# Comparing regulations to protect the commons: an experimental investigation

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**Abstract**

We test in a laboratory experiment three regulations imposed on a common-pool resource game: an access fee and subsidy scheme, transferable quotas and non-transferable quotas. Theory predicts that they all reduce resource use from free access to the same target level without hurting users. We find that all regulations perform equally in reducing resources, although with more variance under the fee scheme. All fail to make all the users better off. The fee scheme performs better than transferable quotas in sorting out the most efficient users but at the cost of hurting them more often.

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# 1 Introduction

The “tragedy of the commons” highlighted by Hardin (1968) is a major problem in societies. It refers to the overuse of common-pool resources (CPR) extracted under open access. Examples include natural resources such as fisheries, forests, water or oil. It also refers to environmental resources, such as clean air since excessive pollution leads to environmental damages, biodiversity loss or global warming. The market economy is inefficient in exploiting CPR because property rights on resources such as water or clean air are difficult to assign and to enforce (Demsetz, 1967).

A solution to mitigate the market failure associated with the tragedy of the commons is regulation. Various regulatory instruments can reduce CPR overuse. One consists in taxing resource extraction or pollution and, possibly, using the money collected to subsidize less resource-intensive or cleaner technologies, or to retrain resource users in other economic activities. Another widespread regulation consists in setting upper bounds on resource extraction or polluting emissions, in the form of rationing rules and emission norms, or extraction/emission quotas which can be exchanged in a market.

The three aforementioned instruments (taxes and subsidies, transferable quotas and non-transferable quotas) are observed worldwide, sometimes to regulate the same resource or environmental problem. For instance, Iceland and New Zealand issue individual harvesting quotas on their fisheries, and allow fishermen to trade quotas. The United States has opted for boat buy-backs financed by landing fees to reduce the stress on crab fisheries in the Bering Sea (Hannesson, 2004). Governments implement various environmental policies to reduce air pollution such as CO2 emissions that cause global warming. European countries tend to tax fossil fuel heavily , and to subsidize energy produced from renewable resources (e.g. wind and solar energy). The European Union has issued CO2 emission quotas for major emitters, and launched the EU Emissions Trading Scheme in which those emission rights are traded. The United States imposed SO2 emission norms on coal power plants before moving to tradable quotas (Burtraw 2000). Water provides a third example of regulation diversity to remedy the tragedy of the commons. Water extraction is sometimes taxed to finance the maintenance or improvement of irrigation ditches. In case of drought, water is often rationed through individual consumption limitations. In some places (e.g. Southern Spain) water markets have existed for centuries (Ostrom, 1990).

The diversity of regulations implemented in practice to tackle the same CPR problem suggests that the choice of instrument does not stand to reason. This article aims at helping policy-makers to make this choice by comparing CPR regulations theoretically and experimentally. Each regulation provides specific incentives to CPR users, thereby affecting their behavior and welfare. It determines the rule of the "CPR game" they play. The success of a new regulation depends on its perception by users.

We focus on three regulations: an access fee and subsidy scheme (FS), transferable individual quotas (TQ) and non-transferable individual quotas (NTQ). We compute a CPR game in which the three instruments lead to the same reduction of CPR extraction in the Nash equilibrium. The two market-based instruments FS and TQ are, in theory, equivalent in the sense that they lead to the same individual extraction choices and payoffs in equilibrium. They are more efficient than NTQ because they minimize the aggregate extraction costs by sorting out the most efficient users, i.e. those with lower extraction or pollution abatement costs, from the less efficient ones. Lastly, all regulations lead to a Pareto improvement from fee access in equilibrium. These theoretical predictions are tested experimentally.

Most of the experimental literature on the "commons" investigates coordination in unregulated CPR games with communication among players and/or with monitoring and sanctioning tools (see Ostrom 2006 for a review). The focus is on the endogenous emergence of self-regulation rules. In Walker *et al.* (2000), commoners vote over extraction rules. In some papers (e.g. Casari and Plott, 2003), these rules are enforced through a peer-monitoring and a punishment process. Several papers (Herr et al., 1997, Mason and Phillips, 1997, Oses-Eraso et al., 2006) investigate the inter-temporal dimension of common-pool resources without regulation that extend the CPR game to encompass dynamic externalities. Other papers evaluate a specific regulation that aims to reduce resource extraction or environmental pollution. Cason and Plott (1996) experimentally evaluate a new auction scheme to trade sulfur dioxide emission rights implemented in the nineties in the United States. Schott et al. (2006) likewise conducted an experiment inspired by catch-pooling practices in Japan where fishermen share their harvest equally within subgroups of different sizes. In a non-point source pollution framework, Cochard et al. (2005) tested the efficiency of ambient taxes, and Cason et al. (2003) experimentally evaluated an auction mechanism to reduce emissions. In a similar framework, Giordana and Willinger (2007) compare three tax policies: a flat tax, an ambient tax and mixed tax. The aim of these papers is to asses how subjects deal with the complexity of regulations which entail endogenous tax rates or prices. Another paper that examines several regulations applied to a pollution problem is Johnson, Rutströmb and George (2006). Subjects play an unregulated "social dilemma" game (resembling a CPR game) which is then regulated through emission permits. They choose one of the following two assignment policies: grandfathering (i.e. permits assigned proportionally on emissions in the unregulated game) and egalitarian. The focus is on eliciting social preferences for regulations and not on their evaluation.

When designing our experimental protocol, we kept our focus on the assessment of the three regulatory instruments in relation to the following criteria: resource preservation, individual profits (and Pareto improvement from free access), and sorting effect (self-selection of the more efficient users). Our design therefore differs from the aforementioned experiments in four main respects. First, subjects sequentially play the common pool resource game under free access (FA) and under the regulatory regimes FS, TQ and NTQ. Each participant takes part in those four treatments. The within-study generates sharper statistical inferences because, as a single subject is observed in several conditions, it automatically controls for individual differences (Camerer 2003, Friedman 1994). This procedure is therefore perfectly suitable for our comparison of the different institutions under consideration. To the best of our knowledge, there is no paper that tests the three regulations in a single experiment. Second, we were willing to facilitate the beliefs on aggregate effort as we were interested in testing the sole effect of the regulatory policies and not the level of information[1]. That is why each participant remains in the same group[2] and is provided with complete information. We did not allow commoners to communicate or coordinate their strategy since we wanted to elicit their non-cooperative behavior. Third, we opted for exogenous and fully enforced rules. The idea is that an external regulator (e.g. public authority) imposes rules in order to correct overexploitation in a CPR. Therefore, the regulator decides on the level of extraction in NTQ, the number and the price of the permits in TQ and the level of subsidy/tax in FS. Finally, we kept our framework as simple as possible by using a static analysis in order to focus on a short-term impact of regulations.

The paper is organized as follows. Section 2 presents the game and the design of the experiment. Section 3 analyses with the mains results of the experiments. Section 4 concludes the paper with further discussion.

# 2 Game and experiment

## 2.1 A common-pool resource game with heterogenous players

A group of $n$ individuals are endowed with $\bar{x}$ production units which can be invested in two markets or production processes. The first market is the common-pool resource (CPR). Its return depends on the total amount invested by all subjects, denoted as $X$ and referred to as "CPR extraction". The per unit benefit of investing in the CPR is $\phi(X) = a - bX$ with $a > 0$ and $b > 0$, which is the average product.[3] The second market is the outside option which yields a fixed return which can be $c_A$ or $c_B$ with $0 < c_A < c_B < a$. An individual's

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[1] Apesteguia (2006) studied behavioral consequences of two degrees of information on CPR (complete vs. incomplete information) and found that information does not alter behaviors, i.e. both levels of information lead to the convergence of the aggregate effort towards the Nash equilibrium.

[2] This repeated "Partners" design may allow participants to build a reputation in FA. However, such strategic behaviors can easily be detected in the last period when the reputation no longer matters. Besides, with two groups per session, we double the number of independent observations compared to a "Strangers" design.

[3] A special feature of CPRs is that by investing $x$ units of extracting effort, an individual obtains a share $\frac{x}{X}$ of total extraction (or harvest) $X\phi(X)$. The linear form $a - bX$ is standard in CPR experiments (Janssen and Ostrom, 2006).

rate of return on the second market can be seen as her or his opportunity cost of extracting the resource. It is referred to as his or her “type” which can be low (for A) or high (for B). Assume that among the $n$ agents, a share $\alpha$ is of type $A$ while the others are of type $B$.

In this set-up, we successively consider four investment regimes: the free-access regime and three regulated regimes. Each regime defines a specific investment game. Under the free-access regime (FA), individuals are free to invest their endowment in the two markets without restrictions. Under individual and non-transferable quotas (NTQ), investment in the CPR is bounded to a quota $\hat{x} < \bar{x}$. Under individual and transferable quotas (TQ), individuals endowed with $\hat{x}$ units of quotas on the CPR can buy or sell those quotas at a fixed price $p$. Under the fee and subsidy scheme (FS), they must pay an access fee of $\tau$ for the first unit invest in the CPR and can receive a subsidy $\sigma$ if they do not invest in the CPR.

