



Teacher guide for the carbon market game

Running it in the lab, theoretical background,
experimental evidence and variants

Behavioral and Experimental Economics Research Lab
Department of Economics



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<https://beer-lab.org/>

How to use this guide

This guide helps you prepare, run and debrief the **carbon market** game of the Behavioral and Experimental Economics Research Lab (BEER Lab) of the Department of Economics at Tecnológico de Monterrey. It is written for instructors of principles of economics, intermediate microeconomics, public economics and environmental economics, with or without prior experience in experimental economics. The game has two versions:

- **Basic version: cap and trade.** The whole class trades a product in a continuous double auction. Every unit sold pollutes, and its environmental cost is shared by everyone. After three free-market periods (the benchmark: a market with an externality), every unit sold requires a permit held by its seller. There are as many permits as units in the social optimum, and sellers either buy them in an auction or receive them for free and trade them among themselves. Students see how an emissions quota changes the downstream product market.
- **Extended version: compare policies.** The same market with a per-unit tax equal to the damage, a standard that lets only the lowest-cost sellers sell, or no policy.

The **quick start** lets you run a session. Chapters 3 to 6 cover the basic version; chapter 7, the extended one. Common rules are explained once; each treatment only states what changes.

Author

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For the instructor

This guide covers the English interface. A separate Spanish version exists. The screenshots were taken on a local instance of the game with simulated decisions; the numbers in them illustrate the interface and are *not* results from a class. Project only aggregate results: never link codes to names, student IDs, seats or individual decisions.

Screenshots of the game's card on teaching-admin.beer-lab.org and teaching.beer-lab.org will be added in the next version of this guide; the procedure is the same as for the lab's other games.

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Quick start

1.1 At a glance

Purpose	Show that a polluting market overproduces, and what happens in the product market when sellers need one permit per unit: fewer units, a higher price, a price for the permit and, if permits are given away, windfall profits for those who receive them.
Participants	The whole class in one market: half buyers and half sellers (with an odd number, one extra buyer). From 20 students ; with 22 or more, the free market trades 11 units at 150 ECU and the social optimum is 9 units.
Market	Continuous double auction, 150 seconds per period. Buyer values 300, 285, 270, ...; seller costs 0, 15, 30, ... (one unit per person per period). Every unit sold has an environmental cost of 60 ECU shared equally by all participants.
Sequence	8 periods: the first 3 are a free market; 4 to 8 require permits (announced on a screen of its own).
Treatments	Permits auctioned among sellers (uniform price; the revenue is returned to everyone) or free permits to randomly chosen sellers, tradable among them before each period.
Duration	35–45 minutes, not counting discussion.
Extended version	Tax, standard or no policy (chapter 7).
Instructor (you)	teaching-admin.beer-lab.org → the game's card → Open panel (section 2.1).
Students	Room link https://carbonmarket.beer-lab.org/room/carbon_market_en , its QR code (section 2.5) or teaching.beer-lab.org .
Report	Free market versus social optimum; before and after the permits (units, prices, private surplus, damage, social surplus, efficiency, buyers' and sellers' earnings, revenue); product price, units, permit price and social surplus by period; price of every trade.

Note

There are two different pages. **teaching-admin.beer-lab.org** is yours: from there you open the game's panel and download this guide. **teaching.beer-lab.org** is for your students:

from there one can only *play*, not create sessions.

1.2 Minimal sequence

Before class

1. Request panel access from lab.economia@servicios.tec.mx stating the game, course, number of students and date. You will receive the password for the **admin** user.
2. Open teaching-admin.beer-lab.org, find **Carbon Market** and click **Open panel**.
3. Rehearse in **Demo** (section 2.3) and choose the treatment (chapter 6).

In class

4. Count the students present (at least 20).
5. In **Rooms**, open the room **[EN] Carbon Market**, choose the configuration, type the *exact* number of students in **Number of participants** and click **Create**.
6. Share the room link or project its QR code. Each student clicks **Start**.
7. Click **Monitor the session**. When it ends, open **Report**, click **Show results** and lead the discussion.

After class

8. In the room, click **Close this room**. The session data stay under **Sessions**.

1.3 Checklist

- ☐ Panel password received and tested at carbonmarket.beer-lab.org/login.
- ☐ Rehearsal done in **Demo**.
- ☐ Treatment chosen: auctioned permits or free permits.
- ☐ At least 20 students; number of participants equal to the number of students present.
- ☐ Room link or QR at hand; tested from a phone.
- ☐ Students told that ECU are experimental units and there is no cash payment.

Accessing the platform

2.1 Your access: teaching-admin and the game's panel

The instructors' page is teaching-admin.beer-lab.org. It is not linked from the beer-lab.org menu: type the address or bookmark it. It gathers all of the lab's classroom games; you can search by title, topic or JEL code.

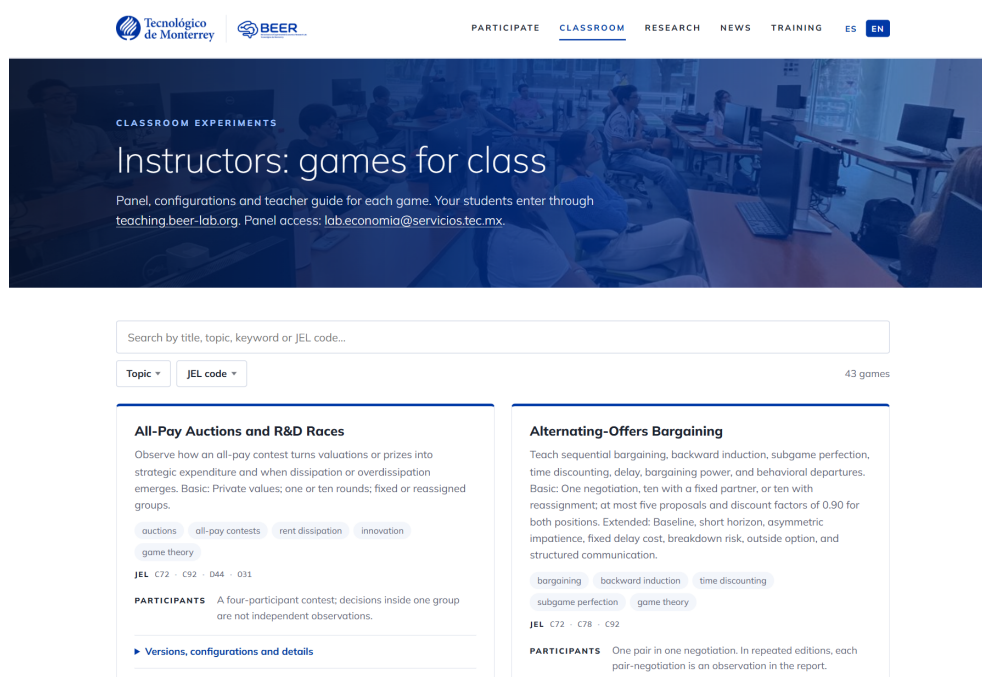


Figure 2.1: Instructors' page: teaching-admin.beer-lab.org. Look for the **Carbon Market** card.

Each game has a card with its description and two buttons: **Open panel** and **Teacher guide (PDF)**. The game's panel (<https://carbonmarket.beer-lab.org>) is protected: **Open panel** shows the **Admin Login** screen, where you type **admin** and the password the lab gave you.

2.2 The panel: minimal vocabulary

Demo	Practice sessions with fictitious participants that you play in several tabs. Never with students.
Rooms	Fixed addresses for the class: basic and extended, in Spanish and English.
Create / Number of participants	Create the session in the room and declare how many people will play.
Monitor	The period and screen of each participant. It does not show decisions.
Advance slowest participants	Moves on whoever is behind; it also closes a trading period (or the permit market) before time runs out.
Report	The instructor report to project aggregate results.
Data	CSV download of the data.
Close this room	Frees the room when you are done.

oTree Demo Sessions Rooms Data Server Check

Demo

[ES] Mercado de carbono — permisos subastados (8 periodos)
[ES] Mercado de carbono — permisos gratuitos negociables (8 periodos)
[EN] Carbon market — auctioned permits (8 periods)
[EN] Carbon market — free tradable permits (8 periods)
[ES] Mercado de carbono — impuesto por unidad (8 periodos)
[ES] Mercado de carbono — norma de costo máximo (8 periodos)
[ES] Mercado de carbono — sin política (8 periodos)
[EN] Carbon market — per-unit tax (8 periods)
[EN] Carbon market — maximum-cost standard (8 periods)
[EN] Carbon market — no policy (8 periods)

Juegos de mercados / Market games — BEER Lab

Mercado de carbono / Carbon market

To add to this list, create a new session config.

Figure 2.2: Demo: the game's 10 configurations (four basic and six extended, in Spanish and English).

oTree Demo Sessions Rooms Data Server Check

Rooms

Current rooms:

[ES] Mercado de carbono
[EN] Carbon Market
[ES] Mercado de carbono — extendido (comparar políticas)
[EN] Carbon Market — extended (policy comparison)

Figure 2.3: Rooms: the game's four rooms.

2.3 Rehearsing before class

In **Demo**, click a configuration: a practice session with 22 participants is created (with fewer, the permits would change nothing; see section 6.1). Open several links **P1**, **P2**, ... in different tabs and trade among them; move the others on from the Monitor.

The screenshot shows the oTree web interface. At the top is a navigation bar with links: oTree, Demo, Sessions, Rooms, Data, and Server Check. Below this is a header for the session: "[EN] Carbon market — auctioned permits (8 periods): session 'hpz4vp1l'". A secondary navigation bar contains icons and labels for Edit, Links, Monitor, Data, Payments, Report, and Description. The main content area explains that users can use session-wide, persistent, or single-use links. It provides a session-wide link: <http://localhost:8034/join/bumolino>. It also mentions persistent links for real sessions. A table lists single-use links for participants P1 through P7, each with a unique URL starting with <http://localhost:8034/initializeParticipant/> followed by a random string.

Participant	Link
P1	http://localhost:8034/initializeParticipant/iynq6tti
P2	http://localhost:8034/initializeParticipant/bgkeh70v
P3	http://localhost:8034/initializeParticipant/jupcee6
P4	http://localhost:8034/initializeParticipant/linx3plg
P5	http://localhost:8034/initializeParticipant/qdxheo1o
P6	http://localhost:8034/initializeParticipant/2emzf8ks
P7	http://localhost:8034/initializeParticipant/s3evu15e

Figure 2.4: A session's links (local copy: the addresses say `localhost`; on the server they say `carbonmarket.beer-lab.org`).

2.4 Creating the session in class

In **Rooms**, open the room for your language, choose the configuration, type the number of students present in **Number of participants** and click **Create**.

oTree Demo Sessions Rooms Data Server Check

Room: [EN] Carbon Market

Create a new session

English room. Only the configurations of this game, language and edition are shown below.

Session Config
 [EN] Carbon market — auctioned permits (8 periods) ▾

Number of participants

 Must be a multiple of 1

Create

[Configure session](#) ⚙️

App sequence

carbon_market (10 rounds) Carbon market: continuous double auction with an external damage per unit sold; free periods, then cap-and-trade with auctioned or grandfathered permits.

Figure 2.5: The form of the basic room in English.

Note

Declare the exact number. Roles (buyer or seller), values, costs and the number of permits are computed when the session is created. If you declare more participants than actually join, the market waits for someone who never arrives, and the environmental cost is split among more people than are playing. If a student disconnects, ask them to reopen the room in the same browser; if they cannot, use **Advance slowest participants**.

oTree Demo Sessions Rooms Data Server Check

[EN] Carbon market — auctioned permits (8 periods): session 'hpz4vp1l'

[Edit](#)
[Links](#)
[Monitor](#)
[Data](#)
[Payments](#)
[Report](#)
[Description](#)

ID	Code	Label	Progress	App	Round	PageName	Waiting	WaitsFor	Since
P1	lynq6ttl		21/120	carbon_market	2	Trade			1m
P2	bgkeh70v		21/120	carbon_market	2	Trade			1m
P3	ljupcee6		21/120	carbon_market	2	Trade			1m
P4	linx3plg		21/120	carbon_market	2	Trade			1m
P5	qdxheo1o		21/120	carbon_market	2	Trade			1m
P6	2emzfbks		21/120	carbon_market	2	Trade			1m
P7	a2qvo16s		21/120	carbon_market	2	Trade			1m
P8	nudedaie		21/120	carbon_market	2	Trade			1m
P9	pi128ij8		21/120	carbon_market	2	Trade			1m
P10	rm6nml4p		21/120	carbon_market	2	Trade			1m

Figure 2.6: Monitor: each participant's period and page.

2.5 How your students join

Students need no account and no installation. They can join through the QR code (below and in appendix A), the link https://carbonmarket.beer-lab.org/room/carbon_market_en, or the

catalogue teaching.beer-lab.org.



English, basic

carbonmarket.beer-lab.org/room/carbon_market_en



English, extended

carbonmarket.beer-lab.org/room/carbon_market_extended



Español, básica

carbonmarket.beer-lab.org/room/carbon_market_es



Español, extendida

carbonmarket.beer-lab.org/room/carbon_market_extendido

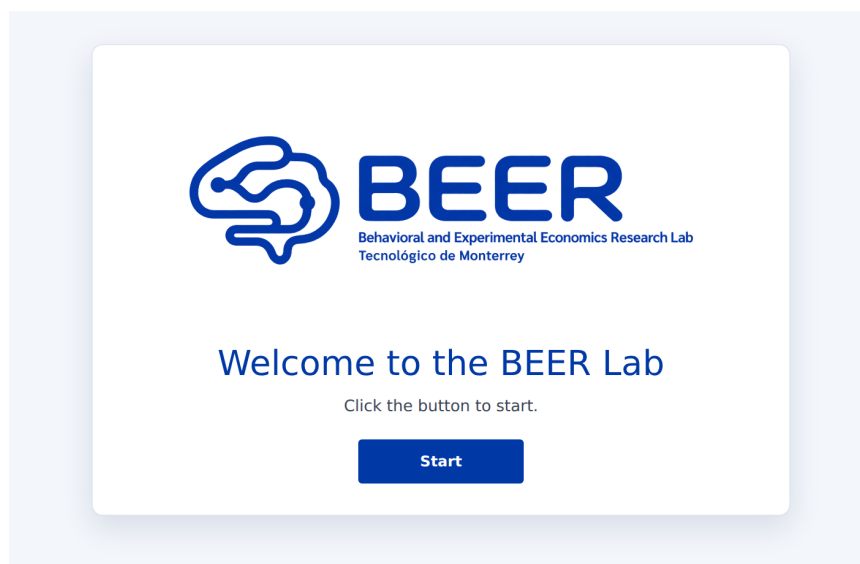


Figure 2.7: The room a student opens.

