



Instructor guide to externalities and regulation

Laboratory implementation, theoretical foundations,
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 supports the Externalities and Regulation family developed by the Behavioral and Experimental Economics Research Lab in the Department of Economics at Tecnológico de Monterrey. It is written for instructors in microeconomics, public economics, environmental economics, regulation, industrial organization, experimental methods, and introductory economics. No prior experience with oTree or environmental instruments is assumed. The discussion moves from session logistics to theoretical predictions, experimental evidence, and standards for a careful debrief.

The family combines one basic design and eight extensions in a single application. The three basic modes offer one round, ten rounds with fixed firms, and ten rounds with reassignment. The extensions compare no regulation, dirty technology only, a clean standard, a Pigouvian tax, a clean-technology subsidy, tradable permits, hidden harm, and uncertain harm. Common elements are explained once; each variant is then documented for the specific mechanism and teaching question it isolates.

An instructor may read the document operationally, conceptually, or modularly. For an immediate class, use the quick guide, access chapter, and one lesson plan. For a substantive debrief, study the model, benchmarks, and aggregate report. For a sequence across several classes, the discussion notes and solved exercises connect the activity to distribution, information, uncertainty, and institutional design.

Author

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For the instructor

Project only the anonymous aggregate report. Do not display participant codes or associate choices with names, student IDs, computers, or seats. The report remains hidden until the instructor deliberately reveals it.

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Quick guide and learning outcomes

1.1 Access through the updated laboratory website

Start at <https://beer-lab.org/en/>. Select **CLASSROOM** in the top navigation menu; it opens <https://teaching.beer-lab.org/en/>. In the **Classroom experiments** catalog, use the search box to locate the activity by name. You can also filter by **Topic** or **JEL code**. Clear any filters left from an earlier search before looking for another game.

Each family's card distinguishes **Español** and **English** access links. The **Show extended version** checkbox selects that edition before following a link. Catalog language and session language are separate choices: verify both. Students use the room specified by the instructor; the instructor prepares and monitors the session through this family's own administrative pages.

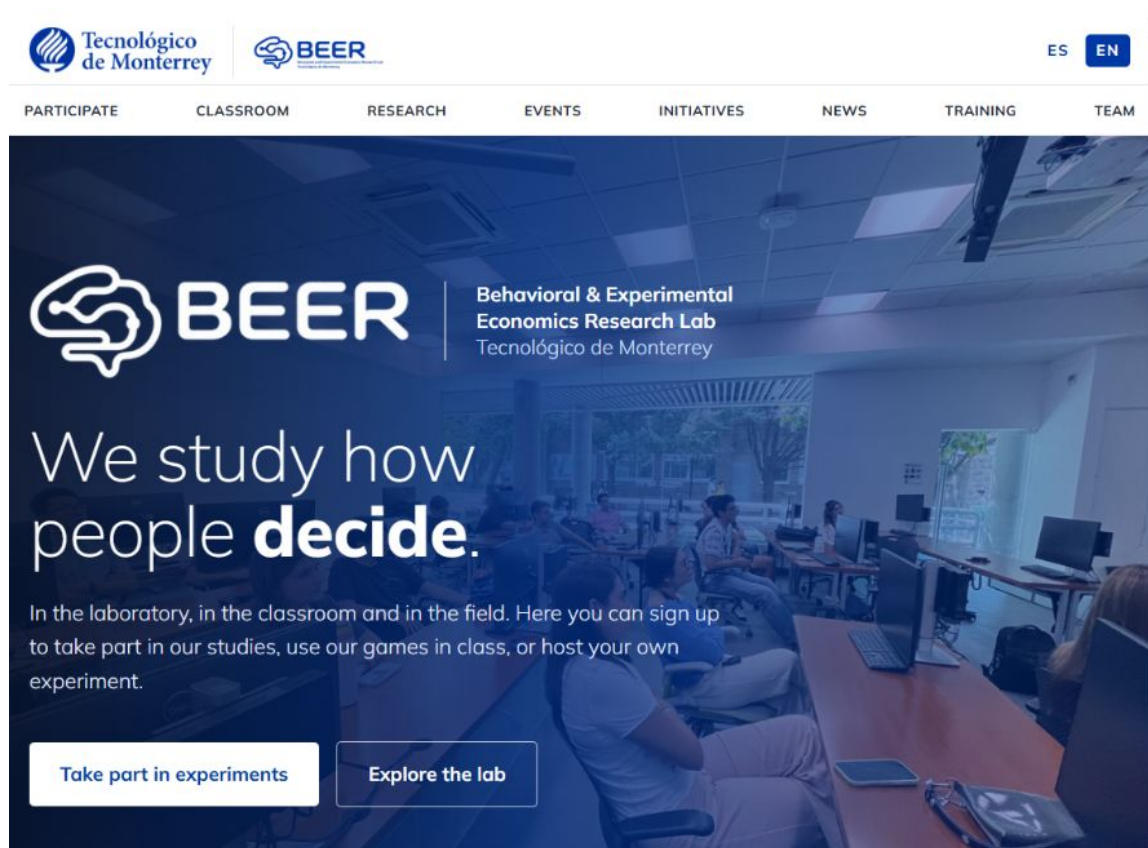


Figure 1.1: Current institutional website. Select CLASSROOM in the top navigation menu to open the teaching experiments. Captured on October 7, 2026.



Figure 1.2: Current catalog: search by title, topic, or JEL code. Then locate this family's card and select language and edition. Captured on October 7, 2026.

Checking resources, comprehension, and participant requirements

Before opening the room, check the selected configuration and the number of students present. The session-creation form states the group size and minimum required by that configuration. An individual activity accepts any positive participant count; an interactive activity must satisfy its stated requirement: complete groups when size is fixed, or a minimum participant count when size is flexible. Requirements may change across treatments, for example when adding a third party or changing an institution's size. If you edit a grouping parameter, check the requirement for the edited configuration, rather than relying only on the demo's suggested count.

In the instructions, ensure that students can identify what each role receives, what they can decide, and how the outcome is calculated. An initial account, a distributable budget, and final earnings need not be the same amount. Refer to the resources panel and the example for the selected treatment. Do not carry the basic edition's endowment into a treatment that changes accounts or introduces additional positions.

ECU stands for *Experimental Currency Units*: the activity's unit of account. An outcome of 100 ECU does not automatically equal 100 pesos or 100 dollars. Conversion depends on the session configuration. Before announcing a payment, confirm with the laboratory whether money is paid, the conversion rate, and which decisions count for payment. In hypothetical modules, describe amounts as outcomes in the stated situation.

When a comprehension check is included, an incorrect response receives an explanation beside that question, identifying the submitted answer and the correct answer. Other answers remain in the form. Ask the student to return to the example, locate the relevant rule, and redo the calculation before correcting the response. Avoid revealing answers to the entire class for an individual error, and do not interpret a comprehension mistake as an economic choice in the game.

es y regulación — una ronda	Externalidades y regulación / Externalities and Regulation — BEER Lab Seleccione una variante de este juego. Select a version of this game.
es y regulación — 10 rondas, mismas empresas	
es y regulación — 10 rondas, empresas reasignadas	
and Regulation — one round	
and Regulation — 10 rounds, same firms	
and Regulation — 10 rounds, reassigned firms	
es y regulación extendida — sin regulación	
es y regulación extendida — tecnología sucia obligatoria	
es y regulación extendida — estándar de tecnología limpia	
es y regulación extendida — impuesto pigouviano	
es y regulación extendida — subsidio a producción limpia	
es y regulación extendida — permisos transferibles	
es y regulación extendida — daño no cuantificado antes de decidir	
es y regulación extendida — daño ambiental incierto	
ternalities and Regulation — no regulation	
ternalities and Regulation — dirty technology only	
ternalities and Regulation — clean-technology standard	
ternalities and Regulation — Pigouvian tax	
ternalities and Regulation — clean-production subsidy	
ternalities and Regulation — tradable permits	
ternalities and Regulation — damage not quantified before choice	
ternalities and Regulation — uncertain environmental damage	

Figure 1.3: Demo contains only the configurations of this game family, in both languages and editions.

