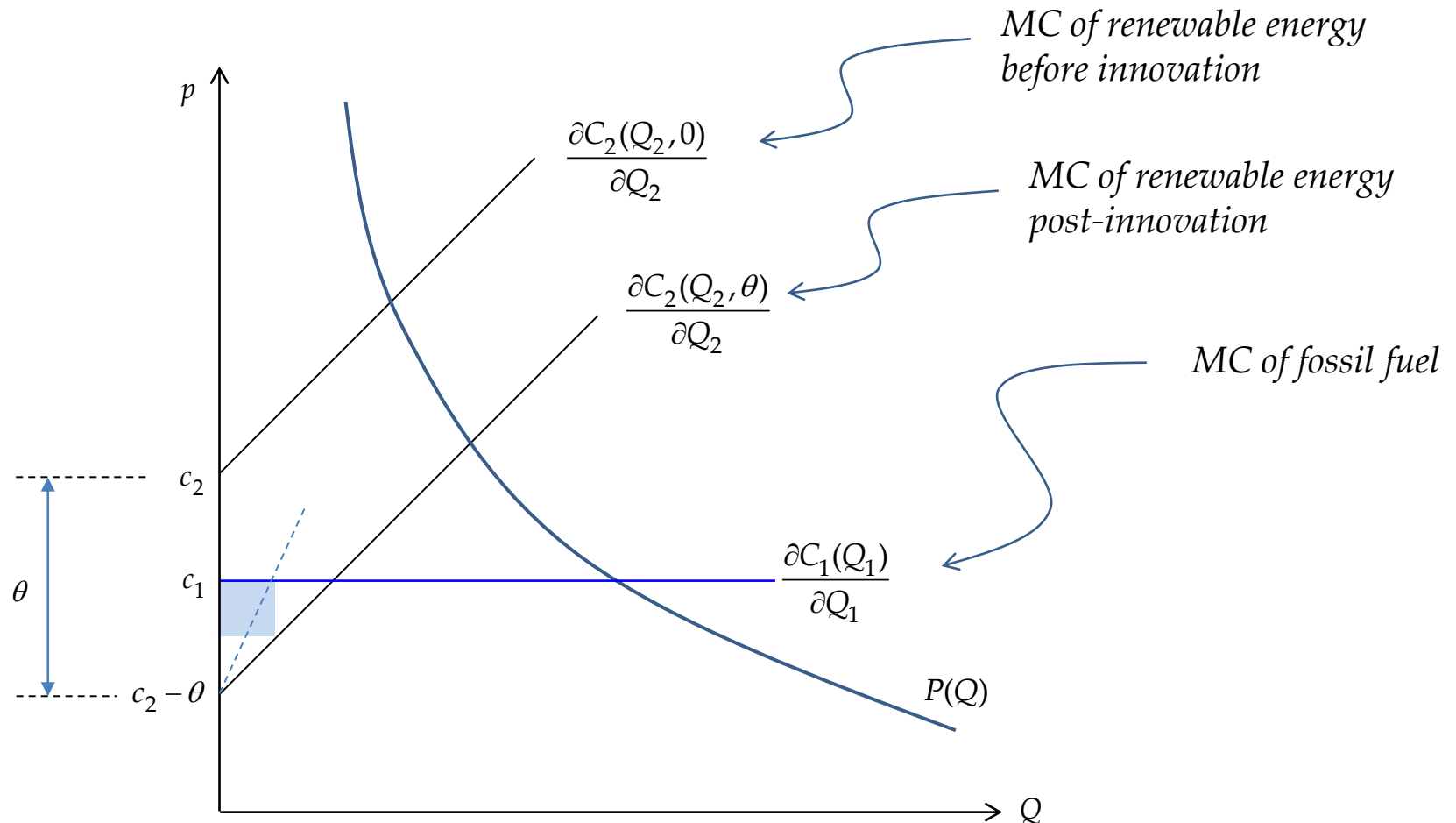
policy choice

R&D Decisions

innovation outcomes

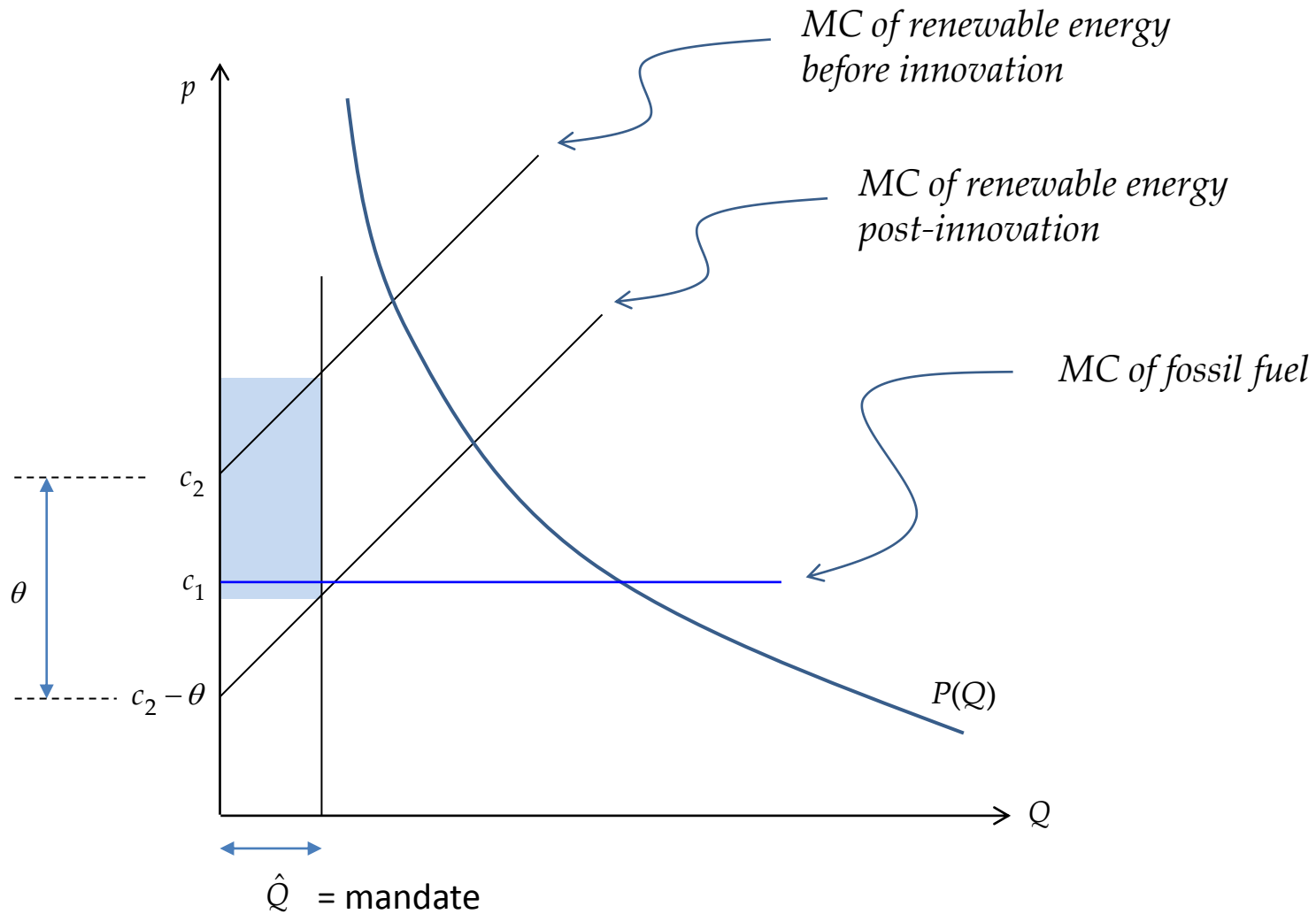Innovation pricing market adoption

- Analyze three settings: *laissez faire*, **mandate**, and **carbon tax**

- There is an **R&D sector** that produces innovations that are licensed to the production sector
  - two R&D structures: **single** innovator and **multiple innovators**
    - **endogenous number** of innovators (free entry with **Bertrand pricing**)