INSTRUCTORS AND STUDENTS

Classroom experiments

Experimental economics games for classroom activities and discussion. Open the game your instructor tells you.

Instructors: how to use these games in class or propose a new one → [instructor guide](#)
Lab research: beer-lab.org/en/research

Search by title, topic, keyword or JEL code...

Topic ▾ JEL code ▾ 43 games

All-Pay Auctions and R&D Races

Observe how an all-pay contest turns valuations or prizes into strategic expenditure and when dissipation or overdispersion emerges. Basic: Private values; one or ten rounds; fixed or reassigned groups.

auctions all-pay contests rent dissipation innovation game theory

JEL C72 · C92 · D44 · O31

Address: allpay.beer-lab.org

[Español](#) [English](#)

Alternating-Offers Bargaining

Teach sequential bargaining, backward induction, subgame perfection, time discounting, delay, bargaining power, and behavioral departures. Basic: One negotiation, ten with a fixed partner, or ten with reassignment; at most five proposals and discount factors of 0.90 for both positions. Extended: Baseline, short horizon, asymmetric impatience, fixed delay cost, breakdown risk, outside option, and structured communication.

bargaining backward induction time discounting subgame perfection game theory

JEL C72 · C78 · C92

Figure 2.8: The teaching.beer-lab.org catalogue.

The basic game and its screens

3.1 Rules and incentives

The whole class is one market for a product. When the session is created, half the participants become buyers and half sellers (who produce and sell); with an odd number there is one extra buyer. Buyers are ranked at random and get values that fall in steps of 15 from 300 ECU; sellers get costs that rise in steps of 15 from 0 ECU. Role, value and cost stay the same in every period.

Each period lasts 150 seconds. Each person can buy or sell *one* unit per period. Buyers post bids and sellers post asks; everyone sees the best of each. A new offer only enters if it improves the current one, and anyone can accept the best offer from the other side: the trade closes immediately at that price. The system does not allow offers or acceptances that lose money on the trade.

The environmental cost. Every unit sold has an environmental cost of $D = 60$ ECU. At the end of each period the total cost, $60 \times$ units sold, is split equally among all N participants (buyers and sellers, whether or not they traded) and subtracted from their earnings. Shares are rounded to 0.1 ECU.

$$\pi_i = \underbrace{(v_i - p) \text{ or } (p - c_j)}_{\text{earned from trading (0 if no trade)}} - \frac{60 Q}{N} \left[- \text{permit} + \frac{\text{revenue}}{N} \right],$$

where Q is the number of units sold in the whole market in the period. The bracketed part only appears from period 4.

Permits (periods 4 to 8). Before period 4 a screen announces the new rule, valid until the end: *every unit sold requires a permit held by its seller*. Each seller can hold at most one permit, and the market has as many permits as units in the social optimum of *your* class (9 with 22 or more students). A permit is only valid in its period. A seller without a permit can neither post an ask nor accept a bid.

Treatment	How sellers get their permits each period
Auction	Sealed-bid auction among sellers: each bids for one permit (0 if they do not want one). The 9 highest bids win and all pay the same price, the highest bid that did not win (0 if there are 9 bids or fewer). Winners pay even if they then do not sell. The revenue is split equally among all participants.
Free permits	The 9 permits are given away, one each to 9 sellers drawn at random (a new draw every period). Then sellers have 90 seconds to buy and sell permits among themselves in a continuous market with the double-auction rules. Buyers wait.

For the instructor

The instructions explain the environmental cost with an example and only say that a new rule *may* apply from some period on. No screen says “externality”, “internalize”, “Pigou” or “efficient”. Before period 4 starts, ask: if every sale needs a permit, what will happen to the product price? And if permits are free?

3.2 Cover, instructions and comprehension





Welcome to the BEER Lab

The **Behavioral and Experimental Economics Research Lab** of the Department of Economics at Tecnológico de Monterrey is a space for learning about economic decisions through controlled activities.

Today you will take part in a market as a buyer or a seller. Your earnings depend on your decisions and on what happens in the whole market.

During the session

- Do not talk or communicate with other people, except through the means shown on screen.
- Make your decisions individually.
- Follow the on-screen instructions. Do not refresh or close this page.
- If you need help, raise your hand.

I have read and understood the lab rules.

☐ Yes ☐ No

Start

Powered by [oTree](#)

Figure 3.1: Cover page and lab rules.




Instructions

Period 1 of 8

In this activity you are a buyer. Each period you want to buy one unit of a product.

Each period you have your own **value** for your unit: the highest price it is worth paying. If you buy at a lower price you earn the difference; if you buy at a higher price you lose. No one else knows your value.

What you earn from trading = your value – the price you buy at. If you do not buy, you earn 0 from trading.

Example: if your value is 150 and you buy at a price of 120, you earn $150 - 120 = 30$ ECU from trading.

The environmental cost

Producing this good pollutes. Each unit sold in the market has an **environmental cost of 60 ECU**.

At the end of each period, the total environmental cost ($60 \text{ ECU} \times \text{units sold in the whole market}$) is split equally among all 22 participants, buyers and sellers, whether or not they traded, and subtracted from their earnings.

Example: if 10 units are sold in a period in a market of 20 participants, the total environmental cost is $60 \times 10 = 600$ ECU, and each participant pays $600 \div 20 = 30$ ECU.

How trading works

- Each period lasts 150 seconds. Buyers propose a price to buy at (a bid) and sellers propose a price to sell at (an ask); everyone sees the two best current offers.
- A new bid is only accepted on screen if it is higher than the current best bid. A new ask is only accepted if it is lower than the current best ask.
- At any time you can accept the best offer from the other side: as a buyer, you can accept the best ask; as a seller, you can accept the best bid. Accepting closes the trade immediately at that price.
- The system will not let you propose or accept a price that would lose you money on the trade. You can buy or sell at most one unit per period.
- From some period on there may be a new market rule. If there is one, it will be announced before that period and shown on the trading screen.

- There will be 8 periods. Your role and your value or cost stay the same in every period. Your earnings from all periods are added up.
- Your earnings each period = what you earn from trading – your share of the environmental cost. Shares are rounded to 0.1 ECU.
- Amounts are in ECU (experimental currency units). There is no cash payment.

Continue

Powered by 

Figure 3.2: A buyer's instructions: their value, the environmental cost and the trading rules. The last rule warns that a new rule may come.

Instructions

Period 1 of 8

In this activity you are a seller: you produce and sell the product. Each period you can sell one unit.

Each period you have your own **cost** of producing your unit: the lowest price it is worth accepting. If you sell at a higher price you earn the difference; if you sell at a lower price you lose. No one else knows your cost.

What you earn from trading = the price you sell at – your cost. If you do not sell, you earn 0 from trading.

Example: if your cost is 80 and you sell at a price of 120, you earn $120 - 80 = 40$ ECU from trading.

The environmental cost

Producing this good pollutes. Each unit sold in the market has an **environmental cost of 60 ECU**.

At the end of each period, the total environmental cost (60 ECU × units sold in the whole market) is split equally among all 22 participants, buyers and sellers, whether or not they traded, and subtracted from their earnings.

Example: if 10 units are sold in a period in a market of 20 participants, the total environmental cost is $60 \times 10 = 600$ ECU, and each participant pays $600 \div 20 = 30$ ECU.

How trading works

- Each period lasts 150 seconds. Buyers propose a price to buy at (a bid) and sellers propose a price to sell at (an ask); everyone sees the two best current offers.
 - A new bid is only accepted on screen if it is higher than the current best bid. A new ask is only accepted if it is lower than the current best ask.
 - At any time you can accept the best offer from the other side: as a buyer, you can accept the best ask; as a seller, you can accept the best bid. Accepting closes the trade immediately at that price.
 - The system will not let you propose or accept a price that would lose you money on the trade. You can buy or sell at most one unit per period.
 - From some period on there may be a new market rule. If there is one, it will be announced before that period and shown on the trading screen.
- There will be 8 periods. Your role and your value or cost stay the same in every period. Your earnings from all periods are added up.
 - Your earnings each period = what you earn from trading – your share of the environmental cost. Shares are rounded to 0.1 ECU.
 - Amounts are in ECU (experimental currency units). There is no cash payment.

Continue

 Powered by 

Figure 3.3: A seller's instructions.

The comprehension check has three questions: what a buyer with value 150 who buys at 120 earns from trading (30), the environmental cost per participant if 10 units are sold in a market of 20 ($60 \times 10 / 20 = 30$), and the period earnings of a seller with cost 80 who sells at 120, after that cost ($120 - 80 - 30 = 10$). After a mistake it explains the rule and lets the student retry.

Before you start

Period 1 of 8

Answer the three questions based on the instructions (they apply to any buyer or seller).

A buyer has a value of 150 and buys at a price of 120. How much do they earn from trading?

- ☐ 0 ECU
 ☐ 30 ECU
 ☐ 120 ECU
 ☐ 150 ECU

In a period, 10 units are sold in a market of 20 participants. How much environmental cost does each participant pay?

- ☐ 6 ECU
 ☐ 30 ECU
 ☐ 60 ECU
 ☐ 600 ECU

In that same period, a seller with a cost of 80 sells at a price of 120. What are their earnings for the period, after their share of the environmental cost?

- ☐ -50 ECU
 ☐ 10 ECU
 ☐ 40 ECU
 ☐ 90 ECU

Check

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Figure 3.4: Comprehension check.

Por favor corrija los errores.

Before you start

Period 1 of 8

Answer the three questions based on the instructions (they apply to any buyer or seller).

A buyer has a value of 150 and buys at a price of 120. How much do they earn from trading?

- ☐ 0 ECU
 ☐ 30 ECU
 ☐ 120 ECU
 ☐ 150 ECU

Check: what a buyer earns from trading = their value – the price they buy at.

In a period, 10 units are sold in a market of 20 participants. How much environmental cost does each participant pay?

- ☐ 6 ECU
 ☐ 30 ECU
 ☐ 60 ECU
 ☐ 600 ECU

Check: total environmental cost = 60 × units sold; it is divided among all participants.

In that same period, a seller with a cost of 80 sells at a price of 120. What are their earnings for the period, after their share of the environmental cost?

- ☐ -50 ECU
 ☐ 10 ECU
 ☐ 40 ECU
 ☐ 90 ECU

Check: (selling price – cost) – their share of the environmental cost.

Check

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Figure 3.5: Wrong answers: the messages recall the rule without giving the answer.

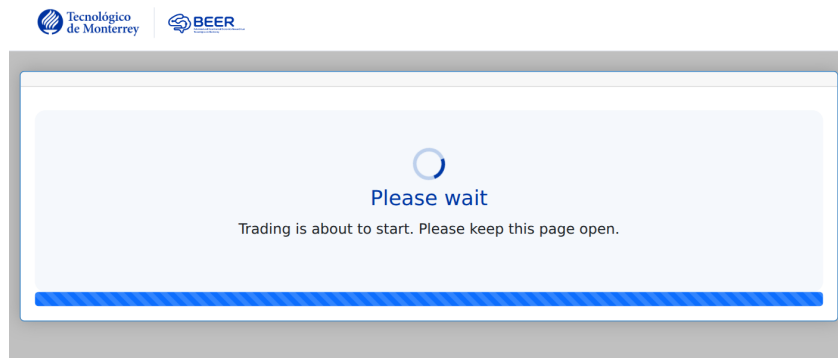


Figure 3.6: Waiting for the whole market to be ready.

What the participant sees

“Please wait” means other people have not finished yet. It is not an error. The participant should not close or refresh the page.

3.3 Free-market periods



Time left to complete this page: **2:25**

Trading

Period 2 of 8

You are a buyer.

Your value (the most it is worth paying)
180 ECU

Best bid
140

Best ask
165

Your bid

Offer to buy

Accept the best offer

Units sold in the market
6

Environmental cost per participant so far
16.4 ECU

Trades closed this period

#	Price
1	180
2	175
3	170
4	165
5	160
6	158

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Figure 3.7: A buyer's trading screen in a free period: their value, the best offers, units sold in the market and the environmental cost per participant so far (simulated decisions).