Rooms

Current rooms:

[ES] Externalidades y regulación
[EN] Externalities and Regulation
[ES] Externalidades y regulación: extendida
[EN] Externalities and Regulation: extended

Figure 1.4: Rooms contains the four rooms for this family: basic and extended editions in Spanish and English.

Room: [EN] Externalities and Regulation

Create a new session

Session Config

[EN] Externalities and Regulation — one round

Number of participants

Complete groups of 4 participants. Use a multiple of 4; minimum 4.

Create

[Configure session](#) 

App sequence

externalities_regulation_game (10 rounds)

A classroom experiment comparing environmental policy instruments.

Figure 1.5: Session-creation form for the basic English room. Check the selected configuration and participant requirement before creating the session.

Downloading a session with several rounds

For the instructor

Open **Data** within the relevant session and use that session's CSV or CSV-for-Excel download link. The general export has one row per participant and columns for the different rounds. Ten rounds do not necessarily mean ten rows per person. When the family provides its own long-format export, observations may instead be organized by participant and round or another unit defined by the design.

Save the original file together with the configuration name, session code, and active-round count. Check that columns for the last active round are present and that the data belong to the selected session. Empty cells can represent inactive rounds, a pending decision, or a field that does not apply to a role; do not automatically recode them as zeros. To compare learning, preserve round and group identifiers alongside participant identifiers. Share only anonymous aggregates in class, and record session incidents before constructing derived tables.

1.2 Family profile

oTree application	externalities_regulation_game
Server family	GAME_FAMILY=externalities
Experimental unit	Community of four heterogeneous firms
Decision	Total output, clean units, and, when applicable, a permit request
Horizon	One or ten rounds
Endowment	40 ECU per firm and round
Reference harm	4 ECU per dirty unit, shared by four firms

Instruments	Standard, tax, subsidy, permits, and harm information
Instructor report	Distributions, round series, efficiency, and choices by firm type
Purpose	Compare production, clean technology, harm, and welfare under different environmental regulation institutions.
Basic edition	one round; 10 rounds, same firms; 10 rounds, reassigned firms.
Extended edition	no regulation; dirty technology only; clean-technology standard; Pigouvian tax; clean-production subsidy; tradable permits; damage not quantified before choice; uncertain environmental damage.
Outcome	Private profit, environmental harm, and total welfare under the selected instrument.
Topics	externalities; environmental regulation; pollution; Pigouvian taxes; permits.
JEL	C92; D62; H23; Q58.

Four firms produce within one community. Production benefit rises at a decreasing rate; base costs and clean-technology premiums differ across firms. Every clean unit avoids harm but may be costly. Every dirty unit avoids the extra cleaning cost and creates a shared loss. This compact structure makes the difference between private choice and social evaluation visible without requiring advanced calculation during play.

1.3 Learning outcomes

After the activity, a student should be able to define an externality as an effect on third parties that is not fully reflected in a decision; reconstruct private earnings from benefits, costs, transfers, and a share of harm; distinguish total harm, private harm, and external cost; calculate social surplus while excluding transfers; identify efficient output and technology for heterogeneous costs; and explain why policies can achieve similar emissions with different distributions and real costs.

The activity also develops institutional-design skills. Students compare command-and-control rules with price and quantity instruments, evaluate cost heterogeneity, interpret missing information, and recognize learning in repeated data. Advanced courses can use the environment to discuss instrument equivalence, fiscal incidence, tax-rate selection, initial rights, and the difference between static efficiency and political legitimacy.

Theoretical foundation

Zero pollution is not the benchmark. An efficient allocation compares the marginal social benefit of output with real production cost, clean-technology cost, and unavoided harm. Cleaning raises surplus when its marginal cost is below the harm avoided; otherwise, tolerating a dirty unit or reducing output can be efficient.

1.4 Minimum class sequence

Allow forty-five to sixty minutes for one configuration and eighty to one hundred minutes for a policy comparison. Use ten minutes for access and instructions, ten to thirty for choices, five to verify completion, and at least twenty for debriefing. Before revealing the report, collect predictions about output, cleaning, harm, and winners or losers. Recorded predictions turn the report into a test of mechanisms rather than a display of numbers.

Access, rooms, and family isolation

2.1 From the lab portal to the game

The institutional path begins at the [BEER Lab portal](#). From the teaching area, open the [teaching catalog](#) and choose *Externalities and Regulation*. The proposed family domain is linked as the [externalities site](#). Until DNS and deployment are configured, the verified instance is the [local demo](#). A localhost address works only on the computer that runs the server.

The /demo view is for instructors and contains exactly twenty-two configurations: three basic Spanish, three basic English, eight extended Spanish, and eight extended English. Isolation is enforced with `GAME_FAMILY=externalities`. If trust, dictator, fisheries, or another family appears, do not start a session: the instance was launched without the correct family filter.

2.2 Four stable rooms

Room	Path	Options
Basic ES	/room/externalidades_regulacion_es	3
Basic EN	/room/externalities_regulation_en	3
Extended ES	/room/externalidades_regulacion_extendida	8
Extended EN	/room/externalities_regulation_extended	8

Give participants the stable room path. The instructor selects a configuration, enters a course-and-date session label, and chooses a multiple of four. With eighteen students, open sixteen seats and assign two observers. An incomplete group cannot calculate shared harm, efficiency, or permit trades.

2.3 Create, monitor, and close

After session creation, oTree displays individual links, Monitor, Data, and Report. For a rehearsal, open each link in a separate private profile because tabs in one profile share cookies. During class, keep Monitor and Report on instructor-only screens. Report first displays a privacy barrier and reveals aggregates only after the instructor selects the reveal control.

oTree
Demo
Sessions
Rooms
Data
Server Check
Logout

[EN] Externalities and Regulation — one round: session 'r4ovzak4' (demo)

New
Links
Monitor
Data
Payments
Report
Description

Below are temporary links for testing and demonstration. To launch a real study, either create persistent links by setting up a [room](#), or create a session through the [sessions page](#).

Choose one of the following options to play the session:

Combined views

Split-screen view
Launch

Grid view
Launch

Session-wide testing link

Open the below link in up to 4 browser tabs.

<http://127.0.0.1:8048/join/nosasute>

Single-use links

Open each link in its own browser tab.

P1	http://127.0.0.1:8048/InitializeParticipant/h0564lyj
P2	http://127.0.0.1:8048/InitializeParticipant/vpmbda26
P3	http://127.0.0.1:8048/InitializeParticipant/loqec98l
P4	http://127.0.0.1:8048/InitializeParticipant/e0mbyasr

Figure 2.1: Links for a four-firm basic session.

Checkpoint

Before sharing the link, verify language, edition, treatment, rounds, matching, and seat count. Open one test participant and confirm that the first screen displays the institutional logos and no Debug info.

Participant experience

3.1 Welcome, laboratory rules, and instructions

The welcome page introduces the BEER Lab, explains the teaching purpose, and requires acceptance of general rules: remain quiet, do not talk, do not inspect neighboring screens, and request help from staff. This common commitment appears before economic instructions so that behavioral expectations are clear before participants encounter a strategic choice.