We first focus on the free-access regime. Under FA, the profit of an individual of type $i = A, B$ who invests $x_i$ units in the CPR and $\bar{x} - x_i$ in the outside option is:

$$\pi_i(x_i, X) = x_i\phi(X) + c_i(\bar{x} - x_i). \tag{1}$$

In the Nash equilibrium of the FA game, each individual maximizes her or his investment strategy $x_i$ given the investment strategies played by the other players $X - x_i$. A player of type $i$ maximizes $\pi_i(x_i, X)$ subject to the capacity constraint $x_i \leq \bar{x}$ and the non-negativity constraint $x_i \leq 0$.[4] An interior solution $0 < x_i < \bar{x}$ satisfies the following first order condition:

$$\phi(X) + \phi'(X)x_i = c_i. \tag{2}$$

The player of type $i$ equalizes the marginal benefit investing in the CPR (left-hand side) with her or his marginal opportunity cost $c_i$ (right-hand side). If marginal benefit is strictly higher than $c_i$ then $x_i = \bar{x}$. If it is strictly lower then $x_i = 0$.

Since $\phi(X) = a - bX$, the above first-order condition becomes $a - bX - bx_i = c_i$ for

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[4] By labeling agents by they type, we implicitly assume that players of same type play the same strategy. We therefore focus on symmetric Nash equilibria.

any $i = A, B$, which yields the following best strategy play by $i$ for any CPR extraction $X$

$$x_i = \begin{cases} 0 & if \quad \frac{a-c_i}{b} - X \leq 0 \\ \frac{a-c_i}{b} - X & if \quad 0 \leq \frac{a-c_i}{b} - X \leq \bar{x} \\ \bar{x} & if \quad \frac{a-c_i}{b} - X \geq \bar{x} \end{cases} \tag{3}$$

Player $i$'s investment in the CPR is decreasing with CPR extraction at a rate which depends on his opportunity cost $c_i$. For a given $X$, type $A$ players, whose opportunity cost of investment in the CPR is lower, tend to invest more in the CPR than type B ones.

Summing up conditions (3) for $i = A, B$ yields the Nash equilibrium investment level in the CPR in an interior solution $0 < x_i < \bar{x}$ for both player types,

$$X^{FA} = \frac{n}{(n+1)b}(a - \alpha c_A - (1-\alpha)c_B). \tag{4}$$

If the above CPR extraction is higher than full investment capacity $n\bar{x}$, then the FA regime leads to a corner solution whereby all players invest their full capacity in the CPR, i.e. $x_i^{FA} = \bar{x}$ for $i = A, B$. The equilibrium extraction level is then $X^{FA} = n\bar{x}$. If $\frac{a-c_B}{b} - X^{FA}$ is negative (with $X^{FA}$ defined in (4)) then only type $A$ players invest in the CPR. In an interior solution where both types invest in the CPR, type $i$'s investment strategy is $x_i^{FA} = \frac{a-c_A}{b} - X^{FA}$ for $i = A, B$ with $X^{FA}$ defined by (4).

We now turn to the three regulatory regimes NTQ, TQ and FS. The aim of those regulations is to reduce CPR extraction to a target $X < X^{FA}$. Each regulation defines a game which provides specific incentives to players. We analyze how those regulations affect player's behavior and derive the Nash equilibrium outcomes.

Under non-transferable quotas NTQ, investment in the CPR is bounded by the same quota $\hat{x}$ with $0 < \hat{x} < \bar{x}$ assigned to each of the $n$ players. Therefore total investment in the CPR cannot exceed $n\hat{x}$. The return per investment on the CPR is at least $\phi(n\hat{x})$. Since $\phi(n\hat{x}) > \phi(X^{FA}) \geq c_i$ for $i = A, B$ and $\phi$ is decreasing in $X$, the return on the CPR is always higher than the return on the outside option $c_i$ for all players $i$ for any $X \leq n\hat{x}$. Therefore a dominant strategy for all player types is to invest all the quotas $\hat{x}$ in the CPR. In other words, quotas are "binding". To sum-up, setting quotas to $\hat{x}$ such that $n\hat{x} < X^{FA}$ implements a target extraction $X = n\hat{x}$ with both types investing all their investment quotas $\hat{x}$ in the CPR.

Under transferable quotas TQ, players are allowed to exchange their $\hat{x}$ investment quotas at an equilibrium price $p$. Players are price takers since $p$ is exogenously fixed in the experiment. Since quotas are binding, the quota equilibrium price is strictly positive. As with NTQ, all quotas are exhausted and the Nash equilibrium CPR extraction is $n\hat{x}$. The return from investing in the CPR is $\phi(n\hat{x})$ in equilibrium. However the opportunity cost now includes the quota price $p$ since, to invest in the CPR, a player has to buy an extra quota or to give up the benefit of selling it. In the equilibrium of the quota market, those who buy quotas (if any) are the low-cost players $A$ and those who sell are the high-cost players $B$.[5] By buying all type $B$ players' quotas, each type $A$ player ends up with $\frac{n\hat{x}}{n\alpha} = \frac{\hat{x}}{\alpha}$ quotas. Since $\hat{x} < \alpha\overline{x}$, each type $A$ player can use all her or his quotas to invest in the CPR. The price $p$ of an equilibrium in which type $A$ players buy and use all type $B$ players' quotas must satisfy the following inequalities:

$$\phi(n\hat{x}) \geq p + c_A \tag{5}$$

$$\phi(n\hat{x}) \leq p + c_B \tag{6}$$

Each type $A$ player buys quotas in the market if the return on a unit invested in the CPR (left-hand side in (5)) is higher than her or his opportunity (right-hand side in (5)) which now includes the price of quotas. Similarly, each type $B$ player sells quotas if the return of a unit invested in the CPR (left-hand side in (6)) is lower than her or his opportunity (right-hand side in (6)). Conditions (5) and (6) imply $\phi(n\hat{x}) - c_B \leq p \leq \phi(n\hat{x}) - c_A$. Any price $p$ in the range $\phi(n\hat{x}) - c_B$ to $\phi(n\hat{x}) - c_A$ is an equilibrium price in the TQ regime whereby only type $A$ players invest in the CPR. It leads to an equilibrium in which gains for trades in the quota market are fully exploited to minimize CPR exploitation costs and, therefore, improve efficiency. In the experiment, we set the price exogenously in the middle of the range $\phi(n\hat{x}) - c_B$ to $\phi(n\hat{x}) - c_A$ to favor this efficiency feature of quota transferability.

Under the fee and subsidy regime FS, players must pay an access fee $\tau > 0$ for the first unit invested in the CPR. Moreover, they recieve a subsidy $\sigma$ if they do not invest any unit in the CPR. Therefore the FS scheme affects a player's marginal decision only for the first

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[5] Heterogeneity in cost $c_A < c_B$ ensures that there are prices $p$ with exchanges, and thus buyers and sellers in the quota market.

unit: the opportunity cost of the *first* unit of investment is $\sigma + \tau + c_i$ for $i = A, B$. As with TQ, the goal of the FS scheme is to reduce CPR extraction to $X < X^{FA}$ with minimized costs by self-excluding high cost players $B$ from the CPR and keeping all low-cost players $A$ investing all their endowment in the CPR in the Nash equilibrium. CPR extraction is thus $n\alpha\bar{x} = X$. A sufficient condition for an access fee $\tau$ and a subsidy $\sigma$ to achieve this goal in a Nash equilibrium is that they satisfy the two following two incentive-compatibility constraints:

$$\bar{x}\phi(n\alpha\bar{x}) - \tau > \bar{x}c_A + \sigma, \tag{7}$$

$$\bar{x}\phi(n\alpha\bar{x}) - \tau < \bar{x}c_B + \sigma. \tag{8}$$

Condition (7) ensures that a type $A$ player prefers to invest all her or his endowment in the CPR, which yields the left-hand side benefit, rather than in the outside option which results in the right-hand side payoff. The reverse condition (8) holds for player $B$.[6] Due to the lump-sum nature of $(\tau, \sigma)$, all other incentive compatibility constraints can be ignored, at least in the experimental example computed below.[7] The two conditions imply that $\tau + \sigma$ must lie between $\bar{x}(\phi(n\alpha\bar{x}) - c_B)$ and $\bar{x}(\phi(n\alpha\bar{x}) - c_A)$. The FS scheme $(\tau, \sigma)$ must be budget balanced in the sense that what is collected on the $n\alpha$ type $A$ players $\tau n\alpha$ must entirely finance the total subsidies $(1-\alpha)n\sigma$ granted to the $(1-\alpha)n$ type $B$ players. Therefore $\sigma$ and $\tau$ must satisfy the following budget-balance constraint

$$(1-\alpha)n\sigma \leq \tau n\alpha. \tag{9}$$

To sum up, the three regulations succeed in reducing extraction from free access to the same target level $X^R$ in the Nash equilibrium. Market-based instruments that are TQ and FS exploit gains for trade to reduce costs by self-selecting only low cost $A$ players in the CPR.

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[6] To be precise, if a type $B$ player deviates from the Nash equilibrium by investing all her or his endowment in the CPR, the payoff should be $\bar{x}\phi(n\alpha\bar{x} + \bar{x}) - \tau$ in (8). However, since $\phi$ is decreasing, (8) is more stringent than $\bar{x}\phi(n\alpha\bar{x} + \bar{x}) - \tau < \bar{x}c_B + \sigma$.

[7] By the other incentive-compatible constraints, we mean those that prevent any player from investing only part of their endowment in the CPR rather than all (for types $A$) or nothing (for type $B$).