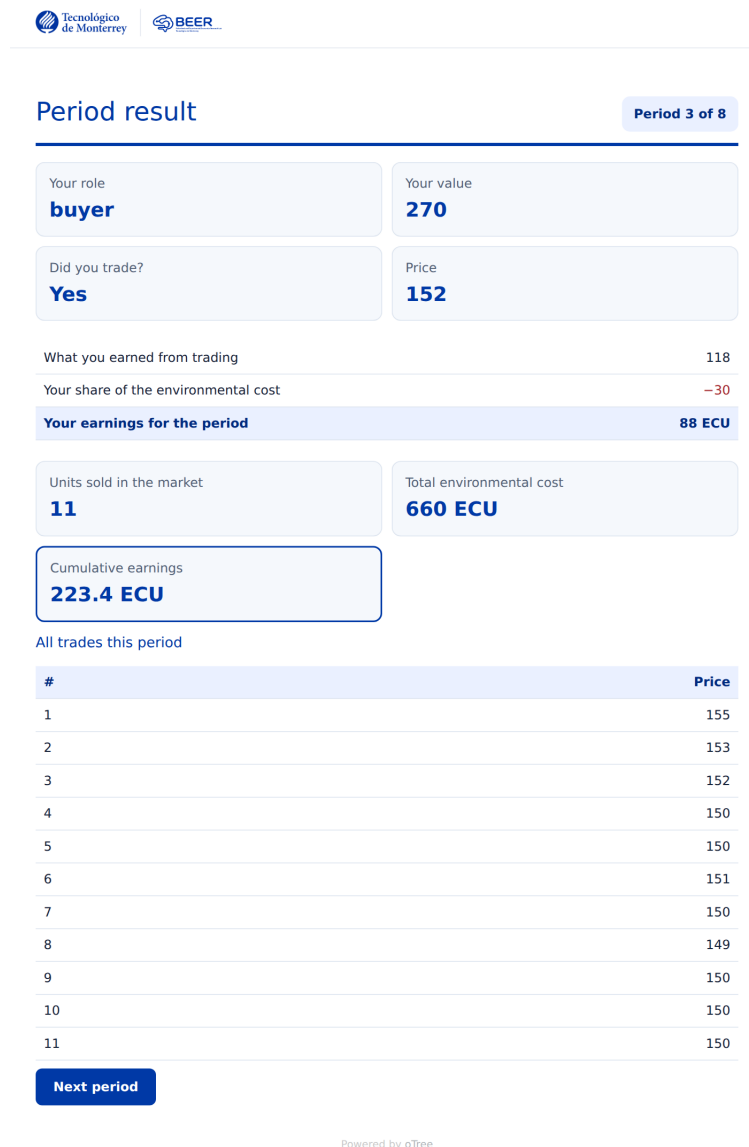
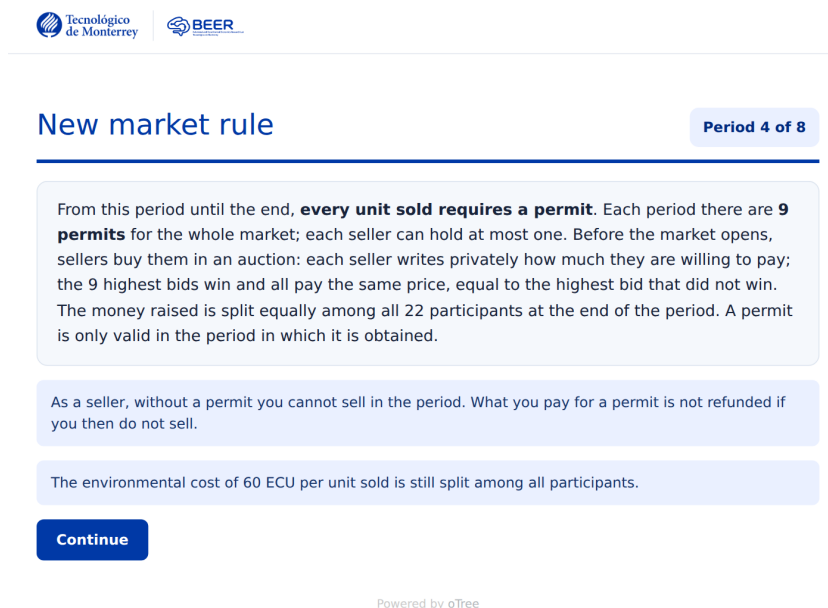


Figure 3.8: Result of a free period: earnings from trading, share of the environmental cost and period earnings (simulated decisions).

3.4 The announcement and the permit auction



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New market rule

Period 4 of 8

From this period until the end, **every unit sold requires a permit**. Each period there are **9 permits** for the whole market; each seller can hold at most one. Before the market opens, sellers buy them in an auction: each seller writes privately how much they are willing to pay; the 9 highest bids win and all pay the same price, equal to the highest bid that did not win. The money raised is split equally among all 22 participants at the end of the period. A permit is only valid in the period in which it is obtained.

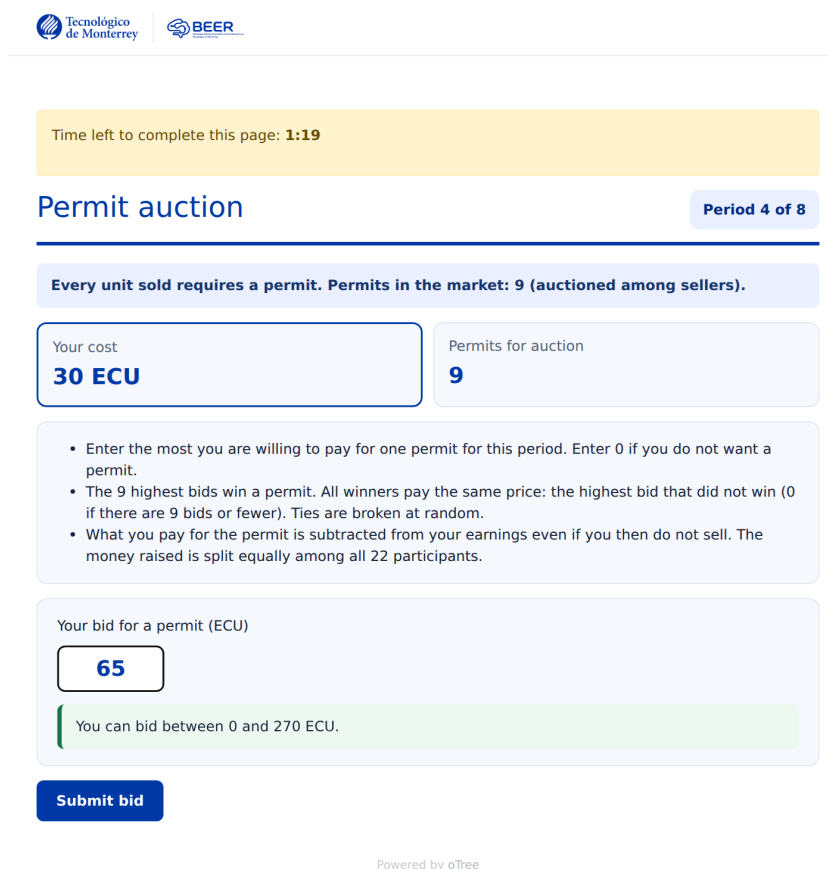
As a seller, without a permit you cannot sell in the period. What you pay for a permit is not refunded if you then do not sell.

The environmental cost of 60 ECU per unit sold is still split among all participants.

Continue

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Figure 3.9: Announcement before period 4 (auctioned permits, 22 participants), as a seller sees it.



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Permit auction

Period 4 of 8

Every unit sold requires a permit. Permits in the market: 9 (auctioned among sellers).

Your cost: **30 ECU**

Permits for auction: **9**

- Enter the most you are willing to pay for one permit for this period. Enter 0 if you do not want a permit.
- The 9 highest bids win a permit. All winners pay the same price: the highest bid that did not win (0 if there are 9 bids or fewer). Ties are broken at random.
- What you pay for the permit is subtracted from your earnings even if you then do not sell. The money raised is split equally among all 22 participants.

Your bid for a permit (ECU): **65**

You can bid between 0 and 270 ECU.

Submit bid

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Figure 3.10: Permit auction: the seller enters the most they are willing to pay. The highest allowed bid is 300 minus their cost, the highest possible product price (simulated decisions).

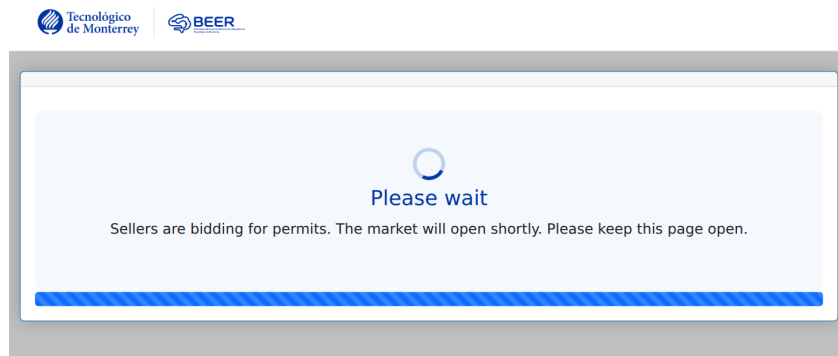


Figure 3.11: Meanwhile, buyers wait.

Time left to complete this page: **2:26**

Trading

Period 4 of 8

Every unit sold requires a permit. Permits in the market: **9** (auctioned among sellers).

You are a seller. You hold a permit: you can sell one unit this period.

Your cost: **120 ECU**

Best bid: —

Best ask: —

Your ask: **Offer to sell**

Accept the best offer

Units sold in the market: **4**

Environmental cost per participant so far: **10.9 ECU**

Trades closed this period

#	Price
1	170
2	175
3	172
4	175

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Figure 3.12: Trading screen of a seller with a permit: the rule and their status (simulated decisions).



Time left to complete this page: **2:25**

Trading

Period 4 of 8

Every unit sold requires a permit. Permits in the market: **9** (auctioned among sellers).

You are a seller. You have no permit: you cannot sell this period.

Your cost
135 ECU

Best bid
—

Best ask
—

You cannot sell this period. You can watch the market until time runs out.

Units sold in the market
4

Environmental cost per participant so far
10.9 ECU

Trades closed this period

#	Price
1	170
2	175
3	172
4	175

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Figure 3.13: A seller without a permit cannot sell: the trading controls are replaced by a notice (simulated decisions).

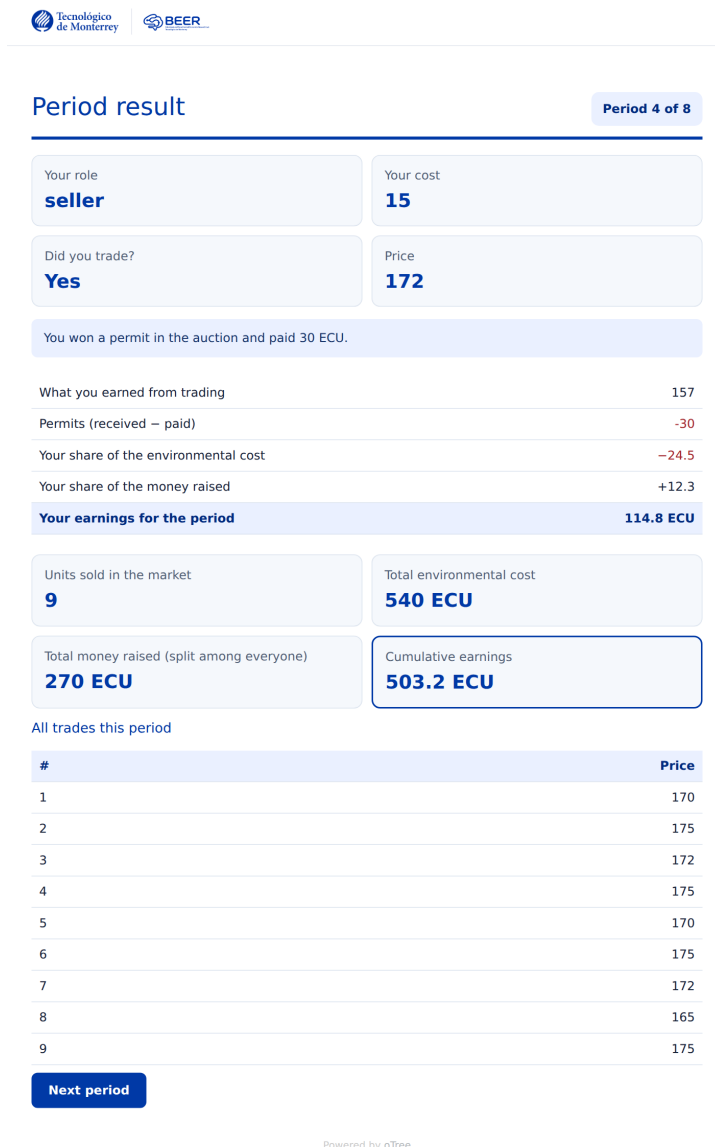


Figure 3.14: Result of a seller who won a permit in the auction: what they paid, their share of the environmental cost and their share of the revenue (simulated decisions).

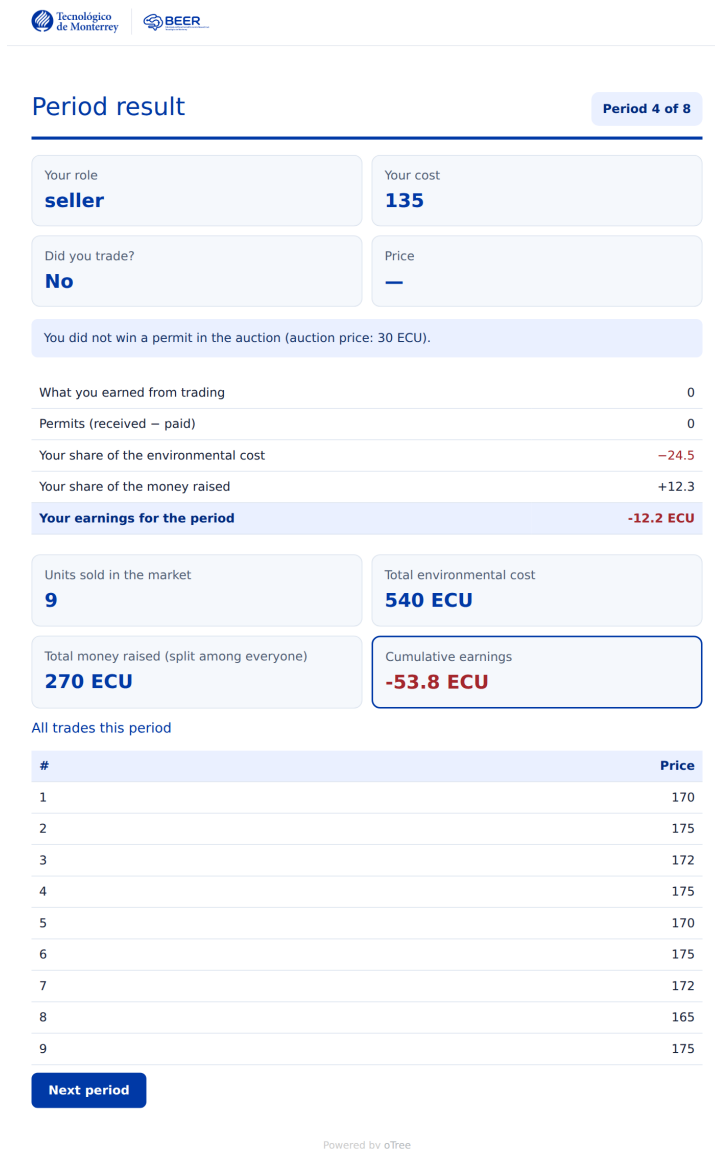


Figure 3.15: Result of a seller who did not win a permit: no sale, but a share of the revenue (simulated decisions).