- We model innovation as a "**replacement technology**" (rather than abatement technology)
  - also, throughout, consider case of "**non-drastic innovation**"

- Assume **constant marginal** environmental damage of **externality**
  - level of naïve carbon tax is obvious and it is **time-consistent**
  - assume **policymaker can commit** to mandate

- $G(\omega)$ can be anything, $F(\theta\,|\,\omega)$ is uniform

Innovation and market for renewable energy – *laissez faire*

- Innovation decreases the MC of producing renewable energy
  - model maintains scalability disadvantage of renewable energy relative to fossil fuel

$$\frac{\partial C_2(Q_2, 0)}{\partial Q_2}$$

MC of renewable energy
before innovation

$$\frac{\partial C_2(Q_2, \theta)}{\partial Q_2}$$

MC of renewable energy
post-innovation

MC of fossil fuel

$$\frac{\partial C_1(Q_1)}{\partial Q_1}$$

$P(Q)$

p

c_2

c_1

$c_2 - \theta$

θ

Q

Innovation with a mandate – one innovator

MC of renewable energy before innovation

MC of renewable energy post-innovation

MC of fossil fuel

p

c_2

c_1

θ

$c_2 - \theta$

$P(Q)$

Q

$\hat{Q}$ = mandate

Innovation with a mandate – multiple innovators