Finally, we set the target $X$ so that all regulations are Pareto improvement compared to free access in the Nash equilibrium. This is what we call the "Pareto dominance condition": a regulation is Pareto dominant rational if everybody obtains a higher profit than under free access. We design an experimental example in which all regulations are Pareto dominant and implement the same target CPR extraction if the subjects play the Nash equilibrium.

## 2.2 An experimental example

The experiment is designed for $n = 8$ subjects, 4 of type $A$ and 4 of type $B$. Therefore $\alpha = 1 - \alpha = \frac{1}{2}$. Subjects are endowed with $\overline{x} = 4$ investment units so that maximal CPR extraction is $X = 4 \times 8 = 32$.

We calibrate the parameters $a$ and $b$ of the average return $\phi$ and the highest opportunity costs $c_B$ so that type $B$ player's marginal benefit from investing in the CPR described in (2) is slightly higher than its marginal cost when everybody invest all their endowment in the CPR. Formally, we set $a = 230$, $b = 3$ and $c_B = 120$ so that $\phi(32) + \phi'(32) \times 4 = a - b \times 32 - b \times 4 = 122 \geq c_B = 120$. The low opportunity cost is $c_A = 90$, which is different enough from $c_B$ to exploit gains for trade in the TQ regime and to design a budget balance FS scheme that keeps only the type $A$ players investing all their 4 units in the Nash equilibrium.[8] With the above parameters, for any $X \leq 32$, the marginal benefit of investing in the CPR $\phi(X) + \phi'(X)x_i$ is always higher than its marginal cost $c_i \in \{90, 120\}$ for any $x_i \leq 4$.[9] Therefore, it is not only a Nash equilibrium strategy but also a dominant strategy for all players to invest all their endowment in the CPR under

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[8] The strength of the social dilemma can also be measured by the Marginal Per Capita Return (MPCR). MPCR is defined as the ratio of benefits to cost for reducing the extraction level by one unit. In our setting, the MPCR is: $MPCR = \frac{bx+bX+c_i}{a}$. It lies between 0 and 1 for a social dilemma with a maximal temptation not to cooperate for values closer to 1. Our parametrization is in line with recent literature on CPR (Janssen and Ostrom, 2006). The range of MPCR in Janssen *et.al.* (2006) is between 0 and 0.97. In our case the range of MPCR is smaller between 0.39 and 0.99 due to the aforementioned Pareto dominance condition.

[9] Even with $x_B = 4$ and if $X = 32$, the marginal benefit 122 is still slightly higher than type $B$'s marginal cost.

free access. The dominant strategies are thus $x_A = x_B = \bar{x} = 4$ for a total investment in the CPR under free-access $X^{FA} = n\bar{x} = 32$. The equilibrium profits are the same for both types $\pi_A(4, 32) = \pi_B(4, 32) = 536$ as they do not invest in the market where their return differ.

To be able to compare regulations, we fix the same target level implemented under the Nash equilibrium of the three regulatory regimes $X$. In order to exploit gains for trade, we set the quotas to $\hat{x} = 2$ so that if all the type $B$ players sell all their quotas to the type $A$ players, each type $A$ players will own 4 quota units which can be used to invest all her or his 4 endowment units in the CPR. Therefore, we can end-up with only the low-cost $A$ players exploiting the CPR under full capacity. The target CPR extraction level is thus $X = n\hat{x} = 16$.[10]

Under non-transferable quota $NTQ$, it is a dominant strategy for all players to use their 2 quota units (half of their endowment) to invest in the CPR, the remaining 2 units being automatically invested in the outside option. Since CPR extraction is $n\hat{x} = 16 =$, the rate of return in the CPR is $\phi(16) = 182$ which is obviously higher than the one under free access $\phi(32) = 134$. Payoffs are $\pi_A(2, 16) = 182 \times 2 + 90 \times 2 = 544$ and $\pi_B(2, 16) = 182 \times 2 + 120 \times 2 = 604$. Both subjects improve their gain compared to FA but those of type B more than those of type A since the return of their 2 units invested in the outside option "market delta" is higher.

Under the transferable quotas regime $TQ$, to obtain a market equilibrium in which type $B$ players sell their 2 quotas to type $A$ players (who therefore can invest their 4 endowment units in the CPR), the price must lie between $\phi(n\hat{x}) - c_B = 62$ and $\phi(n\hat{x}) - c_A = 92$ (see conditions (5) and (6)). We set the price in the middle of this range $p = 77$.[11] The rate of

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[10] We have chosen not to implement the first best CPR extraction level which is $X = 12$ investment units because the "Pareto dominant condition" that imposes a Pareto improvement from free access in the Nash equilibrium would be violated. Moreover, implementing $X = 12$ with uniform quotas, i.e. under $NTQ$ and $TQ$, would require one to assign 1.5 quota units to each subject and, therefore, to divide the quotas.

[11] We have chosen not to endogenize the price to keep the experiment simple enough to be able to test all the regimes within a 2-hours experiments. In particular, we do not examine the issue of the adjustment of

return in the CPR is $\phi(16) = 182$. Payoffs are $\pi_A(4, 16) - 2p = 4 \times 182 - 2 \times 77 = 574$ and $\pi_B(0, 16) + 2p = 4 \times 120 + 2 \times 77 = 634$.

Under the FS regime, the fee $\tau$ and subsidy $\sigma$ to provide with incentive for type $A$ players to invest all their units in the CPR and for type $B$ players not to invest in the CPR must satisfy the incentive-compatibility conditions (7) and (8). With our parameters, it leads to $\bar{x}(\phi(16) - c_B) = 248 \leq \tau + \sigma \leq 368 = \bar{x}(\phi(16) - c_A)$. We pick $\tau + \sigma$ in the middle of this range, i.e., $\tau + \sigma = 308$. The budget balance constraint (9) simplifies to $\tau = \sigma$. Therefore $\tau = 154 = \sigma$. This FS scheme implements $X = 16$ in the Nash equilibrium with same profits and investments than under TQ.

To sum-up, the theoretical predictions of the Nash equilibrium (sometimes also in a dominant strategy equilibrium) of the experimental example are:

1. The free-access leads to CPR over-extraction $X^{FA} = 32$.
2. All instruments lead to a CPR extraction level $X = 16 < X^{FA}$.
3. All regulations are Pareto improving in the sense that everybody obtains a higher payoff than under free access.
4. Both $FS$ and $TQ$ perform equally in sorting the low-cost players since they keep only low-cost players $A$ investing in the CPR. As a consequence, payoffs are equal under FS and TQ, and higher than under NTQ.

## 2.3 Experimental procedure

The experiment, entirely computerized, was conducted at the experimental laboratory of the GAEL research center in Grenoble, France in May-June 2007. A total of 128 engineering and social science students volunteered to participate in one of the 8 sessions. In order to make the decisions non-hypothetical, the subjects were informed at the beginning of the

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prices. As a consequence, we obtain some rationing in the quota market as some subject's offer of a quota or demand could not be satisfied at this price in the experiment. Therefore, even though the exogenous equilibrium price helps subjects to exploit gains for trade, price rigidity penalizes them.

session that at the end they would anonymously be paid an amount in cash depending on their decisions and the decisions of others. Subjects earned 15 Euros minimum and 35 Euros maximum. The currency was the ¥ during the experiment and the exchange rate was 0.1661 Euro = 100¥. A session lasted approximately 2 hours. Before the actual experiment, the experimenter read the instructions aloud to the subjects. In addition, they were able to read these instructions on their individual screen at their own pace. It was made clear that the instructions were identical for all the participants. To control the subjects' understanding of the instructions, they were given a questionnaire. Its correction took place with the experimenter before starting each treatment.

A session was composed of four treatments, each corresponding to one regulation: free access (FA), individual non transferable quota (NTQ), individual transferable quota (TQ) or the fee and subsidy scheme(FS). Each treatment was repeated 7 times. In each session, subjects were randomly and anonymously matched in two groups of 8 players. The group composition and the types of assignment (A and B) remained fixed throughout the session. No interaction between the two groups was possible. Every subject was involved in the four treatments sequentially. To test a possible order effect, the four treatments were sorted differently in every session (8 sessions were conducted). In particular, we made sure that each treatment was played twice in each position (see Appendix A in appendix). Participants had complete information on their own and others payoffs. All the payoff equations and parameters corresponded to the ones depicted in Section 2.2. In order to avoid interferences with subjects' green sensibility, we did not use any term relative to a common pool resource or the environment. We rather mentioned two production markets: one reproducing the CPR incentives (called gamma market) and one corresponding to an outside market with a fixed return (called delta market). The subjects'task consisted in investing their endowment in these two markets. In FA, each subject had to allocate 4 units in the gamma and delta markets (see the protocol in the appendix for more details). The same task was proposed in NTQ except that gamma market was restricted to two units. In FS, subjects paid a fixed tax when allocating one or more units in the gamma market or received a fixed subsidy when allocating nothing in the gamma market. As for TQ, subjects were endowed with two units and decided whether they wished to buy/sell one or two units. Once bids and asks were allocated[12], subjects made their allocation decision.