3.5 Free permits and their market

In this treatment the auction is replaced by a permit market among sellers. A seller who received a permit can use it or sell it; one who did not can buy one. The most anyone can bid is 300 minus their cost.

New market rule

Period 4 of 8

From this period until the end, **every unit sold requires a permit**. Each period there are **9 permits** for the whole market; they are given for free, one each to 9 sellers drawn at random. Before the market opens, sellers have 90 seconds to buy and sell permits among themselves: a seller holding a permit can sell it, and a seller without one can buy one. A permit is only valid in the period in which it is given.

As a seller, without a permit you cannot sell in the period. What you pay for a permit is not refunded if you then do not sell.

The environmental cost of 60 ECU per unit sold is still split among all participants.

Continue

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Figure 3.16: Announcement of free permits, as a seller sees it.

Time left to complete this page: 1:27

Permit market

Period 4 of 8

Every unit sold requires a permit. Permits in the market: 9 (given for free, tradable among sellers).

This period you did not receive a permit. You can buy one from another seller; without a permit you cannot sell the product.

Your cost

30 ECU

Do you hold a permit?

No

Money from permits (sales – purchases)

0 ECU

Best bid for a permit

40

Best ask for a permit

60

Your bid to buy a permit

40**Offer to buy****Buy at the best ask**

- Only sellers take part. This market lasts 90 seconds; then the product market opens.
- A seller holding a permit can offer to sell it or accept the best bid; a seller without one can offer to buy one or accept the best ask. New offers must improve the current ones.
- Money from permits is added to or subtracted from your earnings for the period. The most you can bid for a permit is 270 ECU.

Permits traded this period

#	Price
---	-------

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Figure 3.17: Permit market of a low-cost seller who received no permit: they can offer to buy one (simulated decisions).

Permit market

#	Price
---	-------

24




Time left to complete this page: **1:24**

Permit market

Period 4 of 8

Every unit sold requires a permit. Permits in the market: 9 (given for free, tradable among sellers).

This period you received a free permit. You can use it to sell one unit of the product or sell it to another seller.

Your cost

150 ECU

Do you hold a permit?

No

Money from permits (sales – purchases)

50 ECU

Best bid for a permit

—

Best ask for a permit

—

Your bid to buy a permit

Offer to buy

Buy at the best ask

- Only sellers take part. This market lasts 90 seconds; then the product market opens.
- A seller holding a permit can offer to sell it or accept the best bid; a seller without one can offer to buy one or accept the best ask. New offers must improve the current ones.
- Money from permits is added to or subtracted from your earnings for the period. The most you can bid for a permit is 150 ECU.

Permits traded this period

#	Price
1	50

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Figure 3.19: The high-cost seller accepted the bid and sold the permit it received for free (simulated decisions).

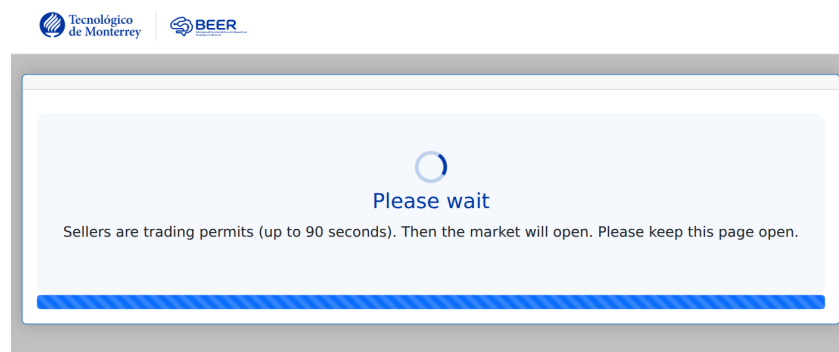


Figure 3.20: Buyers wait while sellers trade permits.

Time left to complete this page: **2:27**

Trading

Period 4 of 8

Every unit sold requires a permit. Permits in the market: 9 (given for free, tradable among sellers).

You are a seller. You have no permit: you cannot sell this period.

Your cost

150 ECU

Best bid

—

Best ask

—

You cannot sell this period. You can watch the market until time runs out.

Units sold in the market

1

Environmental cost per participant so far

2.7 ECU

Trades closed this period

#	Price
1	175

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Figure 3.21: Then, in the product market, the seller who sold the permit can no longer sell (simulated decisions).

Period result

Period 4 of 8

Your role

seller

Your cost

150

Did you trade?

No

Price

—

You received a free permit. You sold a permit for 50 ECU.

What you earned from trading	0
Permits (received – paid)	50
Your share of the environmental cost	-2.7
Your earnings for the period	47.3 ECU

Units sold in the market

1

Total environmental cost

60 ECU

Cumulative earnings

47.3 ECU

All trades this period

#	Price
1	175

Next period

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Figure 3.22: Result of the seller who sold its free permit: earnings without producing (simulated decisions).

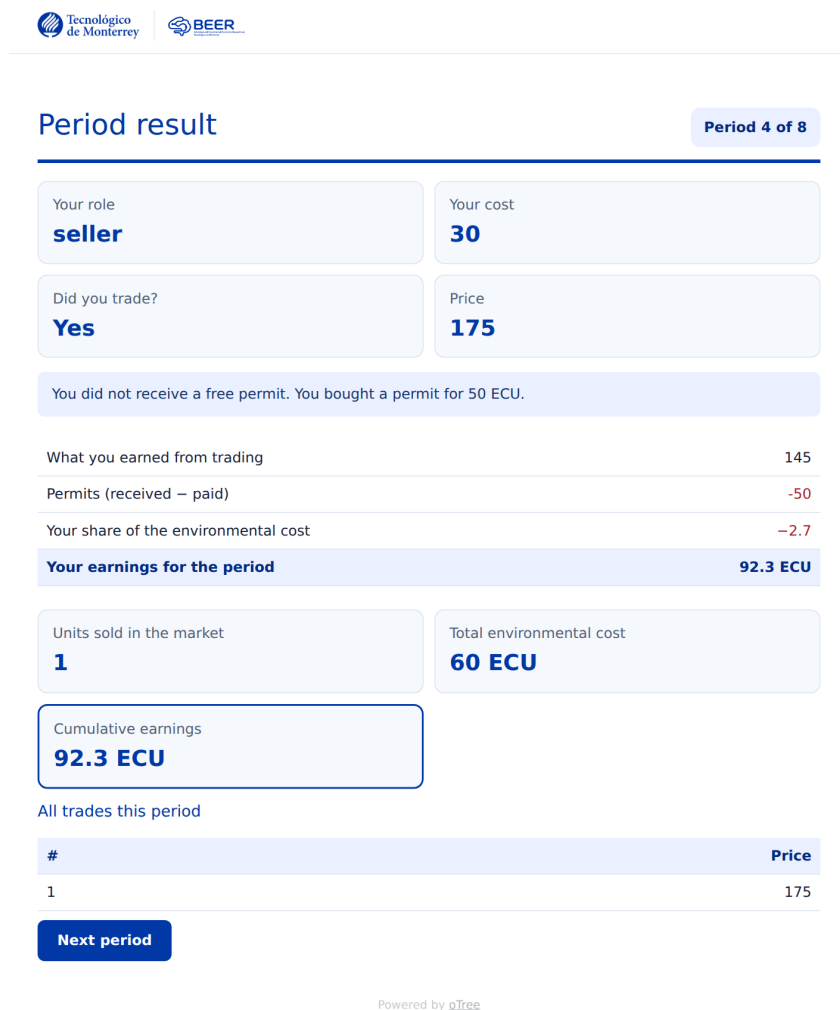


Figure 3.23: Result of the seller who bought the permit and sold a unit (simulated decisions).

End of the activity

Period 8 of 8

Your total earnings

658 ECU

Period	Traded	Price	From trading	Environmental cost	Money returned	Period earnings
1	Yes	175	95	-27.3	0	67.7
2	Yes	175	95	-27.3	0	67.7
3	Yes	152	118	-30	0	88
4	Yes	172	98	-24.5	12.3	85.8
5	Yes	176	94	-24.5	16.4	85.9
6	Yes	178	92	-24.5	18.4	85.9
7	Yes	178	92	-24.5	20.5	88
8	Yes	177	93	-24.5	20.5	89

Thank you for participating. Please wait for your instructor.

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Figure 3.24: End screen: total earnings and history by period (simulated decisions).

Instructor report and debrief

4.1 When to reveal

Report opens with results hidden and shows participants, buyers, sellers and completed periods. Click **Show results** after the last period (or after period 3, to ask for predictions before the permits).

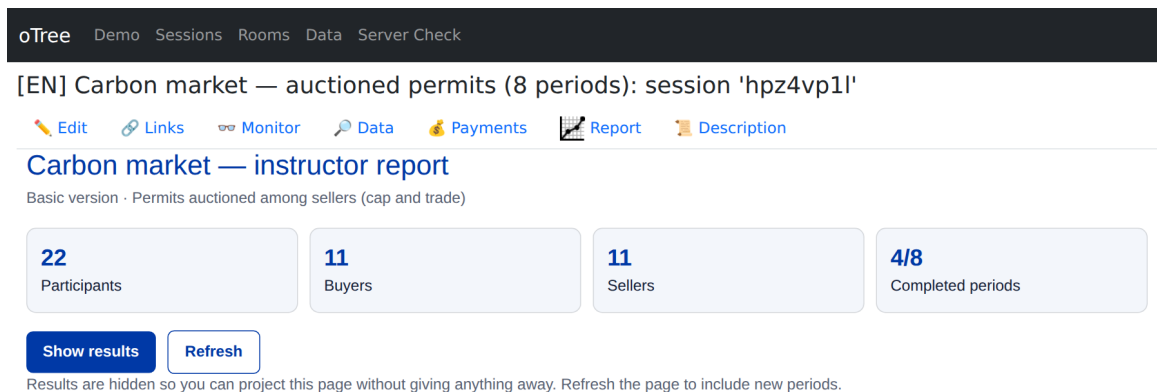


Figure 4.1: Report with results hidden.

4.2 Reading the report

The report follows the price controls report: every chart has a note underneath explaining how to read it, and every benchmark is computed for the actual number of participants.

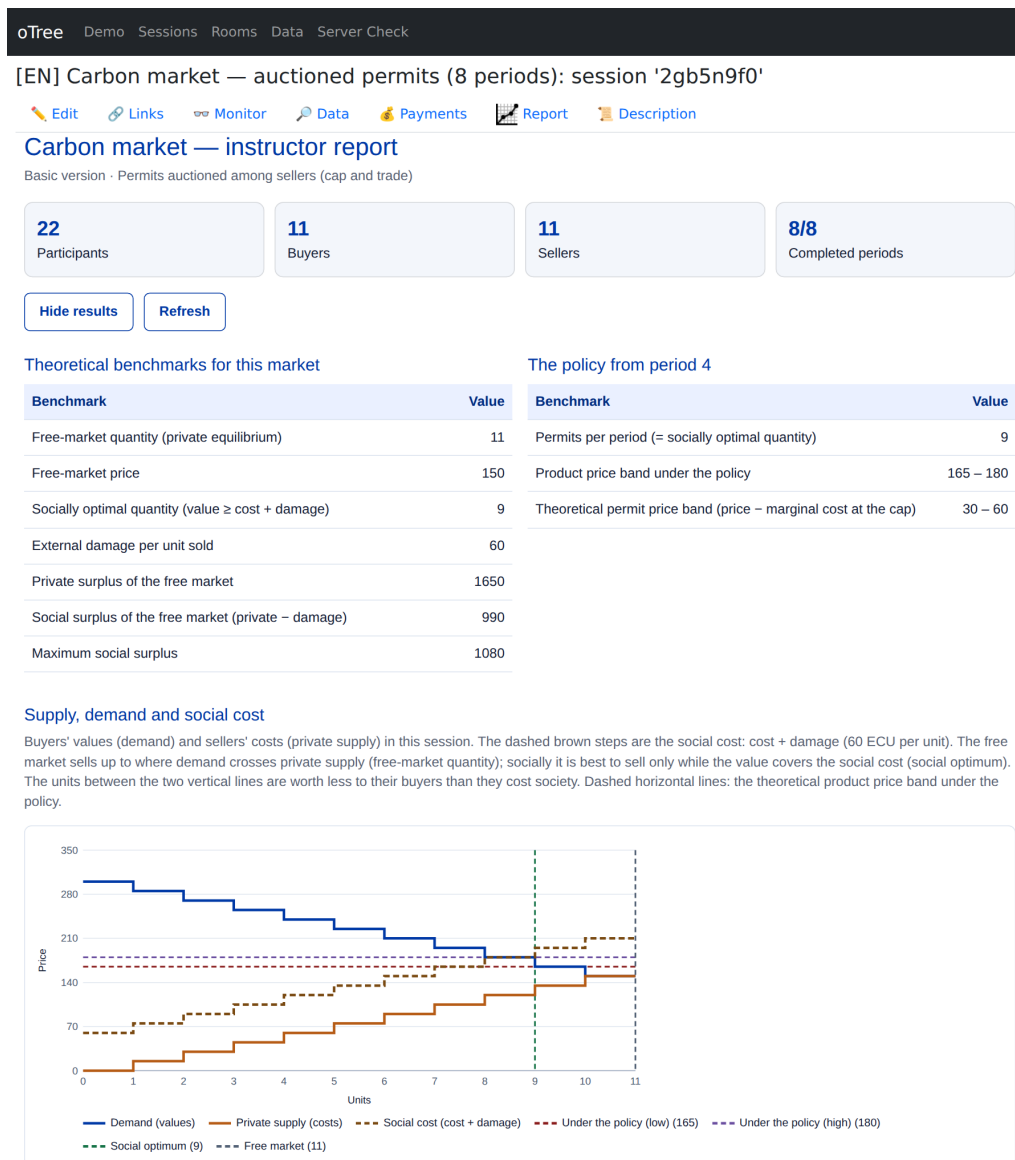
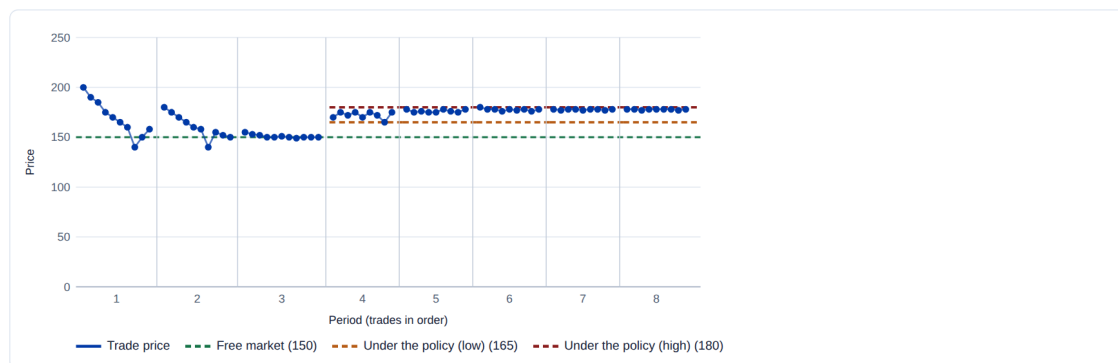


Figure 4.2: Report revealed: free-market and social-optimum benchmarks, the policy, and the session's supply, demand and social cost (simulated decisions).