MC of renewable energy before innovation

MC of renewable energy with 2nd best innovation

MC of renewable energy with best technology

MC of fossil fuel

p

c_2

θ_2

$c_2 - \theta_2$

c_1

θ_1

$c_2 - \theta_1$

$P(Q)$

Q
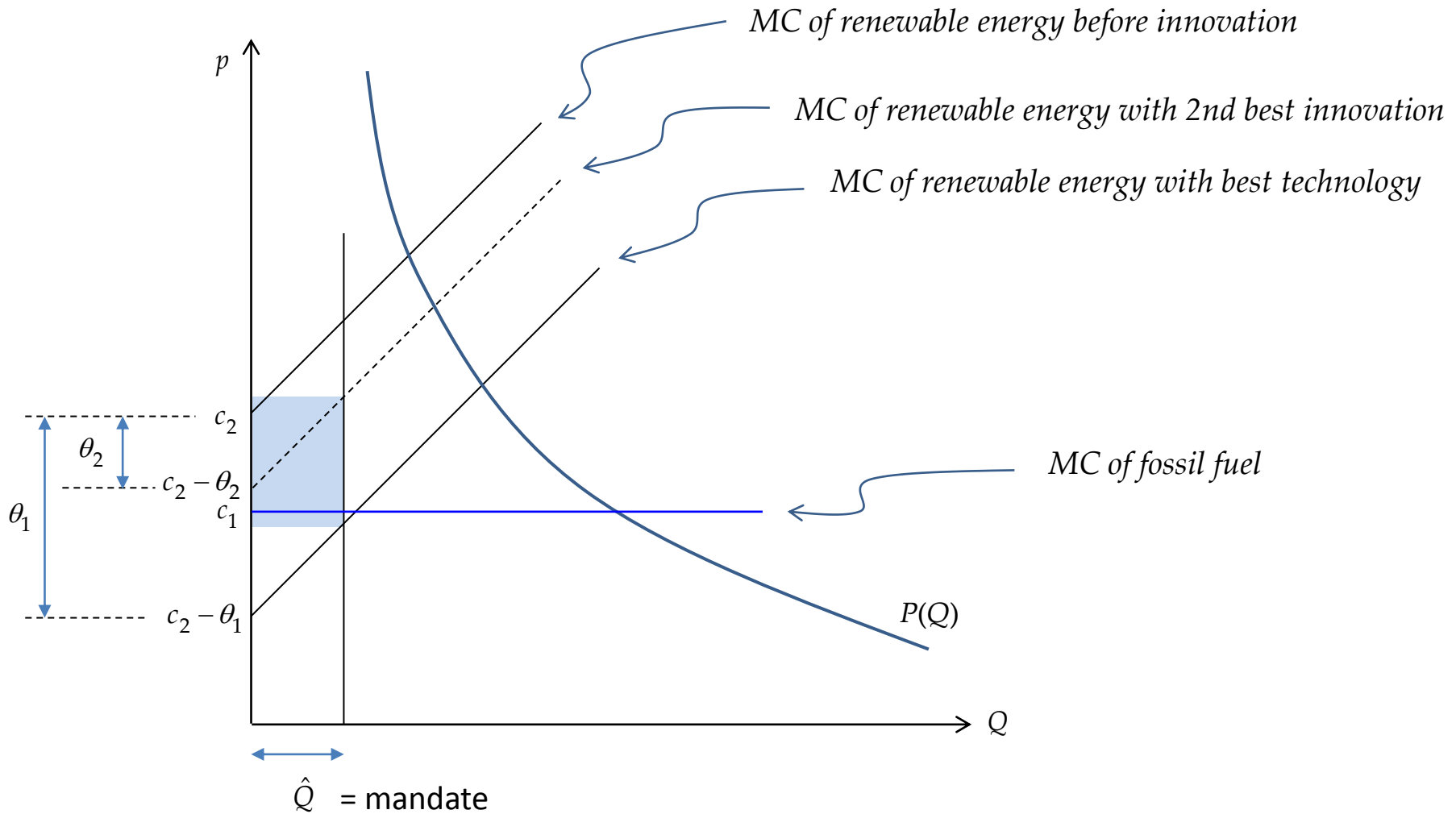
$\hat{Q}$ = mandate

Innovation with a carbon tax – one innovator

MC of renewable energy before innovation

MC of renewable energy with best technology

MC of fossil fuel + carbon tax

MC of fossil fuel

p

c_2

c_1

$c_2 - \theta$

θ

t

$P(Q)$

Q
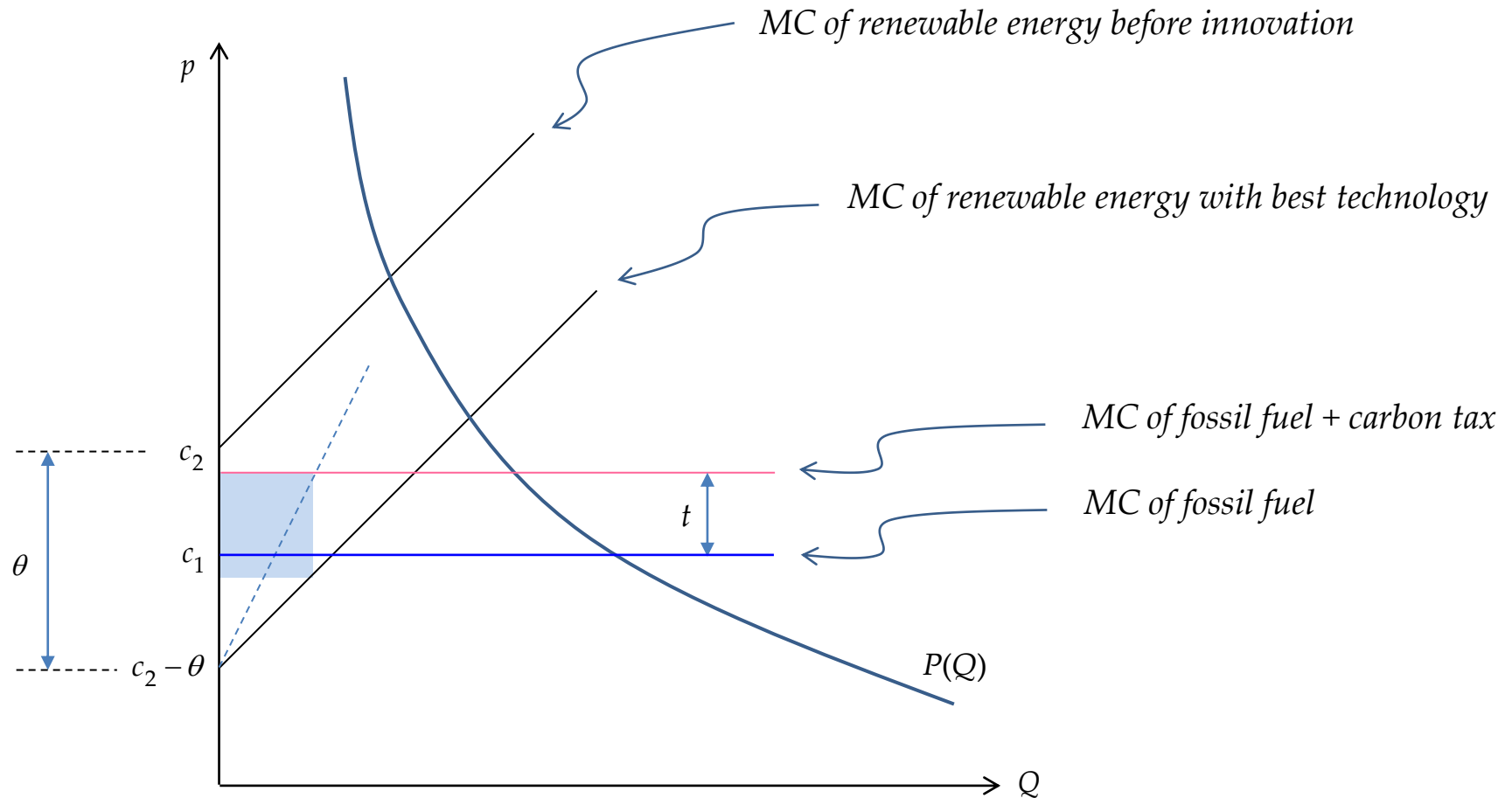
Innovation with a carbon tax – multiple innovators