# 3 Results of the experiment

## 3.1 Learning and Order Effect

We first assess the subjects' understanding of the game given the protocol. We deliberately restricted the number of times each treatment was repeated to 7 to make sure that each subject was able to play the four treatments within a reasonable length of time (about 2 hours). This within-study has the advantage of strengthening the statistical analysis as it removes the sample effect. Nevertheless, it may have two drawbacks. One is that the way subjects play a given treatment can be influenced by what happened during the previous treatment(s) in which they took part. We control this by analyzing the order effect, i.e. we test whether the position in which a treatment was played has an impact on the extraction level. An overall Kruskal-Wallis test fails to reject the null hypothesis that there is no difference between the four positions ($p = 0.4566$) which indicates that the position in the treatment sequence does not affect significantly investment strategies.

The second limit of the protocol is that it leaves very few periods for players to learn the game defined by a treatment. To asses the length of the learning stage we evaluate the convergence to a stable strategy overtime. More precisely, we consider the absolute value of the deviation from the Nash strategy $|x_{it} - x^{Nash}|$ where $x_{it}$ is subject $i$'s strategy at period $t$ and $x^{Nash}$ is the Nash strategy (for this type of subject and this treatment). We asses how the above deviation could be explained by the periods, the treatment and the type of player ($A$ or $B$), all expressed as dummy variables. We therefore estimate the following equation:

$$|x_{it}-x^{Nash}| = c + \sum_{t=2,\ldots,T} \alpha_t * PERIOD_t + \beta * TYPE_B + \sum_{j=FS,NTQ,TQ} \gamma_j * TREAT_j + u_{it} \quad (10)$$

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[12] When the number of bids differs from the number of asks, the bidders or sellers not supplied are determined randomly

where $c$ is a constant, $PERIOD_t$ is a dummy variable equal to 1 for period $t$, $t = 2, \dots, 7$ (the benchmark being period 1), $TYPE_k$ is a dummy variable equal to 1 if subject $i$ is of type $k$ (the benchmark type being $TYPE_A$), and $TREAT_j$ is a dummy variable equal to 1 if the player plays treatment $k \in \{FS, NTQ, TQ\}$, the treatment $FA$ being the benchmark. Based on a Hausman test[13], we present the GLS estimation in Table 1.

Table 1: Nash deviation in absolute value

| **Variable** | **Coefficient** | **(Std. Err.)** |
|---|---|---|
| $PERIOD_2$ | -0.158$^{**}$ | (0.054) |
| $PERIOD_3$ | -0.318$^{**}$ | (0.054) |
| $PERIOD_4$ | -0.357$^{**}$ | (0.054) |
| $PERIOD_5$ | -0.436$^{**}$ | (0.054) |
| $PERIOD_6$ | -0.500$^{**}$ | (0.054) |
| $PERIOD_7$ | -0.469$^{**}$ | (0.054) |
| $TYPE_B$ | -0.059 | (0.061) |
| $TREAT_{FS}$ | -0.282$^{**}$ | (0.087) |
| $TREAT_{NTQ}$ | 0.300$^{**}$ | (0.087) |
| $TREAT_{TQ}$ | 0.695$^{**}$ | (0.087) |
| $c$ | 0.771$^{**}$ | (0.077) |

$^{**}$, $^{*}$,$^{\dagger}$for respectively significant at 1%, 5% and 10%.

First observe that, in addition to the treatment and the subject's type, the coefficients associated with $PERIOD_t$ are significant. Second, the coefficient associated with $PERIOD_2$ is significant and negative, which corresponds to a learning effect between periods 1 and 2. Third the coefficients $\widehat{\alpha}_t$ are decreasing with $t$ suggesting that the investment strategy in the CPR gets closer to the Nash strategy period after period. Fourth, we reject the null hypothesis $\widehat{\alpha}_2 = \widehat{\alpha}_3$ which also means also that the subjects' strategies significantly

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[13] We estimate three econometric models: an ordinary least squares model (OLS) based on the pooled sample, a fixed (FE) and random effects (GLS) models. OLS is inconsistent if there are individual specific effects. The GLS estimator is more efficient than the within estimator if the independent variables are uncorrelated with the individual error term.

differ between periods 2 and 3. However, we always keep the null hypothesis $\widehat{\alpha}_t = \widehat{\alpha}_{t+1}$ for $t \geq 3$: learning occurs mainly in period 1 to 3. We do not reject the null hypothesis $\widehat{\alpha}_7 = \widehat{\alpha}_6 = \widehat{\alpha}_5$ which implies that the strategies are not significantly different for period 5, 6 and 7. In other words the impact of time is not statistically different for period 5 to 7. This may be viewed as an indication of a good convergence of the subjects' strategies.[14]

## 3.2 Resource preservation

We evaluate the performance of the four regimes (the free-access regime and the three regulations) regarding resource preservation. We observe that free access leads to over-investment in the CPR at a level close to the theoretical prediction. Although the Nash equilibrium of $X = 32$ units is not reached, 75.7% of the subjects extract at full capacity, making $X = 28.6$ units by averaging over periods.[15] Under regulation, the investment reduction by half is close to be reached on average. The Nash equilibrium predicts a total investment in the CPR of 16 units under FS, TQ and NTQ. As expected, the two market-based mechanisms FS and TQ implement the same extraction level as the NTQ regulation. The average investments in CPR extraction over the seven periods ($X = 15.26$ under FS, $X = 15.17$ under TQ and $X = 14.88$ under NTQ) are not significantly different according to the Wilcoxon-signed rank test ($p \geq 0.2840$ for NTQ and FS, $p \geq 0.6646$ for NTQ and TQ and $p \geq 0.7268$ for FS and TQ). Though close to the target level, the three regulation means are significantly inferior to 16 according to a one-sample t-test. Whereas regulations NTQ and TQ are designed so that the extraction target level cannot be passed – subjects cannot extract more than 2 units in NTQ and a total of 16 permits are delivered in TQ –, CPR extraction under FS exceeds the 16 units upper bound in 27.6% of cases. FS also presents the highest variability in group extraction with a standard deviation of 4.18. This contrasts with the very low standard deviation in TQ in spite of its relatively

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[14] Note however that the null hypothesis $\widehat{\alpha}_4 = \widehat{\alpha}_5 = \widehat{\alpha}_6 = \widehat{\alpha}_7$ is rejected at 1%.

[15] Subjects do not seek the social optimum which is obtained in our setup when the four players A extract at their maximum capacity and when the four players B extract one unit each: fewer than 6% of players B extract less than 2 units.

higher complexity ($\sigma = 0.60$).

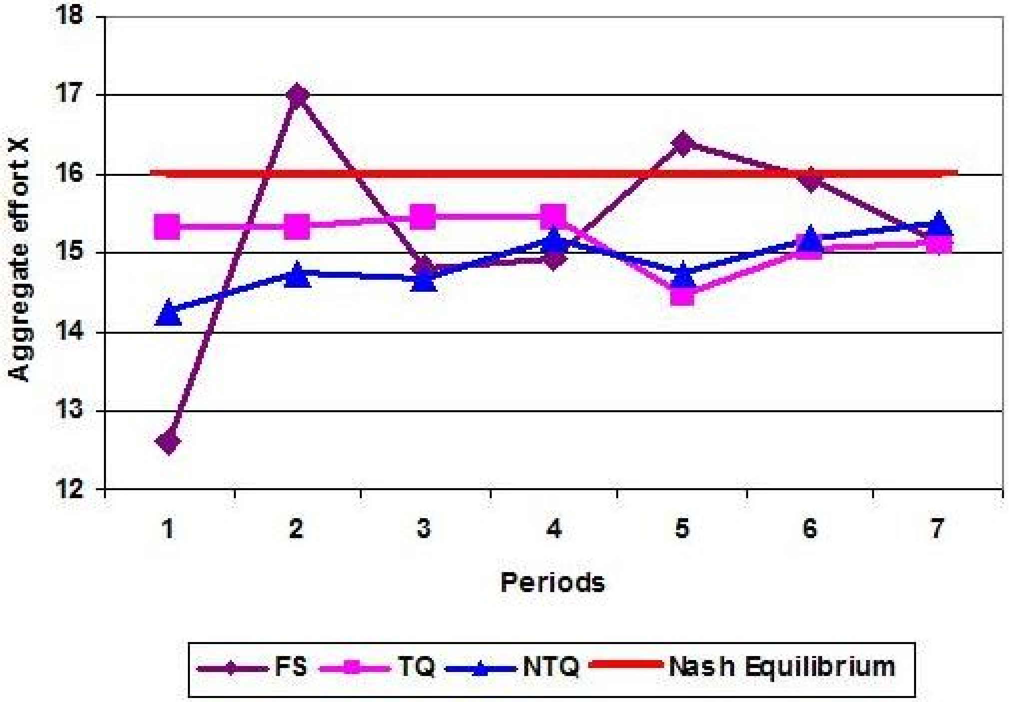

**Figure 1:** CPR extraction in the FS, NTQ and TQ[16] treatments

## 3.3 Profits

We now examine the performance of the three regulations regarding individual welfare and Pareto improvement compared to free access. The experiment was designed so that every subject would experience a profit increase under regulation compared to free access in the Nash equilibrium, this increase being higher and equivalent under the two market-based regulations FS and TQ.

Profits are higher on average under regulations than under FA, and are higher under the two market-based instruments FS and TQ than under TQ. Subjects earn in average 583.7 ¥, 583.4 ¥ and 568.4 ¥ per period respectively in treatments FS, TQ and NTQ; compared with 557.5 ¥ under FA. Consistently to theory, the profits under FS and TQ are not significantly different (Wilcoxon $p \geq 0.3269$). Profits in FA and NTQ are significantly lower than profits in the two market-based instruments ($p = 0.0000$).