- Benchmarks and policy** (figure 4.2): the free market trades q_p units (11 with 22 or more, at 150); the social optimum is q_s , the units whose value covers cost plus damage (9). The policy: permits per period, product price band under the cap (165–180) and theoretical permit price band (30–60).
- Supply, demand and social cost**: the picture of the externality. The dashed brown steps are the social cost (cost + 60). The vertical line at 11 marks what the free market sells; the one at 9, the social optimum. Units 10 and 11 lie between them: their value covers the private cost but not the social cost.

Price of every trade, in order

Each dot is a product-market trade, in the order it closed; vertical lines separate the periods. Dashed lines: the free-market price across all periods and, only in the periods with the policy, the theoretical price band under the policy.



Permit price

One dot per period with permits: the uniform auction price (the highest losing bid), paid by every winner. Dashed lines: theoretical permit price band (the product price under the cap minus the cost of the sellers at the margin).

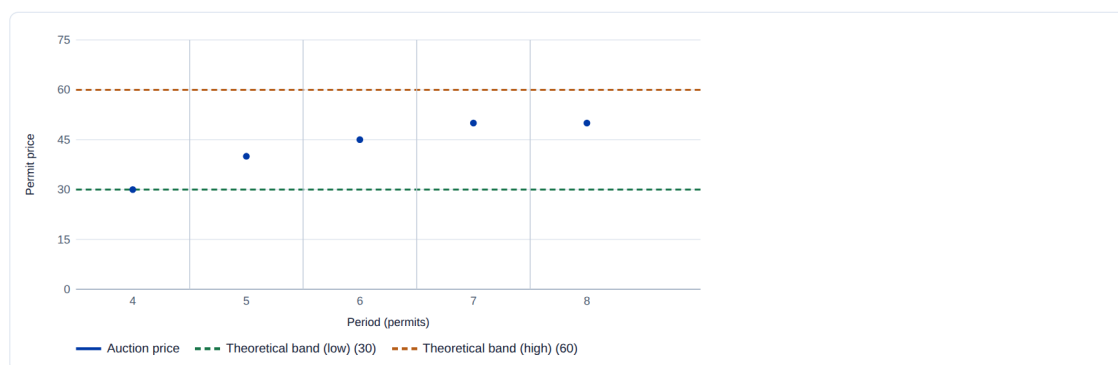


Figure 4.3: Price of every trade in order and the permit price in each auction, with their theoretical bands (simulated decisions).

- Price of every trade, in order:** each dot is a product sale; vertical lines separate the periods. The price converges to 150 in the free periods and jumps into the 165–180 band (drawn only in the periods with permits) when the cap starts.
- Permit price:** with the auction, one dot per period (the uniform price); with free permits, every permit sale between sellers. It should stay within 30–60.

Realized surplus: buyers, sellers and society

Top left, buyers: the steps are demand and each blue bar is the gain of a buyer who bought (from price up to value). Top right, sellers: the steps are supply (costs) and each bar runs from cost up to price; the purple part is what was paid for the permit or as tax and the orange part the net gain (green: income from selling a permit; red: a loss, e.g. a permit paid for and not used). Dashed purple steps: cost + permit price (or + tax), the effective cost of selling. In grey, each side's surplus in the phase's theoretical equilibrium. Bottom, society: demand against the social cost; each unit sold is a bar from social cost up to value, green if it adds social surplus and red if the value does not cover cost + damage (the free market's overproduction). In grey, the maximum social surplus. Choose the period with the buttons.

Period 1

Period 2

Period 3

Period 4

Period 5

Period 6

Period 7

Period 8

Period 8 - Permits auctioned among sellers (cap and trade) · Units sold: 9 (theory: 9) · Units that destroy social surplus: 0 · Efficiency: 100%



Figure 4.4: Realized surplus in a period with permits: buyers, sellers (with what they paid for the permit), society and the period's accounts (simulated decisions).

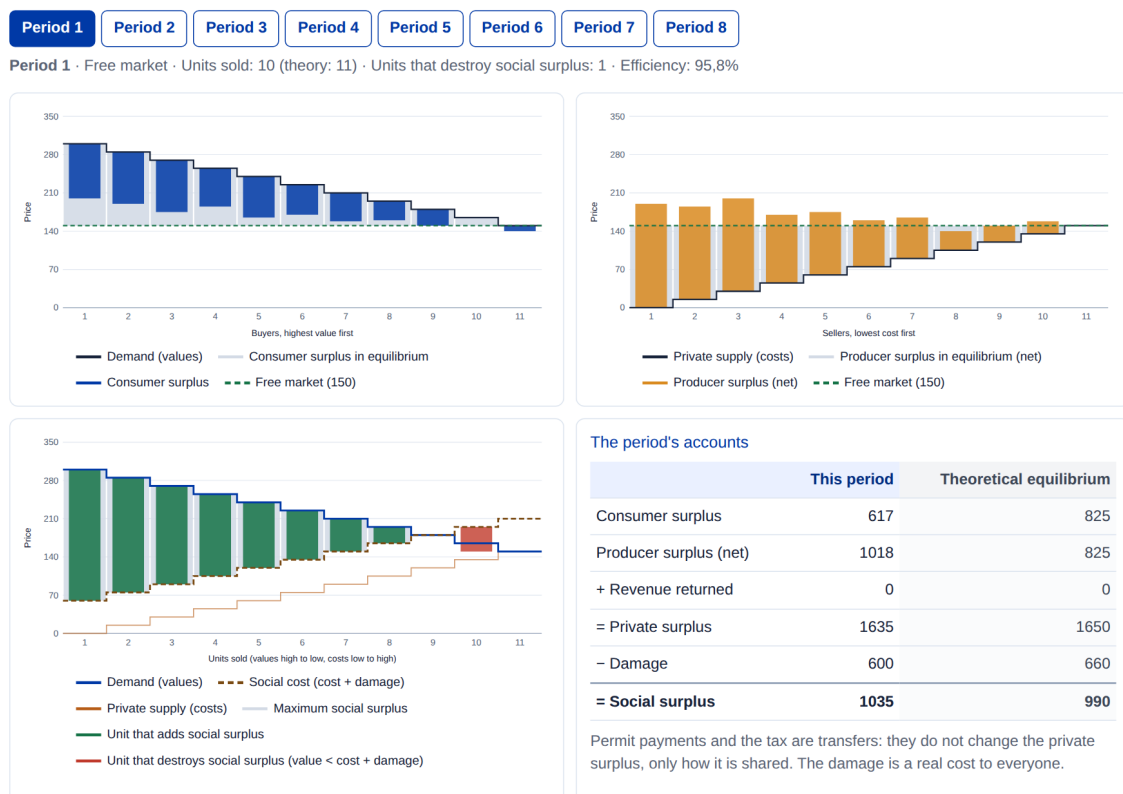


Figure 4.5: The same boxes in a free period: units 10 and 11 show in red, they destroy social surplus (simulated decisions).

5. **Realized surplus** (one button per period; opens on the last): buyers, with a blue bar per buyer who bought (from price up to value); sellers, with a bar per seller who sold, from cost up to price, where the purple part is what they paid for the permit and the orange part their net gain (green: income from selling a permit without producing; red: a permit paid for and not used); and society: demand against the social cost, with one bar per unit sold from social cost up to value, green if it adds and **red if it destroys social surplus**. In grey, the surplus in the phase's theoretical equilibrium (the middle of the price band). The accounts box adds consumer surplus + net producer surplus + revenue = private surplus, and subtracts the damage to reach social surplus: permits and the tax only redistribute.

Before and after the policy (average per period)

	Free market	Auctioned permits	Free market in equilibrium (theory)	Social optimum with the policy (theory)
Periods	3	5	—	—
Units sold	10,3	9	11	9
Product price	160,2	176,3	150	172,5
Permit price	—	43	—	45
Consumer surplus	707,3	570,4	825	607,5
Producer surplus (net)	927,7	659,6	825	607,5
Revenue	0	387	0	405
Private surplus	1635	1617	1650	1620
Damage	620	540	660	540
Social surplus	1015	1077	990	1080
Efficiency	94%	99,7%	91,7%	100%
Smith's α	9,7	2,7	—	—
Sales outside the efficient set	0	0	0	0
Units that destroy social surplus	1,7	0,2	2	0
Damage per participant	28,2	24,5	—	—
Net earnings per participant	46,1	49	—	—

Average per period of each phase and, in grey, the theoretical benchmarks for this number of participants. Consumer surplus = Σ (value – price). Producer surplus (net) = sellers' earnings after paying for permits or the tax. Revenue: auction or tax, returned in equal shares. Consumer + producer + revenue = private surplus = Σ (value – cost); social surplus = private – damage; efficiency = social surplus / maximum social surplus. Smith's α : root mean squared deviation of prices from the phase's theoretical price, as a % of that price. Sales outside the efficient set: units sold by sellers whose cost is not among the K lowest (K = free-market quantity; under the policy, the equilibrium quantity with the policy). Units that destroy social surplus: value < cost + damage, pairing the values (high to low) with the costs (low to high) of the units sold.

Figure 4.6: Before and after the permits, with the free market in equilibrium and the social optimum as benchmarks (simulated decisions).

- Before and after** (average per period, with two grey benchmark columns): units, product and permit prices, consumer surplus, net producer surplus, revenue, private surplus, damage, social surplus, efficiency (social over the maximum), Smith's α (dispersion of prices around the phase's theoretical price, in %), sales by sellers outside the efficient set, units that destroy social surplus, and damage and net earnings per participant. With free permits it adds the permits given to high-cost sellers, those still in their hands when the permit market closes, and the rent of the free permits (permits $\times$ permit price).
- Units and social surplus by period** and a **table by period** with the same measures (figure 4.7).

Results by period

Period	Phase	Units sold	Product price	Permit price	Consumer surplus	Producer surplus (net)	Revenue	Damage	Social surplus	Efficiency	Smith's α	Sales outside the efficient set
1	Free market	10	169,3	—	617	1018	0	600	1035	95,8%	17,4	0
2	Free market	10	160,5	—	690	930	0	600	1020	94,4%	10,4	0
3	Free market	11	150,9	—	815	835	0	660	990	91,7%	1,3	0
4	Auctioned permits	9	172,1	30	596	739	270	540	1065	98,6%	1,9	0
5	Auctioned permits	9	176,2	40	574	686	360	540	1080	100%	2,3	0
6	Auctioned permits	9	177,7	45	561	654	405	540	1080	100%	3,1	0
7	Auctioned permits	9	177,7	50	561	609	450	540	1080	100%	3	0
8	Auctioned permits	9	177,8	50	560	610	450	540	1080	100%	3,1	0

Period totals, with the definitions of the "Before and after" table.

Individual data: Data → Custom export (carbon_market).

Figure 4.7: Units and social surplus by period, and the table by period (simulated decisions).

Debrief script

Start with period 3 in the surplus boxes: project the society chart and ask what the red bars are (units sold although their value does not cover cost plus damage). Ask the high-cost sellers whether selling was worth it (yes: they earned little and paid only 1/22 of the damage). Then move to a period with permits: the red bars disappear, the price rises and the purple part (the permit) appears. With free permits, ask: if the permit was free, why did the product price go up? Who kept the difference?

Theory and evidence

This chapter develops the theory behind the game: the private and the social optimum with the game's induced values and costs, the deadweight loss of overproduction counted unit by unit and with the textbook triangle, the Pigouvian tax, cap and trade and the price of a permit, auctioned versus free permits (including the lottery effect of drawing free permits at random), the performance standard, and how each measure in the instructor report relates to the theory. All numbers are for a class of 22 or more participants (11 buyers and 11 sellers at the margin); the report computes those of your class (section 6.1).

5.1 Notation: private and social optimum

There are N participants: n_B buyers and n_S sellers. The buyer of rank k (from highest value down) values one unit at v_k ; the seller of rank k (from lowest cost up) produces it at c_k . In the game

$$v_k = 300 - 15(k - 1), \quad c_k = 15(k - 1), \quad k = 1, 2, \dots$$

Demand and supply are step functions, $Q^d(p) = \#\{k : v_k \geq p\}$ and $Q^s(p) = \#\{k : c_k \leq p\}$. Every unit sold also causes an external damage $D = 60$. The **private marginal cost** of unit k is c_k ; its **social marginal cost** is $c_k + D$. The two benchmarks are

$$q_p = \max\{k : v_k \geq c_k\}, \quad q_s = \max\{k : v_k \geq c_k + D\}.$$

The free market trades q_p units at any price in the band $[\max(c_{q_p}, v_{q_p+1}), \min(v_{q_p}, c_{q_p+1})]$; with 22 or more participants, $q_p = 11$ and the band shrinks to a point, $p_p = 150$. The social optimum is $q_s = 9$: $v_9 = 180 = c_9 + 60$, while $v_{10} = 165 < c_{10} + 60 = 195$. If q units are traded by the best buyers and sellers,

$$W^{\text{priv}}(q) = \sum_{k=1}^q (v_k - c_k), \quad \text{damage} = Dq, \quad W^{\text{soc}}(q) = W^{\text{priv}}(q) - Dq = \sum_{k=1}^q (v_k - c_k - D).$$

In the game, $W^{\text{priv}}(q_p) = 1650$, the damage is $60 \times 11 = 660$ and $W^{\text{soc}}(q_p) = 990$; at the optimum, $W^{\text{priv}}(q_s) = 1620$, the damage is 540 and the **maximum social surplus** is $W_{\text{max}}^{\text{soc}} = W^{\text{soc}}(q_s) = 1080$. For the trades actually made, W^{priv} is the sum of $v_i - c_j$ over the trades, $W^{\text{soc}} = W^{\text{priv}} - Dq$, and the report's **efficiency** is $E = W^{\text{soc}}/W_{\text{max}}^{\text{soc}}$. A free market exactly at its equilibrium scores $990/1080 = 91.7\%$: the externality costs 8.3% of the maximum even when the market “works”.