MC of renewable energy before innovation

MC of renewable energy with 2nd best innovation

MC of renewable energy with best technology

MC of fossil fuel + carbon tax

MC of fossil fuel

$P(Q)$

c_2

θ_2

$c_2 - \theta_2$

c_1

θ_1

$c_2 - \theta_1$

t

p

Q
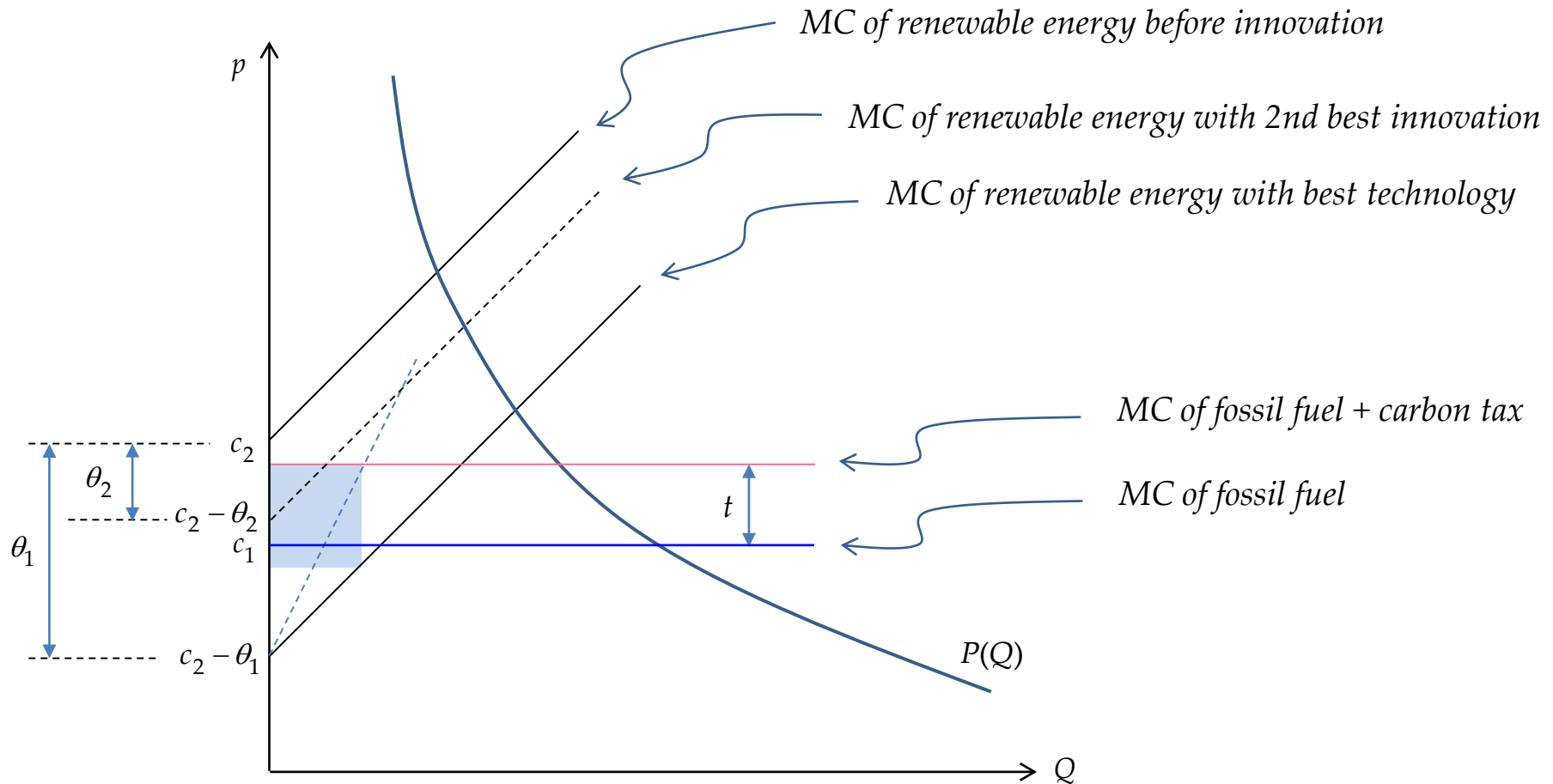
Some results: single innovator

RESULT 1. The welfare maximizing quantity mandate is increased when the social planner takes into account its impact on innovation.

- Ranking of policy tools: need **comparable levels** of "**mandate**" and "**carbon tax**"