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[16] The treatment FA is not included in the figure 1 because of scale effect.

Yet higher average profits under regulations than under FA do not imply higher profits for all subjects. Overall the Pareto dominance of regulations on free-access investment is violated. We observe that profits are higher for all subjects compared to free access in only 71.1% of periods under TQ, 69% under FS and 60.0% under NTQ.[17] This rate of Pareto dominance goes down for type $A$ players (the subjects with lower return outside the CPR) to 53.3% under TQ, 51.1% under FS and 33.5% under NTQ, meaning that almost half of type $A$ players are worse-off under the two market-based regulations, and two-third are under NTQ. Among all subjects, the average profit over the 7 periods is higher under TQ than under FA for 72% of them, compared to 68 % under FS and 55% under NTQ. Over the 7 periods, four subjects always obtain a lower profit under FS than under FA whereas all subject gets more than under FA at least one period under TQ. This statistic suggests, although Pareto-improvement from free-access is often violated, it holds more often and for more subject under the two market-based instruments FS and TQ with a slight dominance for TQ.

To further examine the impact of regulations on the Pareto-dominance condition, we use the following econometric strategy. We first compute a dummy variable equal to 1 if the profit for subject $i$ at period $t$ under a given regulation is greater than the profit obtained in the same period by the same subject under the free-access treatment. We then estimate a logit model to predict the probability of having a higher profit than under free access. We control for the impact of the period, the subject type (A or B) and the treatment (FS, TQ, NTQ). The results are presented in Table 2.[18]

Being a type B subject increases the probability of higher profits after regulation (the marginal effect is equal to 0.43 and is significant at 1%) due to higher outside opportunity . Compared to the NTQ treatment, FS and TQ have a positive and significant impact of the probability of profit improvement (the marginal effects are respectively 0.09 and 0.12 and are significant at 1%). Moreover, we do not reject the null hypothesis of a different

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[17] We compare the observed profit for period $t$ under the regulation with the observed profit under FA for the same period $t$ and the same subject.

[18] We get a pseudo R2 equal to 0.2 which corresponds to a relatively poor predictive power of the logit model. However, at a probability cutoff equal to 0.60, 73% of the subjects are well classified by the model.

Table 2: Probability of profit improvement

| **Variable** | **Coefficient** | **(Std. Err.)** | **Marginal effect** | **(Std. Err.)** |
|---|---|---|---|---|
| $PERIOD_2$ | 0.128 | (0.168) | 0.025 | ( 0.033 ) |
| $PERIOD_3$ | 0.762$^{**}$ | (0.173) | 0.135$^{**}$ | ( 0.026 ) |
| $PERIOD_4$ | 0.490$^{**}$ | (0.170) | 0.091$^{**}$ | ( 0.029 ) |
| $PERIOD_5$ | 0.793$^{**}$ | (0.173) | 0.140$^{**}$ | ( 0.026 ) |
| $PERIOD_6$ | 0.904$^{**}$ | (0.175) | 0.156$^{**}$ | ( 0.025 ) |
| $PERIOD_7$ | 1.002$^{**}$ | (0.176) | 0.169$^{**}$ | ( 0.024 ) |
| $TYPE_B$ | 2.217$^{**}$ | (0.103) | 0.429$^{**}$ | ( 0.016 ) |
| $TREAT_{FS}$ | 0.477$^{**}$ | (0.113) | 0.093$^{**}$ | ( 0.021 ) |
| $TREAT_{TQ}$ | 0.611$^{**}$ | (0.115) | 0.118$^{**}$ | ( 0.021 ) |
| $Intercept$ | -1.120$^{**}$ | (0.144) | | |

$^{**}$, $^{*}$,$^{\dagger}$for respectively significant at 1%, 5% and 10%.

Pseudo R2: 0.20

impact of FS and TQ on the probability of a profit improvement. Pareto dominance is not significantly different under the two market-based instruments. Such results are in line with the non-parametric tests: The percentage of higher profits are similar with the two market-based instruments (Fisher $p = 0.17$) but not between the two market-based instruments and NTQ ($p = 1.240e - 4$ for FS vs NTQ, $p = 1.74e - 6$ for TQ vs NTQ).[19]

### 3.3.1 Sorting Effect

We compare the performance of the two market-based instruments FS and TQ in screening subject types. Since type $B$ subjects have higher investment returns outside the CPR, only type $A$ subjects should invest all their units in the CPR. The market-based instruments

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[19] Note that there is, once again, a form of learning effect between periods 1-2 (marginal effect not significantly different from 0) and periods 3-7 (all marginal effects significantly different from 0). The probabilities of profit improvement in periods 1 and 2 are not significantly different. The probability of profit improvement however increases from period 3.

*FS* and *TQ* differentiate individuals by encouraging type *A* subjects to invest all their units in the CPR and type *B* none of them. Theoretically, FS and TQ perform equally regarding this sorting effect. We argue that in the experiment FS performs better than TQ.

We plot the percentage of subjects investing 0 to 4 units in the CPR four each types in Figure 2 for the FS treatment and in Figure 3 for the TQ treatment.

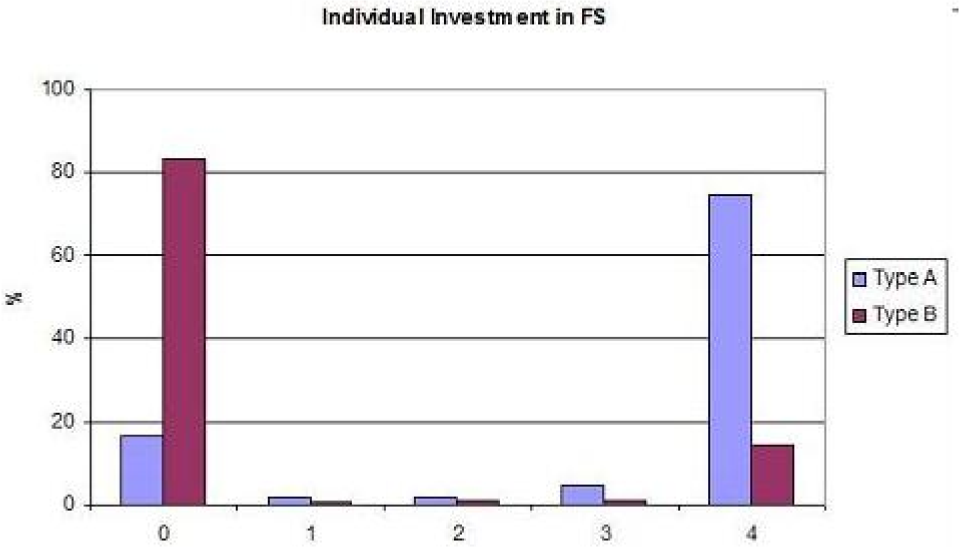

**Figure 2:** Sorting effect -Investment in the CPR under FS

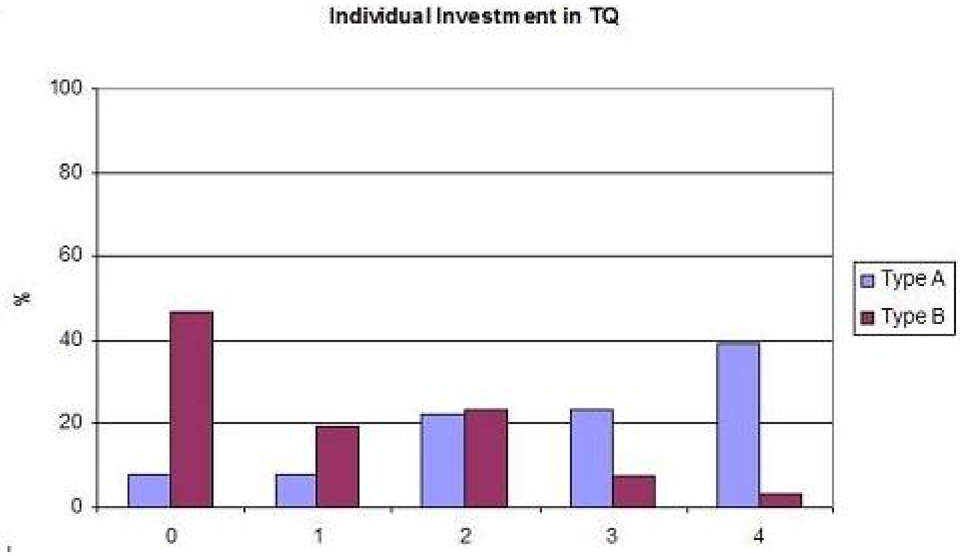

**Figure 3:** Sorting effect -Investment in the CPR under TQ

The theoretical efficient sorting leads to extreme investment decisions: 100% type A should invest their 4 units in the CPR and 100% of type B should invest 0 units in the CPR. The above figures clearly make the point that more subjects choose intermediate investment strategies (1, 2 or 3 units invested in the CPR, the rest being invested in the outside option) under TQ than under FS. Under FS, most subjects choose extreme investment strategies, although few of them choose the "wrong one". Under TQ, more subjects deviate from their Nash strategy but with only a few investment units. More precisely, while 74.7% of type A and 83.3% of type B play Nash in FS, only 39.0% of type A and 46.7% of type B play Nash in TQ (Fisher exact $p = 0.0000$ for types A and B).