Permits and the tax are transfers. With CS the buyers' surplus, PS the sellers' surplus net of what they pay (or receive) for permits and taxes, and R the revenue returned to everyone,

$$\text{CS} + \text{PS} + R = W^{\text{priv}}, \quad W^{\text{soc}} = W^{\text{priv}} - Dq.$$

Unit	Value	Cost	Social cost	Private gain	Social gain
k	v_k	c_k	$c_k + D$	$v_k - c_k$	$v_k - c_k - D$
1	300	0	60	300	240
2	285	15	75	270	210
3	270	30	90	240	180
4	255	45	105	210	150
5	240	60	120	180	120
6	225	75	135	150	90
7	210	90	150	120	60
8	195	105	165	90	30
9	180	120	180	60	0
10	165	135	195	30	-30
11	150	150	210	0	-60
Total 1-9				1620	1080
Total 1-11				1650	990

Theoretical background

The textbook approximation. Straight lines through the steps give inverse demand $P^d(q) = 315 - 15q$, private supply $P^s(q) = 15q - 15$ and social marginal cost $MSC(q) = P^s(q) + D = 15q + 45$. Demand crosses private supply at $q = 11$, $p = 150$, and social marginal cost at $q = 9$, $p = 180$, like the steps. The lines pass through the right-hand corner of each step ($P^d(k) = v_k$, $P^s(k) = c_k$); that detail explains why triangles and steps give different areas (next section).

5.2 The free market: the externality wedge and the deadweight loss

At every quantity the social marginal cost exceeds the private one by the same amount, the **wedge** $D = 60$. The market stops where the private gain runs out ($v_{11} = c_{11} = 150$); society should stop where the social gain runs out ($v_9 = c_9 + D = 180$). The units in between, $k = q_s + 1, \dots, q_p$, satisfy $v_k \geq c_k$ (someone gains by trading them) but $v_k < c_k + D$: each one destroys social surplus. The **deadweight loss of overproduction** is

$$DWL = W^{\text{soc}}(q_s) - W^{\text{soc}}(q_p) = \sum_{k=q_s+1}^{q_p} (c_k + D - v_k) = (195 - 165) + (210 - 150) = 30 + 60 = 90,$$

8.3% of $W_{\text{max}}^{\text{soc}}$. The triangle of the linear approximation is

$$\frac{1}{2} (q_p - q_s) [MSC(q_p) - P^d(q_p)] = \frac{1}{2} \cdot 2 \cdot 60 = 60.$$

Here the steps give a *larger* loss than the triangle. Each step occupies the interval $[k-1, k]$ at the height of the line's right-hand end, where the gap between social cost and value, $MSC(q) - P^d(q) = 30q - 270$, is widest: each overproduced unit loses 15 more than the strip of the triangle above it, and $60 + 2 \times 15 = 90$. With a price ceiling it is the other way round: the units that are lost have positive surplus, and the steps make the loss smaller than the triangle.

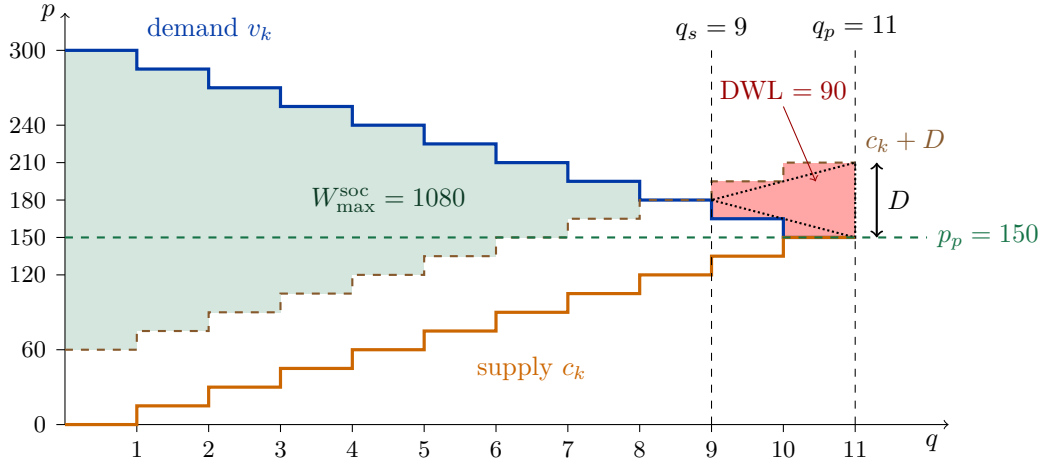


Figure 5.1: The externality with 22 participants. Blue: demand v_k ; orange: private supply c_k ; dashed brown: social cost $c_k + D$. Green: social surplus of units 1–9. Red: units 10 and 11, which the free market trades although $v_k < c_k + D$ (DWL = 30 + 60 = 90). The dotted triangle is the linear approximation (area 60).

Who bears the damage. Everyone, in equal shares: each participant pays Dq/N , that is $660/22 = 30$ in the free-market equilibrium and $540/22 \approx 24.5$ at the optimum, whether or not they traded. A seller who sells one more unit bears only $D/N = 60/22 \approx 2.7$ of the damage of that unit, and its buyer another 2.7; the other 54.5 or so fall on the rest of the class. Strictly, a pair that counted its own shares would trade only if $v_i - c_j \geq 2D/N \approx 5.5$: that rules out unit 11 (private gain 0) but not unit 10, whose gain of 30 exceeds 5.5 yet falls short of the 60 it costs the class. The report keeps the textbook benchmark $q_p = 11$; the larger the class, the smaller D/N . This is the logic of the commons: because the damage is spread over everyone, no one has a reason to stop. It is Pigou's (1920) point: output exceeds the social optimum when private marginal cost is below social marginal cost.

5.3 The Pigouvian tax

A per-unit tax t paid by the seller raises the effective cost of unit k to $c_k + t$. The market trades $q(t) = \max\{k : v_k \geq c_k + t\}$ units, and with $t = D$ the private calculation coincides with the social one: $q(D) = q_s = 9$. The price band $[\max(c_9 + t, v_{10}), \min(v_9, c_{10} + t)] = [\max(180, 165), \min(180, 195)]$ reduces to a single price: buyers pay $p_b = 180$ and sellers keep $p_s = p_b - t = 120$. Compared with the free market, buyers pay 30 more and sellers receive 30 less: with demand and supply equally steep the burden is split in halves, whoever legally pays the tax. Then

$$CS = \sum_{k=1}^9 (v_k - 180) = 540, \quad PS = \sum_{k=1}^9 (120 - c_k) = 540, \quad R = tq = 540,$$

so $W^{\text{priv}} = 1620$, the damage is 540 and $W^{\text{soc}} = 1080 = W_{\text{max}}^{\text{soc}}$. Relative to the free market, $\Delta CS = -285$, $\Delta PS = -285$, $R = +540$ and the damage falls by 120: $\Delta W^{\text{soc}} = -285 - 285 + 540 + 120 = +90$. The private surplus loses only 30 (unit 10; unit 11 had no gain).

Revenue recycling. With $t = D$ the revenue equals the damage, $R = Dq$. Since both are split equally, each participant's share of the revenue (24.5) exactly offsets their share of the damage (24.5). Returning the revenue in equal shares does not undo the incentive, because a participant's share hardly depends on their own sale (only through the same $1/N$ as the damage).

5.4 Cap and trade: the same optimum, set by quantity

Now the regulator issues $Q = q_s = 9$ permits and every unit sold needs one. At product price p a permit is worth $p - c_k$ to seller k . A competitive equilibrium of both markets needs:

1. **Product market:** exactly Q buyers want to buy, $Q^d(p) = Q$, so $p \in [v_{Q+1}, v_Q] = [165, 180]$.
2. **Permit market:** the permits end with the Q lowest-cost sellers: the Q -th prefers using its permit to selling it, $p - c_Q \geq r$, and the $(Q + 1)$ -th prefers not to buy one, $p - c_{Q+1} \leq r$. So $r \in [p - c_{Q+1}, p - c_Q]$.

Together,

$$r \in [v_{Q+1} - c_{Q+1}, v_Q - c_Q] = [165 - 135, 180 - 120] = [30, 60].$$

The permit price is the **wedge between the demand price and the supply price at the cap**, $r = P^d(Q) - P^s(Q)$. With the textbook lines, $P^d(9) - P^s(9) = 180 - 120 = 60 = D$: a cap at q_s yields a permit price equal to the Pigouvian tax. This is the equivalence behind the proposals of [Dales \(1968\)](#) and the result of [Montgomery \(1972\)](#): a competitive permit market reaches an emissions target at least cost. In the discrete market both prices sit on vertical segments of the steps (figure 5.2): at $q = 9$ demand drops from 180 to 165 and supply rises from 120 to 135, so any $p \in [165, 180]$ with $r \in [p - 135, p - 120]$ clears both markets. Only the corner $p = 180$, $r = 60$ reproduces the tax exactly. Nothing in the theory picks a point in the band; the report draws it and uses its middle ($p = 172.5$, $r = 45$) as the phase's theoretical equilibrium.

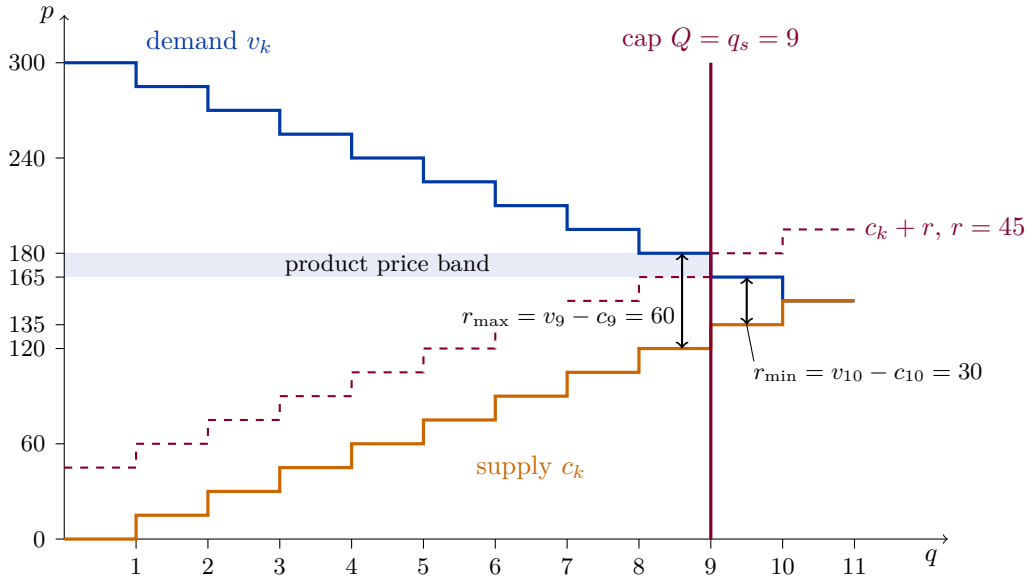


Figure 5.2: Cap and trade with 9 permits and 22 participants. At the cap, the demand price lies between $v_{10} = 165$ and $v_9 = 180$ (shaded band) and the supply price between $c_9 = 120$ and $c_{10} = 135$; the permit price is the gap, between 30 and 60. Dashed purple: the effective supply $c_k + r$ with the report's $r = 45$, which meets demand exactly at the cap.

Who gains within the band. Efficiency is the same at every point of the band ($W^{\text{priv}} = 1620$, $W^{\text{soc}} = 1080$); only the split changes. With the auction:

Point of the band	Product p	Permit r	CS	PS (net)	Revenue $R = Qr$
Lower end	165	30	675	675	270
Middle (report)	172.5	45	607.5	607.5	405
Upper end (= tax)	180	60	540	540	540

The auction. Each seller bids for at most one permit; the 9 highest bids win and all pay the highest losing bid. As in [Vickrey \(1961\)](#), with unit demand and that pricing rule, bidding what the permit is worth, $p^e - c_k$ with p^e the product price one expects, is a weakly dominant strategy: the bid decides whether one wins, not what one pays. If sellers bid that way, the 9 lowest-cost sellers win and the price is the tenth bid, $p^e - c_{10} = p^e - 135$: 37.5 if they expect 172.5, and between 30 and 45 across the band. A winner pays even if it then does not sell, so overbidding can leave a loss (a red bar in the sellers' panel).

5.5 Auctioned or free permits: same efficiency, different winners

Efficiency. When permits can be traded at no cost, their final allocation does not depend on who received them: each permit ends with the seller who values it most ([Coase, 1960](#); [Montgomery, 1972](#)). With free permits the same 9 sellers end up producing as with the auction, at the same product price.

Opportunity cost and pass-through. A free permit is not free to its holder: using it means giving up selling it at r . The holder's effective cost is $c_k + r$, the same as if it had bought the permit, so the product price rises from 150 to the same band, $[165, 180]$, even though nobody paid for the permits.

Windfall rents. The scarcity rent Qr is between $9 \times 30 = 270$ and $9 \times 60 = 540$ (405 in the middle of the band). With the auction it goes to everyone ($405/22 \approx 18.4$ per participant); with free permits it goes to whoever received them. In the middle of the band, net producer surplus is 1012.5 with free permits against 825 in the free market (between 945 and 1080 across the band): *sellers as a group gain from the regulation*, and buyers pay for it (CS falls from 825 to 607.5).