Instructions display the participant's firm type, base cost, and clean premium. The sequence marks the production stage and, for permits, the market stage. A separate box gives the payoff identity. The numerical example uses a cost type different from the participant profile so that it teaches calculation without suggesting a choice. The page states that dirty units are stylized emissions rather than physical tons of a particular pollutant.

3.2 Comprehension and choice

The comprehension page asks participants to calculate the benefit of four units, identify dirty units when some output is clean, and recognize that harm is shared by four firms. Correct answers are thirty-eight ECU, two dirty units, and four affected firms. An incorrect answer produces an explanation and another attempt; the purpose is to equalize understanding, not to screen people out.

Choice menus restrict entries to feasible combinations. Clean units cannot exceed output. A standard imposes its minimum share; dirty-only technology fixes cleaning at zero; permits prevent dirty units from exceeding final holdings. Relevant parameters remain visible, but the interface does not compute or highlight a best response.

3.3 Round result and completion

The result separates firm accounts from community accounts. The individual column lists output, cleaning, dirty units, benefit, real costs, transfers, harm share, and earnings. The collective column reports output, harm, surplus, and efficiency. This separation is central: a policy may raise private earnings through a transfer without creating social resources.



Welcome to the BEER Lab

The **Behavioral and Experimental Economics Research Lab** of the Department of Economics at Tecnológico de Monterrey is a space designed to learn about economic decision-making through controlled activities.



Externalities and Regulation

In this activity we study how production, technology, and regulatory instruments affect private earnings, environmental harm, and social welfare.

During the session

- Remain silent and do not talk or communicate with other participants.
- Make decisions individually and privately.
- Follow the on-screen instructions. Do not refresh, close, or leave this page.
- If you need help, raise your hand or contact the laboratory staff privately.

☐ I have read and understood the laboratory rules.

Start

Powered by [oTree](#)

Figure 3.1: Beginning of the English participant experience. Laboratory welcome and rules.



Round 1 of 1 • Basic version

Production, technology, and external harm

Four firms operate in one community. Each firm chooses how many units to produce and how many to produce with clean technology.

Resources and unit of account

Each participant's initial endowment per round: 40 ECU.

ECU stands for Experimental Currency Units. It is the unit of account for this activity.

This session does not convert ECU into real money.

No regulation

Each firm chooses production and technology without a tax, subsidy, standard, or emissions limit.

Sequence in each round

1. Observe your production and clean-technology costs.
2. If permits exist, first submit a request to buy or sell.
3. Choose total output and clean units.
4. The system calculates dirty units, harm, policy payments, and earnings.
5. Review your private outcome and the community outcome.

Your cost profile

Firm type	1
Base cost per unit	1.0 ECU
Additional cost per clean unit	1.0 ECU

Production benefit

Marginal benefit declines: the ten units generate 11, 10, 9, 8, 7, 6, 5, 4, 3, 2 ECU. Total benefit from q units is therefore $12q - q(q+1)/2$.

$$B(q) = 12q - q(q+1)/2$$

Choosing dirty technology

A clean unit avoids environmental harm but adds your firm's cleaning cost. A dirty unit avoids that extra cost and creates harm for the whole group.

Externality

Total harm equals harm per unit times the group's dirty units. It is shared equally by the four firms, so each firm bears only part of the harm it creates.

Rule in this session: No regulation

Each firm chooses production and technology without a tax, subsidy, standard, or emissions limit.

Harm per dirty unit

4.0 ECU

$$\text{ECU} = 40 + \text{benefit} - \text{base cost} - \text{clean cost} - \text{tax} + \text{subsidy} - \text{permit payment} - \text{damage share}$$

Worked example

A firm with base cost 2 produces 4 units, 2 clean and 2 dirty. Its benefit is 38 ECU. Before policy payments and harm, it earns $40 + 38 - 8 - 4 = 66$ ECU.

Four firms operate in one community. Each firm chooses how many units to produce and how many to produce with clean technology.

Resources and unit of account

Each participant's initial endowment per round: 40 ECU.

ECU stands for Experimental Currency Units. It is the unit of account for this activity.

This session does not convert ECU into real money.

No regulation

Each firm chooses production and technology without a tax, subsidy, standard, or emissions limit.

Sequence in each round

1. Observe your production and clean-technology costs.
2. If permits exist, first submit a request to buy or sell.
3. Choose total output and clean units.
4. The system calculates dirty units, harm, policy payments, and earnings.
5. Review your private outcome and the community outcome.

Your cost profile

Firm type	1
Base cost per unit	1.0 ECU
Additional cost per clean unit	1.0 ECU

Production benefit

Marginal benefit declines: the ten units generate 11, 10, 9, ..., 2 ECU. Total benefit from q units is therefore $12q - q(q+1)/2$.

$$B(q) = 12q - q(q+1)/2$$

Clean and dirty technology

A clean unit avoids environmental harm but adds your firm's cleaning cost. A dirty unit avoids that extra cost and creates harm for the whole group.

Externality

Total harm equals harm per unit times the group's dirty units. It is shared equally by the four firms, so each firm bears only part of the harm it creates.

Rule in this session: No regulation

Each firm chooses production and technology without a tax, subsidy, standard, or emissions limit.

Harm per dirty unit	4.0 ECU
---------------------	----------------

$ECU = 40 + \text{benefit} - \text{base cost} - \text{clean cost} - \text{tax} + \text{subsidy} - \text{permit payment} - \text{damage share}$

Worked example

A firm with base cost 2 produces 4 units, 2 clean and 2 dirty. Its benefit is 38 ECU. Before policy payments and harm, it earns $40 + 38 - 8 - 4 = 66$ ECU.

The numbers are a teaching adaptation. Dirty units represent stylized emissions rather than tons of an actual pollutant.

[Continue](#)

Powered by oTree

Figure 3.3: Current basic-edition instructions, with initial resources and experimental units.
Continuation 2/2.



Review the marked questions. Each shows your answer and an explanation; your other answers are retained.



Round 1 of 1

Comprehension check

Answer the three questions. You may correct your answers after an error.

Resources and unit of account

ECU stands for Experimental Currency Units. It is the unit of account for this activity.

This session does not convert ECU into real money.

What is the total benefit from producing 4 units?

ECU

Your answer: 39. The correct answer is 38. Review the example: benefit adds the first four units, dirty units equal output minus clean units, and harm is shared by four firms.

If output is 4 and 2 units are clean, how many are dirty?

units

How many firms bear a share of total harm?

firms

Continue

Powered by oTree

Figure 3.4: Current comprehension check: specific feedback explains the incorrect answer and preserves the other responses.



Round 1 of 1

Production decision

Choose total output and how many units will be clean. The remainder will be dirty.

No regulation

Each firm chooses production and technology without a tax, subsidy, standard, or emissions limit.

Base cost per unit

1.0 ECU

Additional cost per clean unit

1.0 ECU

Total output

Select output ▼

Clean units

Select clean units ▼

Clean units cannot exceed total output.

Confirm production

Powered by [oTree](#)

Figure 3.5: Output and technology choice.



Round 1 of 1

Round result

Review how your decision and the group's choices determined earnings, harm, and welfare.

Your firm's result

Total output	6
Clean units	1
Dirty units	5
Production benefit	51.0 ECU
Base cost	6.0 ECU
Clean-technology cost	1.0 ECU
Your share of harm	24.0 ECU
Round earnings	60.0 ECU

Community result

Group output	30
Group clean units	6
Group dirty units	24
Total harm	96.0 ECU
Social surplus	37.0 ECU
Efficiency relative to maximum	41.6%

View final summary

Powered by [oTree](#)

Figure 3.6: Private feedback before the instructor report. Individual and community round result.