Remark 1. When the mandate is calibrated to yield the same probability of R&D as the carbon tax, the expected value of the innovation is the same under both policies.
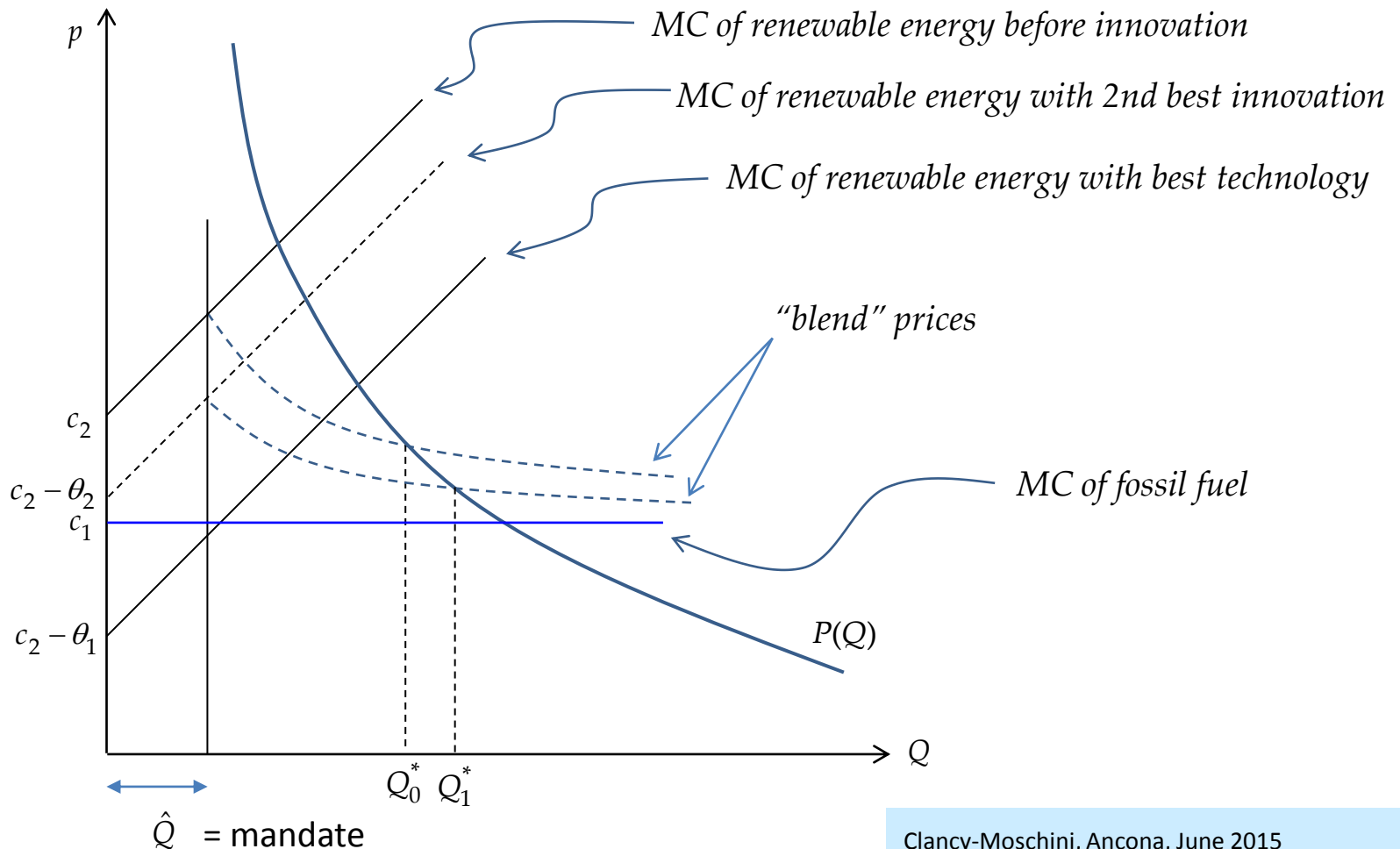
Remark 2. As the cost of R&D increases, the level of the mandate must be progressively increased in order to attain the same probability of R&D as a fixed carbon tax.

RESULT 2. When a mandate is chosen so that R&D is equally probable under a mandate or a carbon tax, then expected welfare is higher with a carbon tax.

- in the absence of innovation, mandate is not capable of achieving first best allocation
  - when the two tools achieve same R&D probability, innovation cannot make up for that
- not clear what happens if mandate is high enough to induce more R&D …
  - numerical analysis

Some results: multiple innovators (free entry in R&D)

RESULT 3. Under a mandate, the gain in consumer surplus from innovation can be more than offset by an increase in damages from the externality when demand is sufficiently elastic and marginal damage is sufficiently high.

MC of renewable energy before innovation

MC of renewable energy with 2nd best innovation

MC of renewable energy with best technology

"blend" prices

MC of fossil fuel

$P(Q)$

c_2

$c_2 - \theta_2$
c_1

$c_2 - \theta_1$

Q_0^* Q_1^*

$\hat{Q}$ = mandate

Some results: multiple innovators (free entry in R&D)

RESULT 4. There is a threshold $\hat{\omega}_t(\hat{n})$ such that
- whenever technological opportunity is "good", i.e., $\omega \geq \hat{\omega}_t(\hat{n})$, the number of innovators is (weakly) higher under a carbon tax than under a mandate.
- whenever technological opportunity is "weak", i.e., $\omega \leq \hat{\omega}_t(\hat{n})$, the number of innovators is (weakly) higher under a mandate policy than a carbon tax.