The lottery effect. In the game the 9 free permits are drawn at random each period among the 11 sellers. The textbook argument assumes they are then traded to the cheapest sellers; consider first what happens if they are not. Each seller receives a permit with probability $Q/n_S = 9/11$, so the expected cost of the holders is

$$\mathbb{E}\left[\sum_{\text{holders}} c\right] = Q \bar{c}_S, \quad \bar{c}_S = \frac{1}{n_S} \sum_{k=1}^{n_S} c_k = 75,$$

that is $9 \times 75 = 675$ instead of $\sum_{k=1}^9 c_k = 540$. All holders can sell (the highest cost, 150, is below $v_9 = 180$), so without permit trading

$$\mathbb{E}[W_{\text{lottery}}^{\text{soc}}] = \sum_{k=1}^Q v_k - Q \bar{c}_S - DQ = 2160 - 675 - 540 = 945,$$

and the whole loss with respect to the maximum is misallocation:

$$W_{\text{max}}^{\text{soc}} - \mathbb{E}[W_{\text{lottery}}^{\text{soc}}] = \underbrace{Q \bar{c}_S - \sum_{k=1}^Q c_k}_{\text{misallocation}} = 675 - 540 = 135.$$

The number H of permits that land with the two high-cost sellers (ranks 10 and 11) is hypergeometric: $P(H = 2) = 36/55 \approx 65\%$, $P(H = 1) = 18/55 \approx 33\%$, $P(H = 0) = 1/55 \approx 2\%$, with $\mathbb{E}[H] = 2 \times 9/11 \approx 1.64$.

22 participants	Units	Social surplus	Efficiency	Loss
Free market in equilibrium (overproduction)	11	990	91.7 %	90
Cap, efficient allocation (auction, or free permits traded)	9	1080	100 %	0
Free permits drawn at random, no permit trading (misallocation)	9	945	87.5 %	135

Giving the permits away at random and stopping there would be *worse* than doing nothing: 87.5 % against 91.7 %. The permit market is what turns the lottery into the efficient allocation. Each permit that moves from a high-cost holder to a low-cost seller without one recovers the difference in costs (from seller 11, cost 150, to seller 2, cost 15: 135); on average 1.64 such sales per period are needed. A high-cost holder that keeps its permit and sells can even produce a unit that destroys social surplus (cost 150 with a buyer of value 180: $180 - 150 - 60 = -30$), so red bars can appear under the cap. The loss grows with the class: with 24 participants (12 sellers for 9 permits) expected efficiency without trading falls to 81.3 %, and with 30 to 69.3 % (some holders cannot even sell: 8.1 units on average), while the free market and the optimum stay at 990 and 1080.

Theoretical background

Does the permit market fix the lottery in the lab? The draw is real, but the permit market has only 90 seconds and every reallocation needs a high-cost holder and a low-cost seller to agree on a price between their values. The report measures how much of the lottery remains: “free permits given to high-cost sellers” is H (expected 1.64 with 22), “permits held by high-cost sellers when the permit market closes” is what is left (0 if trading is efficient), and “sales outside the efficient set” counts the units sold by sellers ranked above q_s . Compare the efficiency of the periods with permits with 87.5 % (no reallocation) and 100 % (full reallocation). [Goeree et al. \(2010\)](#) found that resale did not fully correct a free initial allocation (section 5.8).

5.6 The performance standard

In the extended version’s standard, only sellers with $c_k \leq \bar{c}$ may sell. With $\bar{c} = c_{q_s} = 120$ exactly 9 sellers qualify and the market becomes one with 11 buyers and 9 sellers: $q = 9$ and $p \in [\max(c_9, v_{10}), v_9] = [165, 180]$. It reaches $W_{\max}^{\text{soc}} = 1080$ without revenue; the scarcity rent stays with the authorized sellers (PS = 1012.5 in the middle of the band), as with free permits, but there is no market to correct a mistaken allocation.

Information. To set $\bar{c}$ the regulator must know every seller’s cost. If it errs, the outcome changes:

Threshold $\bar{c}$	90	105	120	135	150	9 sellers at random
Sellers allowed (units)	7	8	9	10	11	9
Social surplus	1050	1080	1080	1050	990	945 (expected)
Efficiency	97.2 %	100 %	100 %	97.2 %	91.7 %	87.5 %

(A threshold of 105 loses nothing only because unit 9 carries no social surplus.) A regulator that could not tell sellers apart and authorized 9 at random would reproduce the lottery. The tax and tradable permits need none of this information: each seller compares its own cost with the tax or with the permit price.

Prices or quantities. With full information the tax and the cap are equivalent. [Weitzman \(1974\)](#) shows that when the regulator is uncertain about costs they are not: a tax fixes the price of

pollution and lets the quantity adjust, a cap fixes the quantity and lets the price adjust, and which instrument has the smaller expected loss depends on the relative slopes of the marginal benefit of reducing pollution (here, the marginal damage) and of its marginal cost; a flat marginal damage favours the price instrument. In this game the damage per unit is constant, the flattest case: a tax equal to D reaches the optimum whatever the costs turn out to be. If every cost were 15 higher than the regulator believed, the optimum would be 8 units ($W^{\text{soc}} = 960$): the tax of 60 would get there by itself, while a cap of 9 permits would let a ninth unit through (945). With costs 30 higher the optimum is again 8 units (840) and the cap gives 810. Use it as a discussion point, not as a general ranking of the instruments.

5.7 From the textbook to the lab: what the report measures

1. **Supply, demand and social cost.** The report's chart is figure 5.1 with your class's numbers: the dashed brown steps are $c_k + D$, the vertical lines mark q_s and q_p , and the horizontal lines the policy's price band (165–180 under the cap and the standard; 180 under the tax).
2. **The three surplus panels.** Buyers: one bar $v_i - p$ per buyer who bought; the grey area is CS in the phase's theoretical equilibrium. Sellers: one bar from cost to price per seller who sold, split into what was paid for the permit or the tax (purple) and the net gain (orange); the dashed purple steps are the effective supply $c_k + r$ or $c_k + t$. Society: the units sold are paired (values from high to low, costs from low to high) and each one is a bar from $c + D$ to v , green if it adds and **red** if $v < c + D$. The signed sum of the bars is W^{soc} , whoever traded with whom. In a free period the red bars are units 10 and 11 of figure 5.1; under a policy they appear only if a high-cost seller sold.
3. **The period accounts** check the identity $\text{CS} + \text{PS} + R = W^{\text{priv}}$, $W^{\text{priv}} - Dq = W^{\text{soc}}$, against the same numbers in the phase's theoretical equilibrium.
4. **Loss decomposition.** With q units traded,

$$W_{\text{max}}^{\text{soc}} - W^{\text{soc}} = \underbrace{(W_{\text{max}}^{\text{soc}} - W^{\text{soc}}(q))}_{\text{quantity: over- or underproduction}} + \underbrace{(W^{\text{soc}}(q) - W^{\text{soc}})}_{\text{allocation: who traded}}.$$

The quantity term is 90 with 11 units, 30 with 10, 0 with 9 or 8, 30 with 7 and 90 with 6. The allocation term is what the textbook ignores: units bought by buyers outside the best q or sold by sellers outside the cheapest q (in the cap periods with free permits, typically high-cost holders). The columns “units that destroy social surplus” and “sales outside the efficient set” (sellers ranked above q_p without the policy, above q_s with it) point to it.

5. **Before and after.** The grey benchmark columns are the following theoretical outcomes (22 or more participants; the cap and the standard at the middle of their band):

	Free market	Tax $t = 60$	Cap, auction	Cap, free permits	Standard
Units	11	9	9	9	9
Product price	150	180	172.5	172.5	172.5
Permit price or tax	–	60	45	45	–
Consumer surplus	825	540	607.5	607.5	607.5
Producer surplus (net)	825	540	607.5	1012.5	1012.5
Revenue	0	540	405	0	0
Private surplus	1650	1620	1620	1620	1620
Damage	660	540	540	540	540
Social surplus	990	1080	1080	1080	1080
Efficiency	91.7 %	100 %	100 %	100 %	100 %

With free permits the net producer surplus includes the rent of the free permits, $9 \times 45 = 405$ (the column “rent of the free permits”); the benchmark for permits held by high-cost sellers at the close is 0.

6. **Convergence:** the coefficient of [Smith \(1962\)](#),

$$\alpha = \frac{100}{p^*} \sqrt{\frac{1}{n} \sum_{t=1}^n (p_t - p^*)^2},$$

with p^* the phase’s theoretical price: 150 in the free market, 180 under the tax, 172.5 (the middle of the band) under the cap and the standard. Under the tax the band is a single price and α measures convergence as in the free market. Under the cap and the standard it does not: if every trade closes at 180, or every trade at 165, $\alpha = 100 \cdot 7.5/172.5 = 4.3$ although both are equilibrium prices. Read it together with the band in the price chart.

5.8 Experimental evidence

The continuous double auction converges quickly to the competitive equilibrium ([Smith, 1962](#)). [Plott \(1983\)](#) brought markets with an externality into the lab and asked whether they behave according to supply and demand, and how a pollution tax, a standard and licences (permits) compare as corrective policies; it is the direct antecedent of this game. Since then the lab has been used to test permit markets before using them in the field. [Goeree et al. \(2010\)](#), with a design motivated by the CO₂ allowance auctions of the US Northeast (RGGI), compared auctioning with free allocation of permits followed by a resale market. According to the paper’s abstract, under free allocation resale did not fully correct the initial allocation (high emitters used their market power to keep permits), whereas the auction assigned most permits to low emitters; the auction yielded higher consumer surplus and slightly lower product prices and removed the large windfall profits of free allocation. [Holt \(2019\)](#) presents classroom versions of these experiments.

5.9 Regularities worth discussing

- The free market trades more units than the social optimum, even though everyone pays a share of the damage. In equilibrium its efficiency is 91.7 %.
- Under the cap, units fall and the product price rises; the permit price reflects the gap between the product price and the marginal seller’s cost, anywhere between 30 and 60.

- With free permits the product price rises too: the permit has an opportunity cost. Those who received permits earn even without producing, and sellers as a group can end up better off than without the policy.
- With free permits, the efficiency of the cap depends on the permit market: compare it with 87.5 % (permits stay where they draw put them) and 100 % (all reallocated).
- Private surplus falls with the policy but social surplus rises: buyers lose, and the revenue (or the free permits) changes who gains.

Note

Results from one class are descriptive: a single market, with periods that are not independent observations. A difference between periods 1–3 and 4–8 mixes the effect of the policy with learning; the extended no-policy configuration serves as a control.

Basic configurations

Both basic configurations have 8 periods of 150 seconds: 3 free-market periods and 5 with permits.

Configuration	What it is for
<code>carbon_market_en_auction</code>	Auctioned permits (uniform price), revenue returned to everyone. The most direct option: the permit price is visible and the rent goes to the public.
<code>carbon_market_en_grandfather</code>	Free permits to random sellers and a permit market among sellers (90 s per period). For discussing opportunity cost and the windfall profits of free allocation. Takes about 7 more minutes.

6.1 Class size

The number of permits is the class's social optimum, q_s , and depends on the number of sellers. With 9 sellers or fewer (18 students or fewer), every free-market unit is worth more than its cost plus the damage: $q_s = q_p$ and the permits change nothing. The report warns about it.

Students	Free market	Social optimum (permits)	Product under cap	Permit
18	9 units, 120–180	9	no change	0
20	10 units, 135–165	9	165–180	30–60
22 or more	11 units, 150	9	165–180	30–60

For the instructor

If you have time for two sessions, play auctioned permits first and free permits second with the same class: the contrast is that of [Goeree et al. \(2010\)](#). Or play the basic version and then the tax from the extended version.

Extended version: comparing policies

The extended version uses the room [EN] **Carbon Market — extended (policy comparison)**. The market, the environmental cost and the three free periods are the same; from period 4 the policy changes.

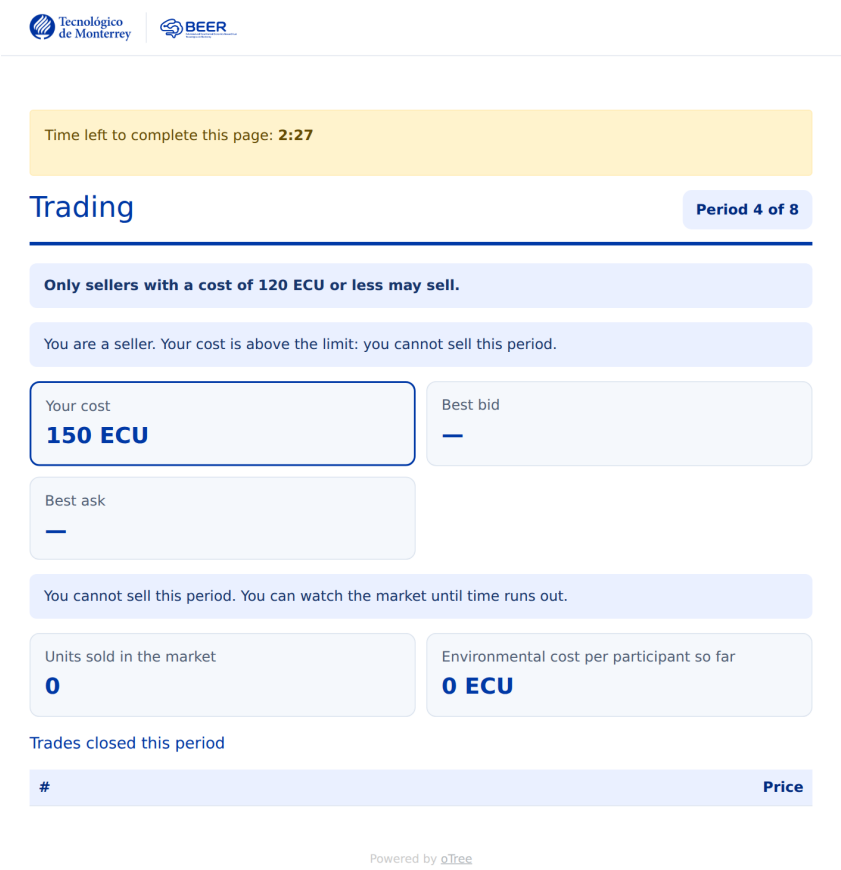
Configuration	What changes from period 4
<code>carbon_market_extended_tax</code>	Each seller pays a tax of 60 ECU per unit sold. The system refuses asks and acceptances below cost plus tax. The revenue is returned in equal shares. Theory: 9 units at 180.
<code>carbon_market_extended_standard</code>	“Command and control” standard: only sellers with a cost of 120 ECU or less may sell (with 22 or more; the level leaves exactly q_s sellers). No revenue. Theory: 9 units at 165–180.
<code>carbon_market_extended_no_policy</code>	Nothing: the externality in all 8 periods. A control group that separates the policy’s effect from learning.