Activity completed

Your decisions were recorded. Please wait for the instructor's directions.

Cumulative ECU
60.0 ECU

Cumulative output
6

Cumulative clean units
1

Cumulative dirty units
5

Total harm in your
groups
96.0 ECU

The instructor can reveal aggregate results without identifying participants.

Powered by [oTree](#)

Figure 3.7: Cumulative summary and completion.

Economic model and accounting

4.1 Benefits and costs

Each firm chooses output q from zero to ten. Production benefit is $B(q)=12q-q(q+1)/2$. Marginal benefits for the ten units are eleven, ten, nine, eight, seven, six, five, four, three, and two ECU. Concavity prevents an automatic maximum-output answer and allows costs and policy to influence the margin.

$$B(q) = 12q - \frac{q(q+1)}{2}.$$

The four types have base costs of one, two, three, and four ECU per unit. Their additional clean costs are one, two, four, and six ECU. If a firm produces q and cleans c , dirty output is $d=q-c$. Real cost is $kq+ac$. Heterogeneity creates differences in efficient scale and comparative advantage in abatement.

4.2 Shared harm and private earnings

With harm h per dirty unit, group harm equals h times the sum of d . Each firm loses one fourth. Private earnings add a forty-ECU endowment, subtract real costs and the harm share, and include policy payments. In the reference case h is four. One additional dirty unit lowers the decision maker's payoff by one ECU and lowers other firms' combined payoff by three. The latter is the marginal external cost.

$$\pi_i = 40 + B(q_i) - k_i q_i - a_i c_i - T_i + S_i - P_i - \frac{h \sum_j d_j}{4}.$$

T denotes taxes, S subsidies, and P net permit expenditure, positive for buyers and negative for sellers. Those entries matter for incentives and distribution, but they are transfers in social surplus. The endowment is also excluded from welfare because it merely keeps interface earnings nonnegative. This distinction prevents the false conclusions that tax revenue automatically destroys value or subsidy payments create it.

4.3 Social surplus and efficiency

$$W = \sum_i [B(q_i) - k_i q_i - a_i c_i] - h \sum_i d_i.$$

The program computes the maximum W exactly for the four profiles and realized harm. When h equals four, type one produces and cleans ten units; type two produces and cleans eight; type three produces and cleans five; type four produces four dirty units. The corresponding maximum contributions are forty-five, twenty-eight, ten, and six ECU, so the group maximum is eighty-nine. Reported efficiency divides observed surplus by this benchmark, subject to caution when observed surplus is negative.

Type four illustrates why zero pollution is not automatically efficient. Cleaning costs six and avoids harm of four. For early units, dirty production still yields positive net benefit; cleaning would consume more resources than the harm it prevents. Additional objectives such as precaution or rights can be introduced, but the benchmark makes the criterion explicit.

Theoretical foundation

The Pigouvian rate is three ECU per dirty unit rather than four. The firm already bears one ECU of its own harm through equal sharing. The tax adds the cost imposed on the other three firms and aligns perceived marginal cost with social marginal cost.

Economic predictions

5.1 No regulation

Taking other choices as given, a firm internalizes only one fourth of harm. For a dirty unit it compares marginal benefit with base cost plus one ECU of own harm. For a clean unit it compares marginal benefit with base cost plus the clean premium. Whenever cleaning costs more than the private harm share, dirty technology can be privately optimal even when cleaning would save social resources. Aggregate output or dirtiness therefore tends to exceed the benchmark.

This is a conditional prediction rather than a psychological label. The interface already includes own harm, so monetary maximizers respond partially. Participants may clean more because of social preferences, environmental norms, mistakes, risk attitudes, or coordination motives. The report identifies the pattern relative to the benchmark without assigning a unique motive.

5.2 Price and quantity instruments

A three-ECU tax raises the perceived cost of a dirty unit to its social cost. Under complete information and monetary maximization, it implements the efficient mix without ordering a specific firm to clean. A three-ECU clean subsidy creates a similar wedge between technologies but may expand total output by reducing the net cost of clean units. Equivalence depends on entry, budgets, baselines, and other margins absent from the simple model.

A fifty-percent standard guarantees a minimum clean share at every firm. It can be simple to explain and verify, but it ignores cost differences and binds heterogeneous types equally. Permits control aggregate dirty units through rights. Trade can transfer rights toward firms with high cleaning cost and cleaning toward low-cost firms. The game uses bilateral requests at an announced price to keep allocation transparent.

5.3 Information and uncertainty

Under hidden harm, the true parameter is four but is disclosed only after choice. A participant cannot be evaluated as if that number had been known. Under uncertain harm, zero or eight is realized with equal probability, so expected harm is four. A risk-neutral expected-money maximizer can use the expectation; a risk-averse participant may clean more or produce less because the environmental shock is shared.

Shared shocks prevent within-group diversification. Compare known and unknown harm to discuss monitoring, public information, quantified risk, and parameter uncertainty.

Versions and treatments

6.1 Configuration map

6.1.1 Basic: one round

Four firms make one unregulated choice. This is the cleanest introduction to an externality and to private versus social accounts. It avoids learning and shared history, but one decision can contain error. Collect a written prediction and spend time reconstructing one observation.

6.1.2 Basic: ten rounds with fixed firms

The same people remain together. The mode reveals learning, stabilization, indirect reciprocity, and responses to group harm. Communication is not enabled. Compare early and late rounds without treating forty decisions as independent.

6.1.3 Basic: ten rounds with reassignment

Groups are rebuilt every round. Comparison with fixed groups weakens common history and opens a discussion of strategy diffusion. Cost type remains with the participant; reassignment is not a change in technology.

6.1.4 Extended no regulation

A ten-round fixed-group control for the extensions. Use it when a contemporary reference with the same duration and session size is needed.

6.1.5 Dirty technology only

Removes the cleaning option. It isolates output contraction as the environmental margin and demonstrates the value of technology availability. It is useful before discussing induced innovation or technology mandates.

6.1.6 Clean standard

Requires at least half of output to be clean. It supports discussion of compliance, rigidity, heterogeneity, and performance versus technology rules. The interface blocks infeasible combinations.

6.1.7 Pigouvian tax

Charges three ECU per dirty unit. Participants see the rate and payment. Compare dirtiness, output, revenue, and efficiency while remembering that revenue is a transfer in the welfare measure.

6.1.8 Clean subsidy

Pays three ECU per clean unit. Compare the technology mix and possible output expansion. Discuss baselines, fiscal cost, additionality, and payment for actions that would have occurred anyway.

6.1.9 Tradable permits

Allocates three initial permits and permits buying or selling up to three at a price of three ECU. Requests execute only with counterparties. Dirty units cannot exceed final holdings. Discuss the cap, trade, and rent distribution.

6.1.10 Hidden harm

Withholds the value four until results. It studies choice under missing environmental information and the value of disclosure. Do not compare choices with complete information without acknowledging the change.

6.1.11 Uncertain harm

Announces harm of zero or eight with equal probability and discloses the realization after choice. It separates expected harm from risk and supports discussion of precaution, learning, and common shocks.



Round 1 of 10

Production decision

Choose total output and how many units will be clean. The remainder will be dirty.

Pigouvian tax

Each dirty unit pays 3 ECU, the marginal damage imposed on the other three firms.

Base cost per unit
1.0 ECU

Additional cost per clean unit
1.0 ECU

Tax
3.0 ECU/units

Total output

Select output ▼

Clean units

Select clean units ▼

Clean units cannot exceed total output.

