Cost Uncertainty in Experimental Emissions Markets and Price Control

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Abstract

In this paper, we use experimental emissions trading markets to investigate the effects of two types of instruments for dealing with the negative effects of price risk, that results from the potential shocks that could affect production costs. As per the results obtained, the first mechanism that allows banking and borrowing permits from one period to another, yields some important benefits in terms of the reduction of price volatility, price dispersion and it significantly increases market liquidity, leading to overall flatter price series. The second instrument, besides allowing for permit transfer, also considers an adjustable supply of permits, such that besides managing to stabilize the price path, it also creates more significant results in terms of settling it around a desired target price level.

Keywords: Market Design; Emission Permits; Experimental Economics; Price Control.

JEL Codes: C91, L51, Q58.

1 Introduction

In the context of an increased worldwide awareness concerning the negative impact of certain industrial activities on the global warming phenomena, the Kyoto Protocol (1997) considered several instruments in order to achieve the stabilization of pollution levels in the atmosphere. In order to meet the obligations under the Protocol, two main types of mechanisms have been regarded: quantity based mechanisms (cap-and-trade programs) and price based mechanisms (taxes). An emissions trading market or a cap-and-trade scheme is widely used nowadays as a way to place a price on carbon dioxide and other greenhouse gases, for limiting pollution. The structure is mainly a market based approach, used for controlling pollution by providing economic incentives, having as a main goal a reduction of pollution levels, by attaching a cost to pollution, in order to stimulate low-carbon development and induce investments in the emissions market.

For its efficient functioning, in a primary market, a central authority sets up a limit or a cap on the amount of pollutant that can be emitted, and within this cap companies are allocated emission allowances or permits, through auctioning or given away for free. Once introduced, the permits can then be freely traded on a secondary market (spot or derivatives) among participants, as needed. Thus, the buyer will pay a charge for polluting, while the seller will be rewarded for having reduced emissions. In this way, potential initial inefficiencies of the primary allocation are intended to be corrected at the least cost.

With the purpose of meeting the environmental standards agreed upon the Protocol, the European Union launched in 2005 the first cap-and-trade system for greenhouse gas emission in the world, the European Union Emissions Trading System (EU ETS). Nowadays, the largest functioning carbon market, the EU ETS has been lately in the center of hot debates and its main design characteristics have been heavily questioned, as due to the initial overallocation of permits, the economic recession that started in 2008 and the diminished demand context, conditions were triggered for a sustained speculative short selling and a massive drop in carbon prices[1].

Therefore, as it is designed at the moment, the market doesn't seem to be able to converge

[1] From a high of 29.2 Euros in 2008, the EUA (EU Allowances) spot price reached in 2016 a low of 3.91 Euros.

towards a carbon price convincing enough, that would stimulate emissions reduction and low polluting technologies investments. As per the previous price volatility registered in the EU ETS, most voices acknowledge the fact that although the EU ETS has been conceived as a pure quantity based instrument, an intervention on the design of the mechanism is needed [2], such that it would induce more pricing certainty, similar to a price based mechanisms, giving a better signal for investors and mitigating the negative effects on permit price volatility of unexpected shocks or shifts in the cost of pollution. The negative effects of permit price volatility could hinder markets forces to allocate abatement responsibilities efficiently and might imply delayed investments and increased costs on the long term in abatement technologies (Zhao, 2003).

However, when designing new policies, authorities have to deal with the issue of incomplete information about the abatement cost and the cost of compliance. Under such uncertainty circumstances, a certain dichotomy might appear between otherwise theoretically equivalent price-based market mechanisms, such as taxes, which fix a certain price level but leave under uncertainty the pollution level, and the quantity-based market mechanisms, such as emissions permits markets, which on the contrary would fix the amount of emissions allowed but leave the prices vary. Thus, although cap-and-trade systems are mostly favored, there might exist some clear advantages of prices if the marginal damages of emissions follow a relatively flat trajectory, as per the case of greenhouse gases. Therefore, the question arises of whether some flexibility could be inflicted into a hybrid cap and trade mechanisms, such that, under cost uncertainty conditions, more elasticity could be induced into the supply, in order to achieve more stable permit prices and reduce price volatility.