For the instructor

The standard assumes the regulator knows which sellers produce most cheaply, which is why in theory it reaches the optimum with the right allocation. Discuss what would happen if it did not (for example, if it forced everyone to cut back equally): permits and the tax need no such information, because each seller decides with its own cost ([Montgomery, 1972](#)).

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Price



Period result

Period 4 of 8

Your role
sellerYour cost
15Did you trade?
YesPrice
185

What you earned from trading	170
Tax paid	-60
Your share of the environmental cost	-21.8
Your share of the money raised	+21.8

Your earnings for the period 110 ECU
Units sold in the market
8Total environmental cost
480 ECUTotal money raised (split among everyone)
480 ECUCumulative earnings
498.4 ECU

All trades this period

#	Price
1	185
2	182
3	185
4	180
5	182
6	180
7	180
8	180

Next period

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Figure 7.4: Result of a seller under the tax: tax paid, environmental cost and share of the revenue (simulated decisions).

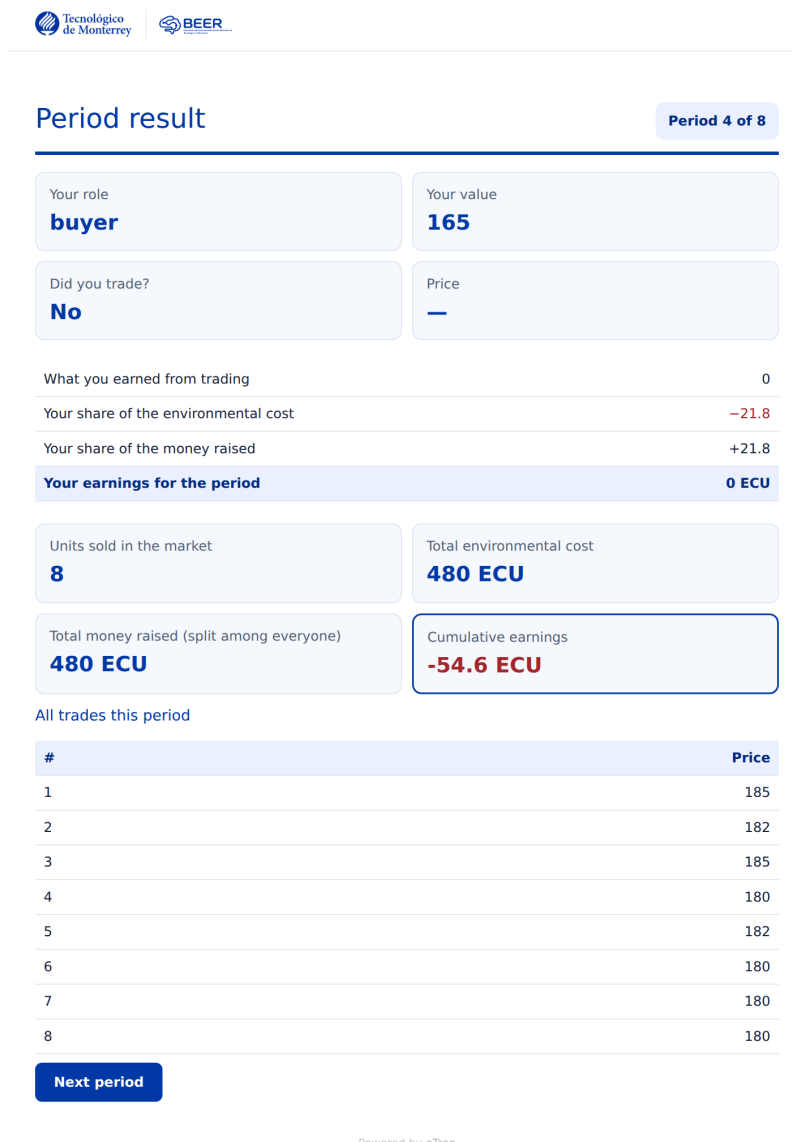


Figure 7.5: Result of a buyer who did not buy: pays a share of the environmental cost and receives a share of the revenue (simulated decisions).

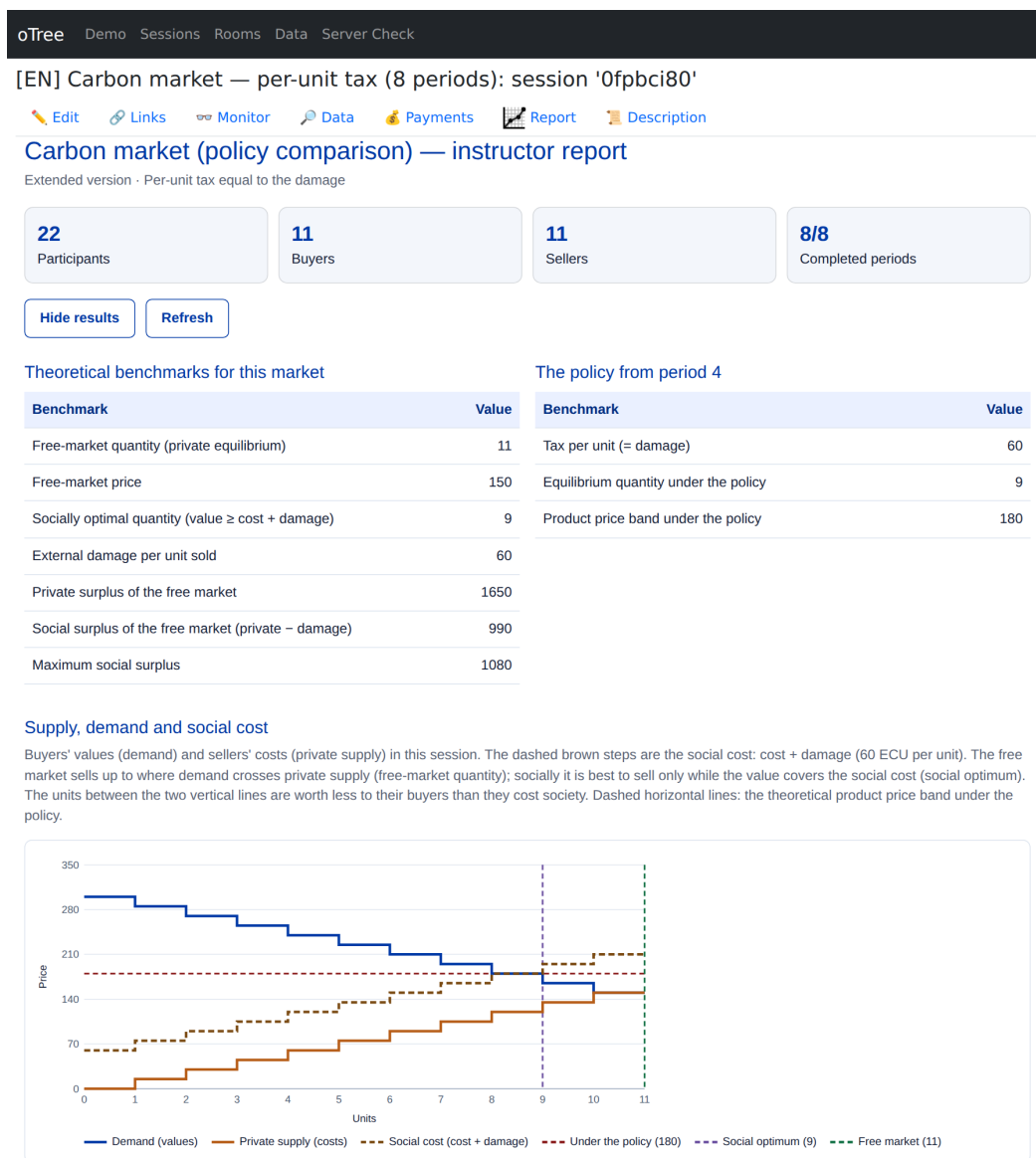


Figure 7.6: Extended report (tax): benchmarks, policy and social cost; with the tax the price band is a single price, 180 (simulated decisions).

Price of every trade, in order

Each dot is a product-market trade, in the order it closed; vertical lines separate the periods. Dashed lines: the free-market price across all periods and, only in the periods with the policy, the theoretical price band under the policy.



Figure 7.7: Price of every trade: from period 4 it moves to cost plus tax, 180 (simulated decisions).

Realized surplus: buyers, sellers and society

Top left, buyers: the steps are demand and each blue bar is the gain of a buyer who bought (from price up to value). Top right, sellers: the steps are supply (costs) and each bar runs from cost up to price; the purple part is what was paid for the permit or as tax and the orange part the net gain (green: income from selling a permit; red: a loss, e.g. a permit paid for and not used). Dashed purple steps: cost + permit price (or + tax), the effective cost of selling. In grey, each side's surplus in the phase's theoretical equilibrium. Bottom, society: demand against the social cost; each unit sold is a bar from social cost up to value, green if it adds social surplus and red if the value does not cover cost + damage (the free market's overproduction). In grey, the maximum social surplus. Choose the period with the buttons.

Period 1

Period 2

Period 3

Period 4

Period 5

Period 6

Period 7

Period 8

Period 8 · Per-unit tax equal to the damage · Units sold: 9 (theory: 9) · Units that destroy social surplus: 0 · Efficiency: 100%



Figure 7.8: Realized surplus with the tax: each seller's purple part is the tax paid, and the dashed purple steps are cost plus tax (simulated decisions).

Before and after the policy (average per period)

	Free market	Tax	Free market in equilibrium (theory)	Social optimum with the policy (theory)
Periods	3	5	—	—
Units sold	10,3	8,8	11	9
Product price	160,2	180,5	150	180
Consumer surplus	707,3	533,2	825	540
Producer surplus (net)	927,7	543,8	825	540
Revenue	0	528	0	540
Private surplus	1635	1605	1650	1620
Damage	620	528	660	540
Social surplus	1015	1077	990	1080
Efficiency	94%	99,7%	91,7%	100%
Smith's α	9,7	0,4	—	—
Sales outside the efficient set	0	0	0	0
Units that destroy social surplus	1,7	0	2	0
Damage per participant	28,2	24	—	—
Net earnings per participant	46,1	49	—	—

Average per period of each phase and, in grey, the theoretical benchmarks for this number of participants. Consumer surplus = Σ (value – price). Producer surplus (net) = sellers' earnings after paying for permits or the tax. Revenue: auction or tax, returned in equal shares. Consumer + producer + revenue = private surplus = Σ (value – cost); social surplus = private – damage; efficiency = social surplus / maximum social surplus. Smith's α : root mean squared deviation of prices from the phase's theoretical price, as a % of that price. Sales outside the efficient set: units sold by sellers whose cost is not among the K lowest (K = free-market quantity; under the policy, the equilibrium quantity with the policy). Units that destroy social surplus: value < cost + damage, pairing the values (high to low) with the costs (low to high) of the units sold.

Figure 7.9: Before and after the tax (simulated decisions).

Debrief script

If you played the basic version and an extended one with the same class, compare: were as many units sold under the tax as under the permits? Did the permit price get close to the tax? Who paid for the policy in each case, and who kept the revenue or the rent?

Lesson plan and reading the results

8.1 Suggested 50-minute session (basic version)

0–5 min	Create the session. Students join by QR or link.
5–12 min	Instructions and comprehension check.
12–22 min	Periods 1 to 3, free market. After period 3 you can reveal the report and ask for predictions.
22–37 min	Permit announcement and periods 4 to 8 (about 7 more minutes with free permits).
37–50 min	Reveal: units, prices, permit price and social surplus; close with the policy question.

8.2 Questions to lead the discussion

- In the free market, why did high-cost sellers sell if each unit cost the group 60?
- With permits, why did the product price rise? Who paid for the policy?
- With free permits, why would a seller who received a permit sell it instead of using it?
- Why can the permit price not exceed 60 when the product sells at 180?
- What is better for the public: auctioning permits or giving them away? And for firms?
- (Extended) Did the tax and the cap give the same result? What if the regulator did not know costs?

8.3 Common misreadings

Misreading	Clarification
“If permits are free, the price does not rise.”	Using the permit means giving up selling it: an opportunity cost that is passed into the price.
“The policy makes everyone worse off because less is sold.”	Private surplus falls, but damage falls more: social surplus rises.
“Sellers pay for the policy.”	With the auction or the tax, buyers pay much of it through a higher price; with free permits, the sellers who received them may come out ahead.
“The permit price should be 60.”	In this design any price between 30 and 60 clears the permit market; 60 is the end where the cap coincides with the tax.

Operation, privacy and troubleshooting

9.1 Privacy and conduct

Participant codes are anonymous: do not ask for or show names alongside individual decisions. Project only aggregate results.

9.2 Common problems

Situation	What to do
A student sees “Session is full”.	Close the room and create another session with the right number.
The market keeps waiting.	Someone did not move on; ask them to reopen the room or use Advance slowest participants .
Nobody trades any more (product or permits) and many seconds are left.	Use Advance slowest participants in the Monitor to close the phase.
The permits changed nothing.	There are fewer than 20 students (section 6.1).
A seller did not submit an auction bid.	When time runs out it counts as 0 (no permit).

9.3 Data for later analysis

Data → **Custom export** (`carbon_market` or `carbon_policy`) downloads one row per person and period: treatment, whether the policy applied, permits in the period, role, value or cost, auction bid, permit received and held at the end, amount paid in the auction, permit purchases and sales and their price, auction price, whether they traded, price, profit from the trade, tax, private earnings, share of the environmental cost, share of the revenue, period earnings, market totals and how many bids and asks they sent (accepted, refused by the policy, invalid). After a blank row comes the log of **every bid and ask**, in order, in the product and the permit markets: period, market, participant, side, price and status (`ok`, `invalid`, `no_permit`, `not_allowed_standard`, `below_cost_plus_tax`, `has_permit`). It contains no personal identifiers.

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QR codes for each room

English, basic



`carbonmarket.beer-lab.org/room/carbon_market_en`

English, extended



carbonmarket.beer-lab.org/room/carbon_market_extended

Español, básica



`carbonmarket.beer-lab.org/room/carbon_market_es`

Español, extendida



carbonmarket.beer-lab.org/room/carbon_market_extendido