Confirm production

Powered by [oTree](#)

Figure 6.1: The common layout emphasizes the policy parameter that changes. Decision under a Pigouvian tax.



Round 1 of 10

Production decision

Choose total output and how many units will be clean. The remainder will be dirty.

Clean-production subsidy

Each clean unit receives 3 ECU. The subsidy lowers the private cost of cleaning but does not limit total output.

Base cost per unit
1.0 ECU

Additional cost per clean unit
1.0 ECU

Subsidy
3.0 ECU/units

Total output

Select output ▼

Clean units

Select clean units ▼

Clean units cannot exceed total output.

Confirm production

Powered by [oTree](#)

Figure 6.2: Decision under a clean subsidy.

Round 1 of 10

Permit market

One permit authorizes one dirty unit. Request to buy or sell; an order executes only when a counterpart exists.

Tradable permits Each firm receives three permits and may buy or sell up to three at a posted price of 3 ECU.

Initial permits 3	Cost of cleaning one unit 1.0 ECU	Price per permit 3.0 ECU
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Your request

Sell 3

Submit request

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Figure 6.3: The two stages of the permit market. Buy or sell request.

Round 1 of 10

Market result

Review your final permits and payment before choosing production.

Initial permits	3
Change in permits	-2
Final permits	1
Net permit payment	-6.0 ECU

Units traded in the group	3
Price per permit	3.0 ECU

A negative payment is revenue from sales.

Continue

Powered by [oTree](#)

Figure 6.4: Holdings and payment after matching.

Research foundations and experimental evidence

7.1 From Pigou and Coase to the laboratory

The Pigouvian tradition argues that a charge equal to marginal external cost can align private choice with welfare. Coase emphasizes that well-defined rights and bargaining may reallocate resources when transaction costs are low, although initial rights remain distributively important. In practice, information, measurement, market power, enforcement, and administrative cost condition both approaches. The classroom game turns these ideas into observable margins without claiming to reproduce a full environmental market.

Plott examined externalities and corrective policies in experimental markets, demonstrating the value of institutional comparisons with controlled parameters. Cason and Plott evaluated an emissions-trading mechanism designed for the United States Environmental Protection Agency, connecting laboratory testing to regulation. Muller and Mestelman reviewed experiments on incentive-based instruments; Requate surveyed policy comparisons under imperfect competition and incomplete information. These studies justify the laboratory as a test bed while showing that outcomes depend on detailed rules.

7.2 Predictions and stylized findings

Experiments commonly find that incentives alter emissions and allocation, but they do not guarantee immediate convergence. Markets may require experience, trade can fall short of its potential, standards can generate compliance at high cost, and harm information can shift choices even without a price change. Deviations can reflect learning, errors, social preferences, loss aversion, heuristics, or perceived legitimacy.

The report enables classroom versions of those questions: whether the tax raises efficiency, whether permits reallocate dirtiness by type, whether subsidies expand output, whether standards force expensive cleaning, and whether uncertainty raises dispersion. A single class cannot identify every mechanism. For treatment comparisons, assign classes or sections before outcomes are observed and hold session size, duration, and instructions fixed.

Attention

The permit market is a posted-price teaching adaptation with limited requests. It is neither a continuous auction nor a replica of a named regulation. Interpret evidence as behavior under the implemented mechanism, not as an estimate of a national policy.

7.3 Connecting one session to the literature

A useful comparison does not require a class to reproduce an article's mean exactly. Begin by identifying the study's institution, information, experience, incentives, and experimental unit. State which elements the activity preserves and which it simplifies. A difference may reveal design sensitivity rather than a failed replication. This practice teaches students to read experimental findings as claims conditional on an environment and population.

When showing a published figure, ask students to translate its axes into report variables: output, dirty units, harm, efficiency, earnings, and trade. Compare effect direction before statistical significance. A teaching session has few groups and was built for comprehension; it is not a confirmatory study. It can still generate hypotheses and reveal which observations would be needed to assess them.

Finally, separate internal and external validity. Laboratory control helps connect a rule to a response within the environment. Relevance to an industry depends on technologies, scale, enforcement, damages, and actors that the game abstracts. Require every conclusion to state the mechanism learned and the additional information needed before recommending field policy.

Instructor report and interpretation

8.1 Privacy and reveal timing

Report displays participants, groups, completed group-rounds, and pending decisions. While work remains, the instructor can keep outcomes hidden. Revealing shows mean output, clean and dirty units, harm, efficiency, and ECU, followed by histograms, round series, and a table by firm type. No participant code is shown. This design reduces individual exposure and prevents partial feedback from guiding unfinished choices.

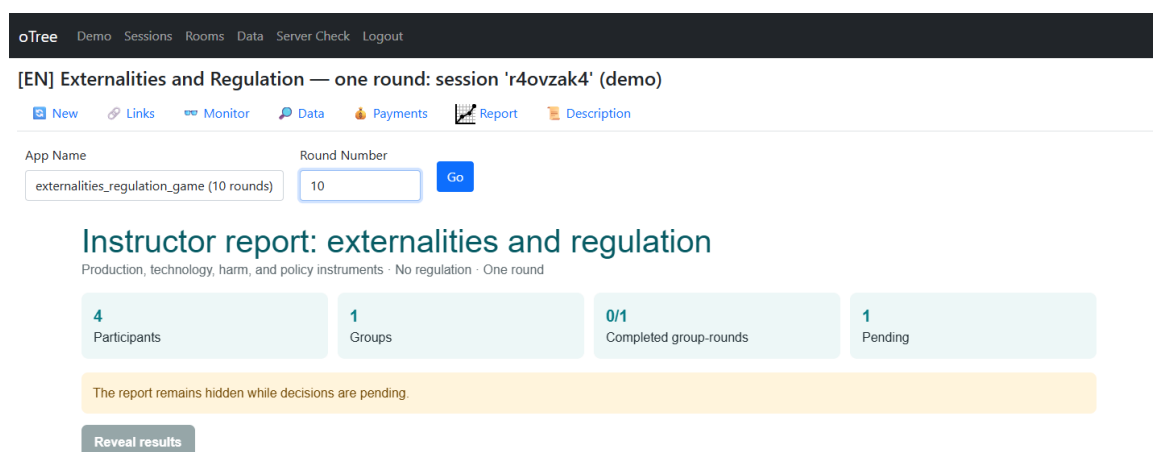


Figure 8.1: Instructor control over feedback timing. Protected report before reveal.

8.2 Reading the components

Mean output describes scale; clean and dirty units separate technology; clean share allows comparison across output levels; mean harm captures the environmental consequence; efficiency compares observed and maximum surplus; mean ECU describes private incentives. Histograms reveal heterogeneity hidden by averages. Round series show adaptation but must be read with the number of groups. The type table links choices to costs.

The permit report adds permits traded. High volume does not establish efficiency: the cap may be wrong, the announced price may not represent scarcity, and trades may redistribute without improving allocation. Check whether low-clean-cost firms sell permits and clean more while high-clean-cost firms buy. Then examine harm and surplus rather than trade alone.