RESULT 5. When the mandate is tuned so that the probability of R&D under a mandate is equal to the probability of R&D under a carbon tax, then the expected technology realized after innovation is better under a carbon tax.

RESULT 6. When the mandate is tuned so that the expected best technology is the same under either policy, then the distribution of outcomes under a carbon tax is more disperse than under a mandate.

Numerical Results: Baseline parameters

	Laissez-Faire		Mandate		Carbon Tax	
	Single Innovator	Free Entry	Single Innovator	Free Entry	Single Innovator	Free Entry
Optimal instrument	-	-	18.65	16.05	23.45	23.40
$E[n]$	0.25	1.52	0.78	2.66	0.56	3.08
$E[\theta_1]$	9.66	16.05	15.63	24.76	14.44	24.17
$\sqrt{Var(\theta_1)}$	20.59	30.15	19.8	28.16	20.45	29.95
$E[Q_2]$	2.64	8.94	18.66	21.68	9.76	23.32
$E[W]$	126	412	146	455	315	689

RESULT 7 (numerical). In all parametric combinations that we considered, expected welfare under the optimal mandate is always lower than under the optimal carbon tax.

RESULT 9 (numerical). In all parametric combinations considered, with multiple innovators, expected welfare with the optimal mandate is always lower than with the naïve carbon tax.

Numerical Results: Optimal policy instruments

	Optimal Mandate			Optimal Carbon Tax		
	No Innovation	Single Innovator	Free Entry	No Innovation	Single Innovator	Free Entry
Baseline	2.4	18.6	16.0	20.0	23.5	23.4
$\eta = 0.25$	1.1	1.5	13.3	20.0	24.4	23.4
$\eta = 1$	5.2	15.2	16.0	20.0	22.5	22.7
$x = 10$	0.0*	0.0*	0.0*	10.0	14.0	14.4
$x = 40$	30.3	41.8	47.0	40.0	47.8	42.8
$k = 0.03\bar{\pi}$	2.4	18.6	16.6	20.0	23.9	22.3
$k = 0.12\bar{\pi}$	2.4	18.1	16.0	20.0	23.0	24.0
$E[\omega] = 15$	2.4	9.5	10.0	20.0	21.7	21.8
$E[\omega] = 60$	2.4	31.4	33.3	20.0	29.3	24.8

Numerical Results: Welfare Gains Decomposition

	ΔW with innovation, *laissez faire*	static ΔW with naïve level of policy	additional ΔW due to policy-induced innovation	additional ΔW due to optimal choice of policy instrument	Total ΔW
	$W_1^0 - W_0^0$	$W_0^n - W_0^0$	$(W_1^n - W_0^n)$ $-(W_1^0 - W_0^0)$	$W_1^* - W_1^n$	$W_1^* - W_0^0$
Mandate	412	2	3	37	455
Carbon Tax	412	97	173	7	689

Conclusions

- In addition to correcting **externalities**, environmental **policy** has another important effect:
  - **promote innovation**

- How effective are "**mandates**" vis-à-vis this twin challenge?
  - mandates can be **useful tools** – can improve outcomes relative to *laissez faire*
    - the prospect of **innovation is crucial** – it increases the level of mandates significantly
  - optimal mandate levels are however sensitive to the innovation process
    - technological opportunity; structure of R&D industry (e.g., single or multiple innovators)

- But: relative to a **carbon tax**, the performance of **mandates** appears **inferior**
  - a naïve carbon tax tends to yield higher welfare than a (*ex ante* optimal) mandate
  - mandates provide stronger incentives when technological opportunities are weak
    carbon tax provides stronger incentives when technological opportunities are strong

THANK YOU