Another measure of the sorting effect is the percentage investment from each type in the CPR. Type A subjects represent 84.3% of total investment in the CPR under FS but only 74.6% under TQ. Overall subjects of types $A$ invest significantly more under FS (3.35 vs. 3.01 average units per capita, $p \leq 0.02966$). On the other hand, type $B$ subjects invest significantly less (0.67 vs. 0.83, $p \leq 0.02930$).

We provide further evidence of a better sorting with FS than with TQ by estimating a model predicting the probability of playing the Nash strategy by each subject and each period on the sub-sample defined by the treatments FS and TQ. We control with dummies for the period, for the type and the treatment (TQ being the benchmark). The results are summarized in Table 3 below.

We found that playing FS has a positive and significant impact on the probability of playing Nash compared to TQ which is the benchmark in the estimation: the marginal effect of the FS dummy is equal to 0.38 and is significant at 1%. This strengthens our point that FS is more efficient than TQ in sorting types by making them play Nash more often. Another interesting result is that type $B$ subjects are more likely to play Nash than type $A$, which means investing nothing in the CPR under both regulations. One reason might be that playing Nash is more difficult under TQ for type $A$ subjects since they need to purchase 2 more units of quotas while type $B$ subjects can simply not use their quotas. We examine the impact of such market frictions in the next section.

Table 3: Probability of playing Nash

| **Variable** | **Coefficient** | **(Std. Err.)** | **Marginal effect** | **(Std. Err.)** |
|---|---|---|---|---|
| $PERIOD_2$ | 0.244 | (0.194) | 0.055 | ( 0.043 ) |
| $PERIOD_3$ | $0.622^{**}$ | (0.196) | $0.134^{**}$ | ( 0.038 ) |
| $PERIOD_4$ | $0.738^{**}$ | (0.196) | $0.156^{**}$ | ( 0.037 ) |
| $PERIOD_5$ | $1.227^{**}$ | (0.203) | $0.240^{**}$ | ( 0.031 ) |
| $PERIOD_6$ | $1.359^{**}$ | (0.205) | $0.260^{**}$ | ( 0.030 ) |
| $PERIOD_7$ | $1.079^{**}$ | (0.200) | $0.216^{**}$ | ( 0.033 ) |
| $TYPE_B$ | $0.411^{**}$ | (0.107) | $0.095^{**}$ | ( 0.025 ) |
| $TREAT_{FS}$ | $1.709^{**}$ | (0.111) | $0.379^{**}$ | ( 0.022 ) |
| $Intercept$ | $-1.267^{**}$ | (0.161) | | |

$^{**}$, $^{*}$,$^{\dagger}$for respectively significant at 1%, 5% and 10%.

Pseudo R2: 0.14

## 3.4 Discussion

Maybe the most puzzling experimental result is that FS performs poorly in improving subjects' profit from free access despite a better sorting. Intuitively, we would expect investment to be allocated more efficiently with a better sorting which should favor higher profits and therefore more frequent Pareto improvement from free access. We do not however observe that in the experiment. In this section we investigate why.

One explanation might be that the FS scheme induces a surplus which is not shared by the subjects. In the experiments, the FS scheme might be unbalanced: subjects might pay more through the fees than they receive in total through the subsidies. This imbalance would create a surplus which would be taken out of the social welfare and therefore might explain lower profits. In contrast, under TQ, the permit market clearing ensures that no money is taken out of the economy. We found that, although the budget is in deficit on average in the periods 1, 3, 4 and 7 and in surplus in the period 2, 5 and 6, it is balanced on aggregate. Moreover, this deficit or surplus is marginal as it never goes beyond 4% of the social welfare. Thus the budget surplus does not seem to be the reason for the lowest profits under FS.

We look more carefully at the deviations from Nash and its impacts of payoffs. As mentioned before, subjects tend to deviate more often from their Nash strategy under TQ than under FS: the deviation rate is overall 57% under TQ and significantly higher than 21% under FS (Fisher Exact, $p = 0.0000$). However Figures 2 and 3 clealry show that when subjects deviate from Nash they tend to deviate more under FS than under TQ. The lump-sum nature of FS provides incentives for extreme strategies: 4 or 0 units in the CPR. Investing 1 to 4 units in the CPR costs the same price: 154¥ from tax plus 154¥ from giving up the subsidy, which amounts to a 308¥. As for TQ, the marginal cost for extraction is 77¥ (i.e. the value of one permit). Almost all those who deviate under FS choose the opposite strategy from Nash: investing all their units when Nash predicts no investment and vice-versa). Under TQ many subjects deviate by not buying any trading permits or only one, and thus invest 1, 2 or 3 units. They pay or give up only 1, 2 or 3 times 77¥ and not four times, i.e. $4 \times 77 = 308$¥ like those who deviate from Nash under FS.

The extreme deviation under FS clearly has an impact of profits. The high-power incentive FS scheme improves sorting at the cost of a harsher punishment for those who deviate. In order to asses the cost of deviating from Nash under both regulations, we evaluate the relative average loss from Nash deviation in the following way. For each regulation and type, we compute the average profit obtained by subjects playing Nash and the average profit for those who deviate from the Nash strategy for the same period. We then take the difference between the two terms, divided by the average profit for those who play Nash. By taking the average over the 7 periods we obtain Table 4 below.

The relative profit loss of those who deviated from the Nash strategy is higher under FS than under TQ for both types. The difference is greater for the $B$ types: those who invest in the CPR perform 15% less under FS than under TQ. For the FA types, those who invest less than their 4 units in the CPR enjoy 15.2% less profits under FS and 8.1% less under TQ. This highest loss from Nash deviation has an impact on the Pareto-dominance condition. Even if the CPR extraction is on average sufficiently preserved to allow for

Table 4: Relative profit loss from Nash deviation

| **Treatment** | **A** | **B** | **Total** |
|---|---|---|---|
| FA | -12.6% | -4.4% | -8.4% |
| FS | -15.2% | -14.7% | -15.0% |
| TQ | -8.10% | -2.9% | -5.5% |
| NTQ | -23.2% | -14.0% | -18.6% |

a profit improvement, some subjects experience a reduction of profits with regulations because they deviate from the Nash strategy. We find evidence that deviating from Nash is more likely to reduce profits from free access under all regulations. By comparing the profit of those who play Nash under free access and deviate from Nash under regulation during the same period, we obtain a percentage of lower profits under regulation: 91% for NTQ, 85% under FS, and 45% under TQ. In contrast, if we consider those who play Nash in the same period, the percentage of lower profits under regulation goes down to 41% for NTQ, 25% for FS and 18% for TQ. Those who are the more likely to lose from regulation are the type $A$ players whose return outside the CPR is the lowest. It turns out that the inequality among types measured as the difference between type $A$ and type $B$ average profits, is higher under FS (68.7 on average) than under TQ (59.5, Wilcoxon, $p \geq 0.0829$). This distributional impact of the FS regulation in favor the richer subject (defined as those with higher outside opportunities) is detrimental to its acceptability (defined as profit improvement from free access). It thus seems that FS is provide more incentives but hurt more less subjects than TQ.

We lastly examine in more detail the reason for a higher rate of Nash deviation and therefore poor sorting under TQ. First, we observe that subjects do not make a mistake by buying or not selling permits they don't use. Once the bids and asks are allocated, only 4.4% of the subjects do not use their permit(s). The non-use of permits is therefore not a cause of deviation. Second, subjects might fail to invest all their units, or may invest nothing at all, because of market frictions. As we have imposed market clearing at an exogenous price for the TQ regulation, there might be some imbalance between asks and bids and therefore some rationing. On the other hand, we do not force the FS scheme to be budget balanced.

To asses the performance of TQ without rationing we compute the experimental results as if all wishes were fulfilled. We simulate a regulation in which permit wishes (asks and demands) in TQ are regarded as actual investment. In such a configuration, permits act as a proportional fee/subsidy scheme. Buying one 77¥ permit in order to extract one more unit is equivalent to paying a 77¥ tax for extracting one more unit. Market frictions are removed as the regulator bears the imbalance between buys and sells (or tax and subsidy) although the cost of deviation is similar to TQ.

Unsurprisingly, using trade wishes as investment decisions lowers the deviation rate from 57% to 39% ($p = 0.0000$). Yet it remains significantly more important than the 21% deviation rate under FS ($p = 0.0001$). Removing market friction does not significantly improve sorting: type $A$'s investment share increased from 74.6% to 75.9% which is still lower than the 84% share under FS. Overall profits are not improved (581.8¥ in average compared to 583.7¥ in FS and 583.4¥ in TQ) and the aggregated investment in the CPR exceeds the 16 units targeted by the regulation. Lastly, using permit trade wishes as investment decisions does not improve Pareto dominance: 66.2% of the decisions improve profits from free access, compared with 71.1% under TQ and 69.0% under FS. These simulation suggests markets frictions are not the main explanation for TQ under-performance in sorting. It is mostly due to the payment scheme which is per-unit under TQ (77¥ per investment) rather than fixed under FS ($4 \times 77 = 308$¥ which is the sum of the fix fee and the subsidy). As a consequence, it therefore exhibits less power incentives.