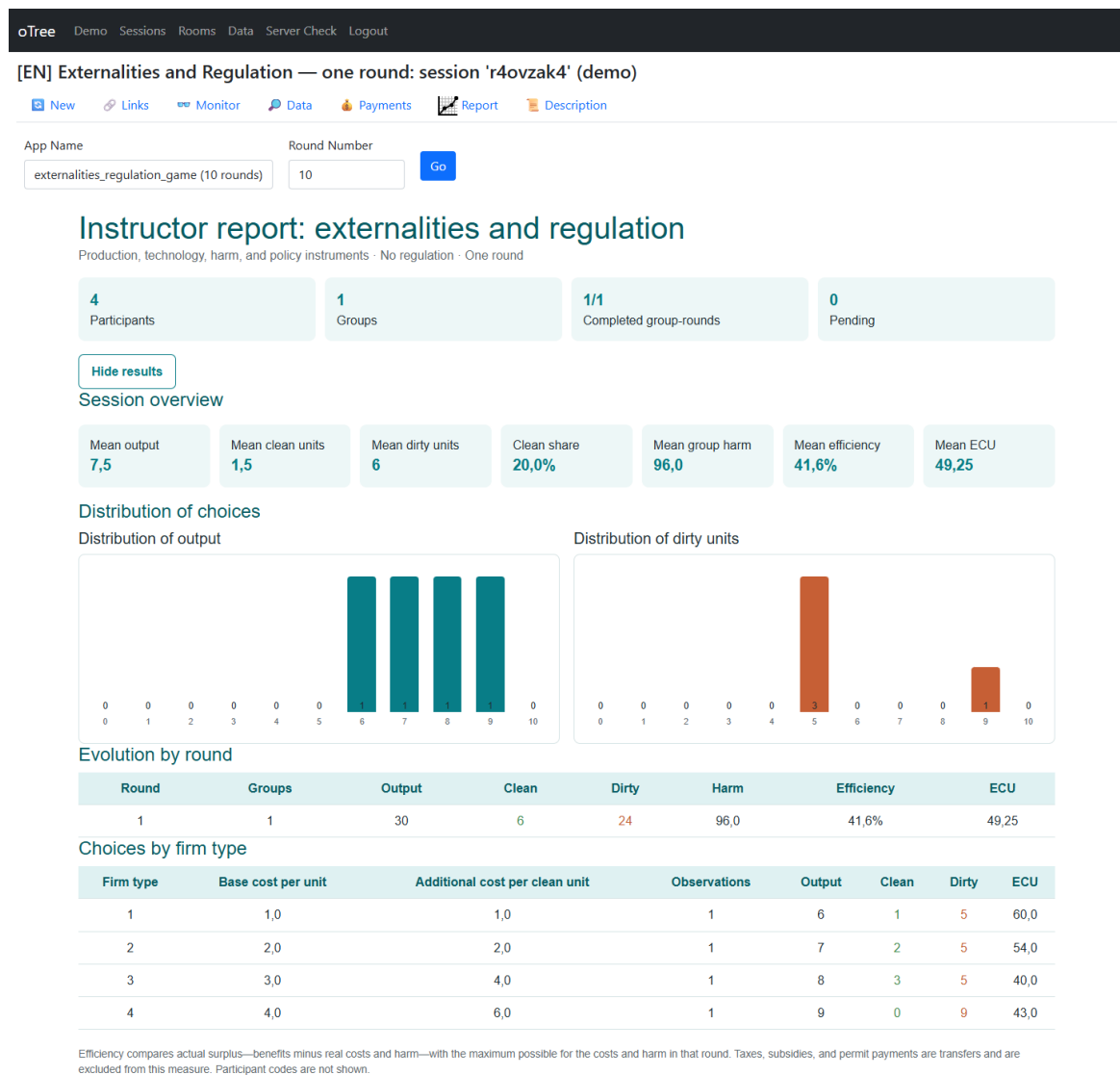


Figure 8.2: Basic aggregate report after reveal.

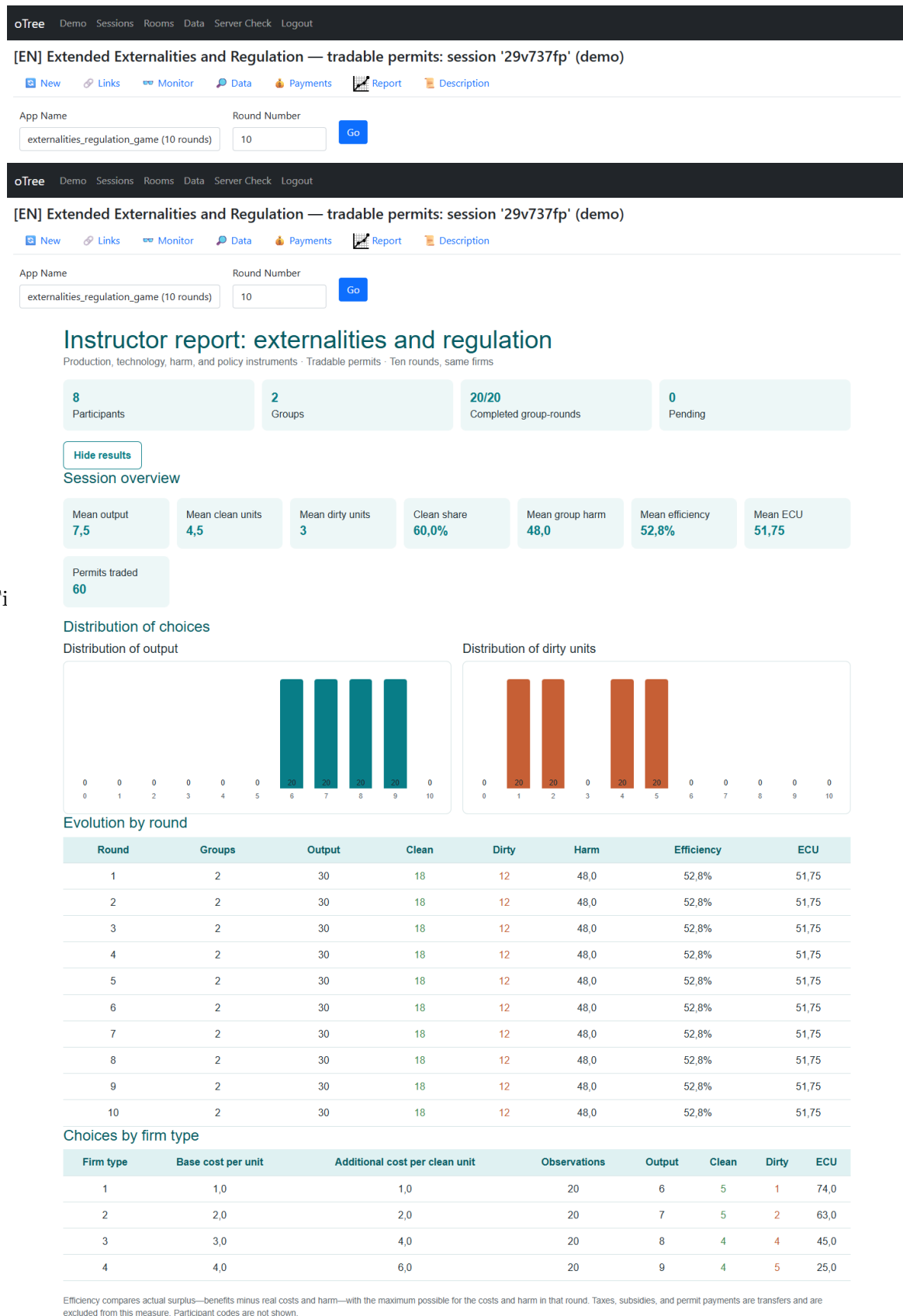


Figure 8.4: Permit report with trades, time paths, and choices by cost type. Continuation 2/2.

Feedback script

Begin with what changed in choices. Move to marginal mechanisms, then efficiency, then distribution, and close with design limits. This sequence prevents a chart from becoming an automatic normative conclusion.

For a two-report comparison, prepare a table before revealing numbers. Rows should include output, clean share, harm, surplus, efficiency, ECU by type, and transfers; columns should show treatment and difference. Collect expected signs and reasons first, then enter observed values. When a prediction fails, check comprehension, incentive strength, heterogeneity, and the number of independent groups before rejecting a theory.

Use histograms to ask whether the mean represents the class. A stable average can conceal polarization or exchanges of position. Over ten rounds, compare initial and final distributions and ask whether an aggregate trend reflects movement by every firm or adjustment concentrated in one type. The cost table helps prevent an explanation that attributes every difference to preferences.

Lesson plans and debrief scripts

9.1 A fifty-minute class

Create and test a one-round session before class. Use the first five minutes for laboratory rules without announcing a correct decision. Allocate ten minutes to instructions and comprehension, five to choices, five to class predictions, and twenty to the report. Use the last ten minutes to connect the result to marginal external cost, the corrective tax, and the limits of one observation.

Begin the board discussion with four questions: how much was produced, how much was clean, who paid for harm, and why private earnings differ from surplus. Draw one additional dirty unit and split its four ECU: one enters the firm's own account and three fall on others. Only then derive the Pigouvian rate. The concrete decomposition is usually clearer than presenting the formula before play.

9.2 A ninety-minute comparison

Assign groups or sections to no regulation and tax, or to standard and permits. Hold participant count, rounds, and parameters fixed. Before reveal, teams predict dirtiness, output, efficiency, type earnings, and fiscal outcomes. Project reports side by side and complete a matrix with the direction of change, observed evidence, and mechanism.

For tax versus subsidy, add total output and expenditure or revenue. For standard versus permits, emphasize who cleans and at what cost. For known versus uncertain harm, compare both mean and dispersion and record realizations. In every comparison, ask which real-world margin is absent: administration, innovation, evasion, consumer incidence, or unequal household exposure.

9.3 Formative assessment

Use an exit note with three components: an accounting identity, a marginal prediction, and a conditional recommendation. A student might reconstruct one firm's ECU, explain how behavior changes when its clean premium falls, and recommend an instrument under an information constraint. Grade the separation of incentives, welfare, and distribution.

For the instructor

Do not reward a policy solely for reducing harm without checking output and costs, and do not reject it because private earnings fall when revenue is transferred. Require an explicit metric and counterfactual for every conclusion.

Solved exercises

10.1 Step-by-step problems

10.1.1 Production benefit

At $q=4$, $B=48-10=38$ ECU. The fourth unit adds eight because marginal benefits are eleven, ten, nine, and eight.

10.1.2 Unregulated earnings

A type-two firm produces four, cleans two, and its group generates eight dirty units. Benefit is 38, base cost 8, clean cost 4, and harm share 8. Earnings are $40+38-8-4-8=58$ ECU.

10.1.3 Marginal external cost

One dirty unit creates four ECU of group harm. The firm bears one under equal sharing and shifts three to other firms. Marginal external cost is three ECU.

10.1.4 Corrective tax

With a tax of three, a dirty unit adds one of own harm and three of tax. The perceived additional cost of four equals total social harm.

10.1.5 Surplus and transfers

If a firm pays twelve ECU in taxes, private earnings fall by twelve but social surplus does not subtract revenue. It does subtract real production cost, clean cost, and harm.

10.1.6 Clean standard

At output seven, a fifty-percent rule requires at least four clean units because the half is rounded upward. At most three units remain dirty.

10.1.7 Permit holdings

A firm begins with three and buys two. It ends with five and pays six ECU. It may use at most five dirty units; additional output must be clean.

10.1.8 Expected harm

With zero or eight equally likely, expected harm per dirty unit is four. The expectation matches known harm, but the distribution of earnings differs.

10.1.9 Efficient type one

Total clean cost per unit is two and avoids harm of four. Cleaning is efficient. Marginal benefits through unit ten are at least two, so output and cleaning are ten.

10.1.10 Efficient type four

Cleaning costs six extra and avoids four, so dirty technology is efficient. Base cost plus harm is eight; the first four marginal benefits, eleven through eight, justify four units.

After each solution, change one parameter and ask students to update the answer without restarting. This reveals which terms govern the margin. If harm rises to eight, type four now prefers cleaning to harm; if the permit price rises above the clean premium, a potential buyer may become a seller.

Discussion notes for deeper use

The following notes are independent modules lasting five to fifteen minutes. Each provides a context, an analytical task, and an interpretive caution. Select only those that fit the course.

11.1 A cement plant beside a neighborhood

A low-cost plant creates output and employment, but its emissions affect households that do not participate in the production decision. Ask students to separate private benefit, production cost, and shared harm. Then compare unregulated output with the social-surplus benchmark.

Do not imply that every polluting activity should disappear. Efficiency compares marginal benefit with marginal production cost and marginal unavoided harm. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.2 Two technologies and heterogeneous costs

Four firms face different clean-technology premiums. A uniform rule requires the same clean share from every firm. Ask which firm should abate first and why. Marginal cleaning cost, rather than firm identity, organizes the least-cost allocation.

A uniform standard can reduce emissions while remaining more expensive than an instrument that equalizes marginal abatement costs. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.3 A tax below total harm

Each dirty unit causes four ECU of group harm, but the emitting firm already bears one fourth through the shared loss. Have the class compute the marginal external cost imposed on the other three firms: three ECU. This is the corrective rate used in the activity.

Mechanically setting the tax at four would count again the part of harm already included in the firm's private payoff. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.4 A subsidy and the public budget

A three-ECU clean subsidy changes the relative price of technologies, although the payment does not create real resources. Compare the behavioral response, the real cleaning cost, and the fiscal outlay. The game's social-surplus measure treats the subsidy as a transfer.

Do not equate a higher private payoff with higher welfare. The source of public funds and the marginal cost of taxation are useful extensions. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.5 Permits and initial allocation

Every firm starts with three permits and may buy or sell at an announced price. Show that initial allocation affects payments and distribution, while trade can move permits toward firms with higher cleaning costs.

An efficient outcome still requires an appropriate cap and a functioning market. Tradability cannot repair a poorly selected aggregate limit. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.6 Hidden harm

Firms know costs and benefits, but the harm parameter is disclosed only after they choose. Ask what decision rule is defensible without environmental information. Compare caution, expectations, and learning after disclosure.

Do not interpret a risky choice as environmental indifference when the participant was not given the relevant information. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.7 Uncertain harm

Harm per dirty unit is either zero or eight ECU with equal probability and is realized after decisions. First calculate expected harm of four ECU. Then discuss why risk aversion, perceived ambiguity, or attention can separate behavior from expected value.

A short run cannot identify risk preferences on its own because random realizations also move observed outcomes. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.8 Dirty technology only

A firm chooses output but has no cleaning option. Use the treatment to separate the scale margin from the technology margin. Compare output contraction with substitution toward clean production.

Present this as a technological counterfactual, not as a policy recommendation. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.9 A fifty-percent clean standard

Every firm must produce at least half of its units with clean technology. Examine compliance, total output, and costs by firm type. Ask whether a percentage rule differs from an absolute emissions limit.

Formal compliance does not guarantee least cost or a socially appropriate total amount of emissions. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.10 Learning over ten rounds

Groups observe outcomes and can adjust output and cleaning for ten periods. Look for trends and responses to extreme outcomes. Separate calculation, imitation, experience, and mechanical repetition as possible channels.

Rounds are not independent observations. Read the report as a trajectory rather than as a survey of eighty people. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.11 Firm reassignment

Participants move across groups between rounds while retaining their cost type. Compare stability and strategy diffusion with fixed groups. Ask which information travels across communities.