# 4 Conclusion

In this paper our aim was to compare the performance of three different instruments designed to reduce overuse in common pool resources, namely: two market-based instruments - a price based one, fees and subsidies, and a rights-based one transferable quotas -, as well as a command-and-control instrument - non transferable quotas scheme. We designed a static theoretical model of extraction of a resource, with a population of agents with constant but heterogeneous opportunity marginal extraction costs (low and high). Apart from the classical analysis in terms of welfare, this model imposes a Pareto-improving condition for the instruments to be acceptable by users. The comparison is based on theoretical prediction and an experiment in which each subject is exposed to all the instruments, with the free-access regime as a benchmark.

We find that, consistently with theory, all instruments perform equally in preserving the resource on average. Yet the variance is lower under quotas because extraction is bounded upward. In contrast the extraction rate targeted by the regulation is often exceeded under the fee and subsidy scheme. The two market-based instruments succeed in screening the subjects with higher opportunity cost of resource extraction. This makes these instruments more profitable than non-transferable quotas on average and also for more subjects: those who experience a Pareto-improvement from free access are more numerous. Yet, in contrast to the Nash equilibrium predictions, some of the subject are worse off than under the free access regime even with the two market-based instruments.

Interestingly, the two market-based instruments, which are equivalent in theory, perform differently regarding sorting and Pareto improvement from free access. We found that the fee and subsidy scheme scores better in sorting out the high-cost types but leads to slightly fewer Pareto improvements from free-access than transferable quotas. The lump-sum nature of the access fee and subsidy for not investing in the resource provides high-power incentives for extreme investment strategies (investing all the endowment or nothing in the common-pool resource), which definitively favors sorting. Yet the subjects are more hurt if they make “mistakes” by not playing Nash, which means not using the extreme strategy or, more often, using the “wrong” extreme strategy. This is why this better sorting does not translate into higher profits for more subjects. Under transferable quotas, subjects are charged only a marginal over-cost of extraction through the cost of purchasing quotas. They might not found a buyer or a seller for their quota. Consequently they more often invest few units (one to three) in the common-pool resource which is a smaller deviation from Nash. Although they generally incur a loss of profit from this Nash deviation, it is also limited because the extraction rate is bounded upward by quotas.

Our experiment sheds light on the choice of instruments for common-pool regulation. It confirms the dominance of market-based regulations over nontransferable and uniform quotas for efficiency and individual welfare. It also makes the distinction between market-based instruments relying on price or quantity. We provide experimental evidence that high-power incentive price schemes can be very costly for users, thereby questioning their political feasibility. Even if they sort out the less efficient users better than tradable extraction quotas, those who do not respond properly to incentives pay a higher cost. Moreover, total extraction is not bounded upwards by quotas which reinforce the profit loss in case of deviation. This trade-off between high power incentives and political feasibility which is not an issue in theory arises in our experiment. It might matter in practice.

# APPENDIX

# A Treatments order

| | Treatment 1 | Treatment 2 | Treatment 3 | Treatment 4 |
|---|---|---|---|---|
| Session 1 | NTQ | FA | FS | TQ |
| Session 2 | FS | TQ | NTQ | FA |
| Session 3 | FA | FS | TQ | NTQ |
| Session 4 | TQ | NTQ | FA | FS |
| Session 5 | NTQ | TQ | FA | FS |
| Session 6 | FS | FA | TQ | NTQ |
| Session 7 | FA | NTQ | FS | TQ |
| Session 8 | TQ | FS | NTQ | FA |

# B Experimental Protocol

## B.1 Introduction read to subjects by experiment monitor

Good evening. Can I have your attention please. This is an experiment in decision making in economics. The instructions are simple. All profits you make during the experiment will be totalled and paid to you in privacy in cash at the end of the experiment. The amount paid depends on decisions making during the experiment. The experiment will last 2 hours.

As you see, you are 16 participants at this experiment. To guarantee anonymity, each participant is identified by a code number. During experiment, it is forbidden to communicate in any way with other participants. Keep concentrate on your own computer screen and keep silent during the whole experiment. If you have any problems feel free to raise your hand and one of the experiment monitors will assist you.

You will be able to read all the instructions on your own computer screen.

The money of the experiment is the Yen. The exchange rate of the experiment is 100 Yen=0.1661 Euro.

You can now press the button -START-

## B.2 Instructions on screen

### GENERAL INSTRUCTIONS

This is an experiment in decision making in economics.

At the beginning of the experiment, two groups of 8 individuals are created. The composition of these two groups will remain the same during the whole experiment. The two groups will work independently.

***Page break***

Each of you is the producer of a good on market "gamma" and of a good on market "delta". You are endowed in production units that you must distribute on these two markets. More precisely, you will decide a production level on market gamma. The production units non utilized will be automatically assigned to market delta.

On market gamma, the production generates a gain. The gain increases with the number of individual production units and decreases with the units produced by all of the producers of the group.

On market delta, the production also generates a gain. The gain increases with the number of production units. It is independent of the units produced by all of the producers of the group.

***Page break***

There are two types of producers, A and B. This type was assigned randomly and permanently to each individual for the whole experiment. On market delta, the production per unit is more profitable for producer B.

***Page break***

The experiment comprises four distinct treatments which will be run successively. Each treatment consists on a succession of 7 periods. At each period, you will decide the number of units you will produce on market gamma. The remaining units will be intended to market delta. At the end of each period, you will set the following information:

- Total production of the group on market gamma
- Your own total gain in the two markets.

***Page break***

In order to help your decision making, you will set for each treatment a table of possible gains function of the production units repartition on the two markets and of the total production level of the group on market gamma. The table indicates the total gain generated by the two markets (gamma and delta).

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The production rules differ at each treatment. These rules will be announced at the beginning of each new treatment.

***Page break***

## TREATMENT FA

Your production capacity and the one of the other producers is fixed to 4 units. At each period, we will decide the number of production units ($x = 0, 1, 2, 3, 4$) on market gamma. The total production level ($X$) is the sum of production units in the group on market gamma. Here, X is comprised between 0, and $4 \times 8 = 32$.

The number of production units on market delta is the difference between production capacity and the number of units decided on market gamma ($4 - x$).

***Page break***

In each group, there is 4 producers A and 4 producers B. On market gamma, the two types of producers have a unitary production gain of $(230 - 3X)$ yen . On market delta, producers A have a unitary production gain of 90 yen and producers B have a unitary production gain of 120 yen .

***Page break*** You are producer A/B, your unitary gain on market delta is thus:...

The gain of your activity on market gamma :

- increases with your individual production level ($x$)

- decreases with total production level of your group ($X$).

The gain of your activity on market delta :

- increases with production units non assigned on market gamma ($4 - x$).

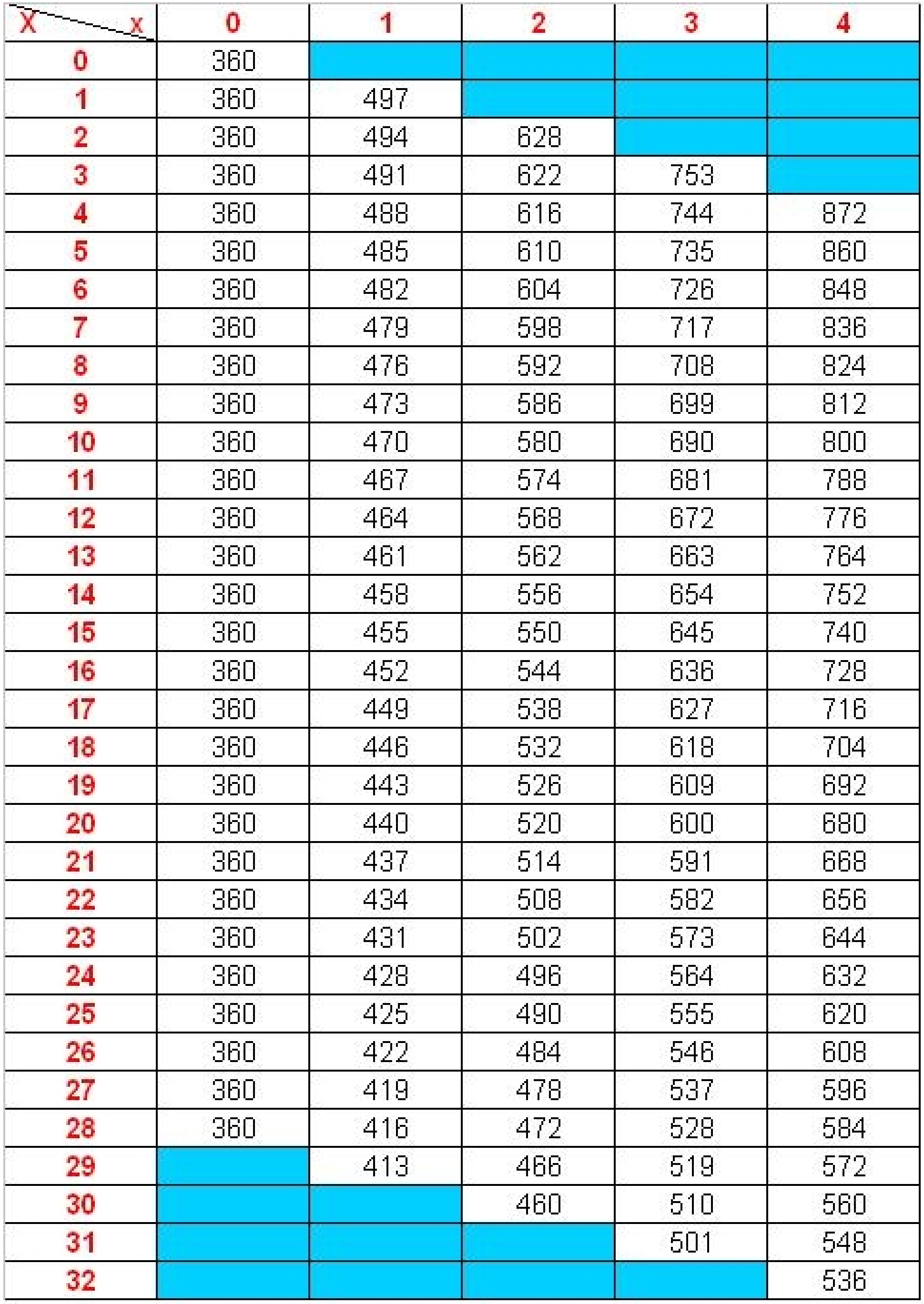
***Page break***

For each individual, total gain is calculated as follows:

$$\text{Producer A} : \underbrace{(230 - 3X) \times x}_{\textit{gains on market gamma}} + \underbrace{90(4 - x)}_{\textit{gains on market delta}}$$