Reassignment weakens shared history but does not eliminate individual learning or temporal dependence. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

11.12 Equity and efficiency

A policy raises social surplus but distributes private earnings unevenly across firm types. Require explicit criteria: efficiency, harm, fiscal cost, profits, dispersion, and legitimacy. Then explore

tradeoffs.

Do not turn efficiency into an automatic claim about fairness. The experiment separates indicators precisely to sustain that discussion. Require every conclusion to name a counterfactual, an observed indicator, and the assumption that connects them. Then ask what additional evidence would separate competing explanations.

Suggested use

Collect an individual prediction, follow with paired reasoning, and only then compare with the aggregate report. Record disagreements before presenting the benchmark.

Data, export, and troubleshooting

12.1 Main variables

The export records language, edition, treatment, matching, round, group, type, costs, announced and realized harm, output, clean and dirty units, permit requests and trades, tax, subsidy, total harm, harm share, earnings, surplus, and efficiency. Preserve a data dictionary with every export. oTree codes are technical identifiers and should not be combined with names without an institutional protocol.

The observation is a firm-round, but many outcomes are determined at group-round level. Individual-level standard errors ignore this dependence. Description is sufficient for teaching. Research requires a protocol, consent, treatment assignment, power analysis, and inference that respects clustering and repeated observations.

12.2 Frequent problems

If a participant sees Please wait, check whether the other three firms reached the same stage. If a link says the user does not exist, the database may have been reset; distribute the stable room route. If No more pages left appears, verify that FinalSummary remains in the page sequence. If Demo shows other families, inspect GAME_FAMILY. If Report remains hidden, confirm that groups and rounds are complete.

In the permit market, an unfilled request is not an error: it requires a counterparty. When quantities do not match, deterministic rationing preserves the total number of permits. If a production option is missing, inspect the standard or holdings constraint. Before changing code, reproduce the issue in a new session and record the configuration, round, and screenshot.

Checkpoint

Close a session only after checking Monitor, Final Summary, Report, export, and the absence of pending participants. Record the configuration, attendance, incidents, and any change made during class.

Instrument choice and institutional analysis

13.1 Prices versus quantities

The comparison between a tax and a permit system is not exhausted by saying that one sets a price and the other sets a quantity. Under certainty, competition, and frictionless implementation, either can be calibrated to produce the same aggregate result. Under cost uncertainty, the relative slopes of environmental benefits and abatement costs determine which error is more expensive. Weitzman's logic implies that a price limits the marginal compliance cost firms face, whereas a quantity limits emissions. The activity does not estimate unknown curves, but it makes the intuition concrete: the tax keeps its rate while dirty output varies; permits preserve a cap while scarcity and allocation determine who emits.

To teach the comparison, first ask which variable each rule fixes. Then introduce a surprise: one firm learns that cleaning is more expensive than expected. Under a tax it may pay and emit; under a cap it must clean or acquire a right. The preferred response depends on the harm from missing the environmental target and the cost of unexpected abatement. The exercise forces students to state uncertainty and an objective rather than choosing an instrument by label.

13.2 Heterogeneity, least cost, and incidence

The four cost types show that avoiding one dirty unit does not cost the same everywhere. An identical standard distributes obligations simply but may require expensive cleaning while cheap opportunities remain unused. A common tax lets every firm compare the rate with its clean premium. A permit market combines an aggregate constraint with trade in the right to emit. Evaluate these predictions in the report's type table rather than through the aggregate mean alone.

Least cost does not imply an acceptable distribution. Initial permit allocation changes payments and wealth even if final emissions coincide. A tax transfers resources to a regulator; a subsidy transfers resources to firms; a standard may pass costs to consumers who are absent from the model. Because households and government are not represented, the report does not calculate full incidence. Use ECU by type as a starting point and require the class to add missing actors before making a recommendation.

13.3 Information, monitoring, and administrative capacity

A regulator must measure emissions or a correlated variable. A tax requires verification of its base; permits require registries, ownership, and enforcement; standards require observation of technology or performance; subsidies require proof of additionality. Hidden harm represents a different failure: emissions may be observable while their consequences remain unknown. Separating behavioral information from harm information prevents the vague claim that a policy fails simply because information is incomplete.

Administrative capacity also consumes real resources that the surplus measure omits. Two instruments with the same laboratory outcome may differ outside the laboratory if one requires continuous monitoring, a liquid market, or frequent rate updates. Ask each team to list the data, institutions, and enforcement needed to operate its instrument. Classify each requirement as represented, abstracted, or impossible to observe in the session.

13.4 Innovation and time horizon

Costs and technologies are fixed in this version. The experiment therefore captures static incentives at the intensive margin rather than long-run investment. In a dynamic setting, a predictable charge can raise the value of clean invention; a standard can direct innovation toward a target; permits can create a volatile carbon price; subsidies can reduce learning costs. The literature distinguishes static efficiency from dynamic incentives and warns that irreversibility and diffusion can change instrument rankings.

A useful verbal extension gives each type an option to pay a fixed amount now to lower its future clean premium. Before programming it, the class can calculate the investment's present value under each policy. This exercise connects the activity to discounting, expectations, and policy credibility. It also shows why ten rounds with fixed parameters cannot establish which instrument generates more innovation.

13.5 From classroom evidence to a recommendation

A defensible recommendation specifies the problem, objective, information, constraints, and distributional criterion. The report supplies behavior under controlled rules; it does not estimate external harm or administrative cost in the field. Use a five-column matrix: prediction, result, plausible mechanism, alternative evidence, and condition for validity. A treatment difference is informative only when sessions are comparable and the mechanism changes in an identifiable way.

Close with a conditional recommendation. If marginal harm is known and emissions are reliably measured, one rule may be attractive for stated reasons; if costs are highly uncertain or enforcement is weak, the conclusion changes. Conditional language is a sign of applied-economic rigor. It also prevents a stylized classroom activity from being extrapolated to environmental problems with different scales, harms, and institutions.

13.6 Limits, ethics, and extensions

The design uses abstract firms, shared monetary harm, and simultaneous choices. It omits consumers, exposed households, health, location, environmental accumulation, strategic enforcement, lobbying, and irreversible investment. Clean technology is divisible and known. These simplifications isolate incentives but limit claims about real policy.

ECU are teaching points and do not represent wages or compensation for environmental harm. Do not label participants as polluters or morally deficient. Choices under artificial rules may reflect comprehension, experimentation, or strategy. Preserve anonymity, explain the purpose after the session, and allow questions about data use.

Future extensions may add investment, inspections and fines, communication, voting over rates, affected households, product markets, entry, or auctioned permits. Every addition should answer one question and preserve an interpretable comparison. Realism without a clear counterfactual can reduce learning.

13.7 Checklist

Checkpoint

- The instance uses `GAME_FAMILY=externalities`, and Demo shows 22 configurations.
- The room matches language and edition; participant count is a multiple of four.
- Treatment, rounds, matching, and parameters were verified.
- Welcome, comprehension, choice, result, completion, and report were rehearsed.
- Report is instructor-only, and results remain hidden until debriefing.
- The discussion separates behavior, mechanism, efficiency, distribution, and limitations.
- The export is stored with date, course, and configuration without exposing codes.

Glossary

Externality: An effect on third parties that is not fully incorporated in private choice.

Clean unit: An output unit produced at an additional cost that avoids environmental harm.

Dirty unit: An output unit produced without cleaning that creates shared harm.

Pigouvian tax: A unit charge equal to the relevant marginal external cost.

Standard: A direct constraint on technology, share, or emissions.

Permit: A tradable right authorizing one dirty unit in this activity.

Social surplus: Benefits minus real costs and harm, excluding transfers.

Efficiency: Observed surplus relative to the feasible maximum under the parameters.

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