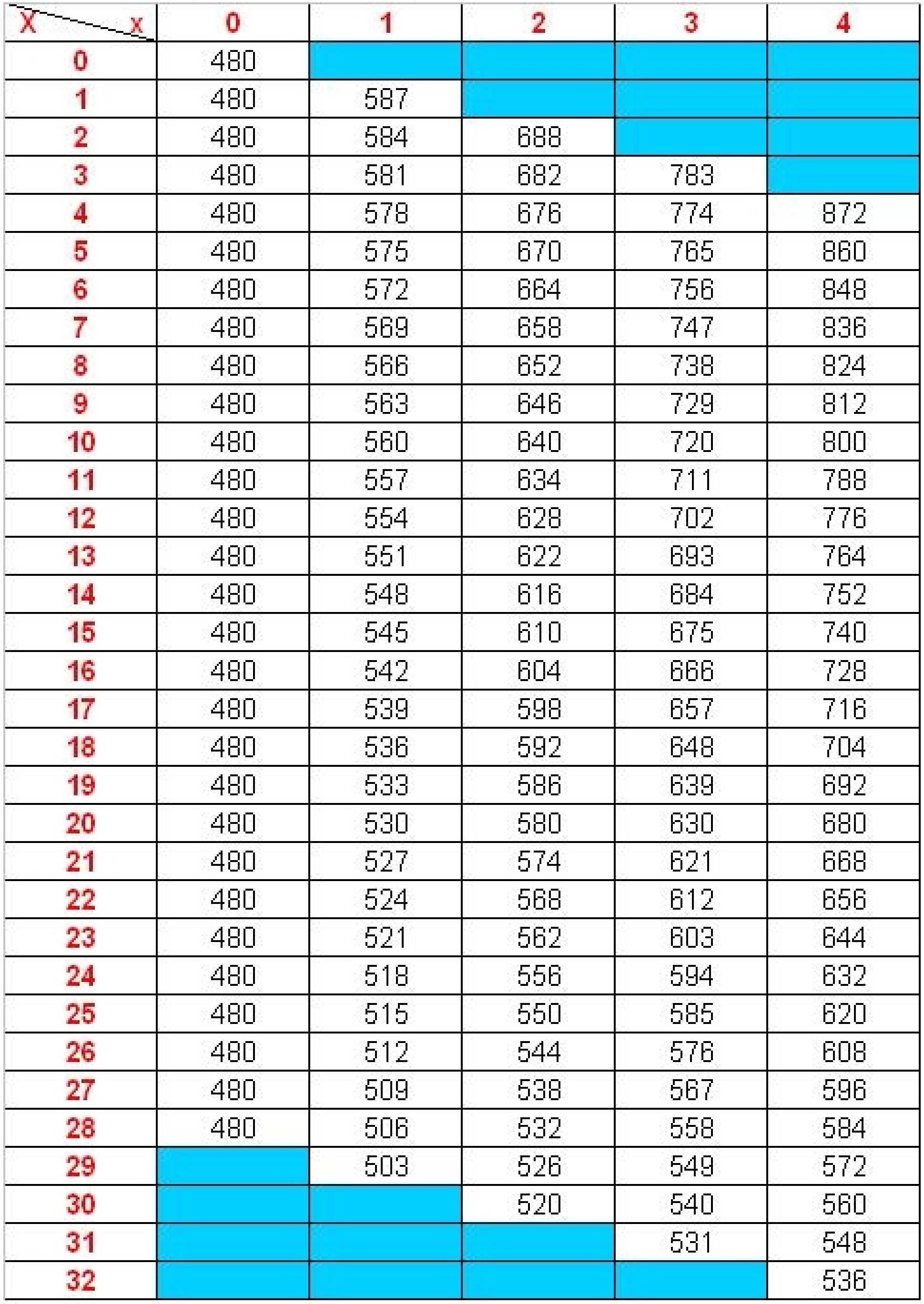
$$\text{Producer B} : \underbrace{(230 - 3X) \times x}_{\textit{gains on market gamma}} + \underbrace{120(4 - x)}_{\textit{gains on market delta}}$$

**Payoff matrix of player type A – Treatment FA.**



| X \ x | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 360 | | | | |
| 1 | 360 | 497 | | | |
| 2 | 360 | 494 | 628 | | |
| 3 | 360 | 491 | 622 | 753 | |
| 4 | 360 | 488 | 616 | 744 | 872 |
| 5 | 360 | 485 | 610 | 735 | 860 |
| 6 | 360 | 482 | 604 | 726 | 848 |
| 7 | 360 | 479 | 598 | 717 | 836 |
| 8 | 360 | 476 | 592 | 708 | 824 |
| 9 | 360 | 473 | 586 | 699 | 812 |
| 10 | 360 | 470 | 580 | 690 | 800 |
| 11 | 360 | 467 | 574 | 681 | 788 |
| 12 | 360 | 464 | 568 | 672 | 776 |
| 13 | 360 | 461 | 562 | 663 | 764 |
| 14 | 360 | 458 | 556 | 654 | 752 |
| 15 | 360 | 455 | 550 | 645 | 740 |
| 16 | 360 | 452 | 544 | 636 | 728 |
| 17 | 360 | 449 | 538 | 627 | 716 |
| 18 | 360 | 446 | 532 | 618 | 704 |
| 19 | 360 | 443 | 526 | 609 | 692 |
| 20 | 360 | 440 | 520 | 600 | 680 |
| 21 | 360 | 437 | 514 | 591 | 668 |
| 22 | 360 | 434 | 508 | 582 | 656 |
| 23 | 360 | 431 | 502 | 573 | 644 |
| 24 | 360 | 428 | 496 | 564 | 632 |
| 25 | 360 | 425 | 490 | 555 | 620 |
| 26 | 360 | 422 | 484 | 546 | 608 |
| 27 | 360 | 419 | 478 | 537 | 596 |
| 28 | 360 | 416 | 472 | 528 | 584 |
| 29 | | 413 | 466 | 519 | 572 |
| 30 | | | 460 | 510 | 560 |
| 31 | | | | 501 | 548 |
| 32 | | | | | 536 |

**Payoff matrix of player type B – Treatment FA.**



| X x | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 480 | | | | |
| 1 | 480 | 587 | | | |
| 2 | 480 | 584 | 688 | | |
| 3 | 480 | 581 | 682 | 783 | |
| 4 | 480 | 578 | 676 | 774 | 872 |
| 5 | 480 | 575 | 670 | 765 | 860 |
| 6 | 480 | 572 | 664 | 756 | 848 |
| 7 | 480 | 569 | 658 | 747 | 836 |
| 8 | 480 | 566 | 652 | 738 | 824 |
| 9 | 480 | 563 | 646 | 729 | 812 |
| 10 | 480 | 560 | 640 | 720 | 800 |
| 11 | 480 | 557 | 634 | 711 | 788 |
| 12 | 480 | 554 | 628 | 702 | 776 |
| 13 | 480 | 551 | 622 | 693 | 764 |
| 14 | 480 | 548 | 616 | 684 | 752 |
| 15 | 480 | 545 | 610 | 675 | 740 |
| 16 | 480 | 542 | 604 | 666 | 728 |
| 17 | 480 | 539 | 598 | 657 | 716 |
| 18 | 480 | 536 | 592 | 648 | 704 |
| 19 | 480 | 533 | 586 | 639 | 692 |
| 20 | 480 | 530 | 580 | 630 | 680 |
| 21 | 480 | 527 | 574 | 621 | 668 |
| 22 | 480 | 524 | 568 | 612 | 656 |
| 23 | 480 | 521 | 562 | 603 | 644 |
| 24 | 480 | 518 | 556 | 594 | 632 |
| 25 | 480 | 515 | 550 | 585 | 620 |
| 26 | 480 | 512 | 544 | 576 | 608 |
| 27 | 480 | 509 | 538 | 567 | 596 |
| 28 | 480 | 506 | 532 | 558 | 584 |
| 29 | | 503 | 526 | 549 | 572 |
| 30 | | | 520 | 540 | 560 |
| 31 | | | | 531 | 548 |
| 32 | | | | | 536 |

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