There is a consistent amount of studies that converges towards the conclusion that the expected net benefits of using a hybrid approach with both a price control and a quantity control mechanism exceed those of pure price or quantity control in cap and trades systems (Pizer, 2002; Burtraw et al., 2009; Fell and Morgenstern, 2009; Fankhauser et al., 2010). Seminal work of Weitzman (1974) tries to determine for the first time the conditions under which price based mechanisms are preferred to quantities. This theoretical model and others that followed (Roberts and Spence, 1976; Weitzman, 1978; Yohe, 1978) are set in a single-period, static framework. Nev-

[2]Several mechanism of controlling the amount of permits available such as the MSR (Market Stability Reserve) have been proposed and should be enforced starting with 2019-2020.

ertheless, in reality, most regulations exist in a multi-period, dynamic framework, which allow for the inter-temporal transfer of permits, that represents the potential to bank and borrow permits between periods.

The banking feature has been adopted by the majority of existing and proposed tradable permit markets and allows for emissions permits to be transferred, such that coupons can be saved for future use. Although at the beginning the motivations for sustaining the possibility of banking was to allow firms to smooth the transition to more stringent future limits through early abatement, more recently most debates consider it as a solution for addressing uncertainty and the risk of unexpectedly high costs. Therefore, as per the examples below, an increasing amount of work, sustains the idea that an expanded banking and borrowing system could deal with cost uncertainty shocks in a manner similar to a price mechanism, as it would allow firms to transfer obligations across periods of time as a reaction to the unexpectedly high or low marginal costs.

Rubin (1996) tries to provide a more general treatment of inter-temporal trading in continuous time through the use of the optimal-control theory by allowing both borrowing and banking. Further on, Kling and Rubin (1997) have analyzed the potential consequences of inter-temporal trading on social damages of pollution. Schennach (2000) explores the consequences of imposing constraints on borrowing and introducing uncertainty in the model, by considering stochastic emissions and random events that may affect the marginal abatement cost, and thus providing a pioneering attempt to model the permit price dynamics in continuous time with stochastic emissions. Such mechanisms are shown to have the potential to represent an effective hedging reaction against risk of abatement costs and price uncertainty and although might diminish the certainty over emissions over a compliance period, it will nevertheless maintain certainty of aggregate emissions over a longer time period.

Some recent studies show that banking and borrowing design elements, in emission carbon markets, can improve the efficiency of discretionary price control mechanisms (Fell and Morgenstern, 2010). Moreover, some studies consider that banking should be a compulsory design feature of emission trading schemes, considering the above mentioned advantages it provides, but nevertheless is not suitable enough for being implemented and play alone the role of a price control feature, as only de facto price control mechanisms have the potential of providing a clear visibility for investors about the price expected (Jotzo, 2011).

Nevertheless, the inter-temporality established through banking and borrowing only fixes to a certain extend the ratio of prices between periods and helps hedging against the price risk; it does not actually determine a certain price level in any period. Such an interest, that could be triggered by the motivation for mimicking a price-based system in terms of price stability, represents mainly a commitment to fulfill the objective of stabilizing permit prices around a particular price target or path of price targets. Newell et al. (2005) demonstrate that a bankable permit system in a multi-period setting can be used to create the same outcomes as a price-based system, provided the permit level will vary each period with past cost shocks. Other proposed price control instruments refer to price ceilings and price floors, used for targeting price uncertainty in cap and trade markets. Grull and Taschini (2011) and Fell et al. (2012) perform a dynamic numerical analysis, comparing two instruments of price ceiling control mechanisms with banking allowed, finding that the hard ceiling might decrease price volatility and achieve price targets to a higher extent than a soft ceiling [3].

Therefore, a pure cap and trade mechanism lacks a certain degree of on-going adaptability potential, that would allow the right instruments to be triggered such that cost shocks might be dealt with in due time, in order to maintain in the market, the needed carbon price that would stimulate emissions reduction and low polluting technologies investment. Tradable emission permits are supplied for a fixed level of emissions, letting the market forces to determine the right cost of pollution. But as per previous price volatility registered in the most cap-and-trade markets, it obviously appears a need for low price control mechanisms, which would induce more elasticity in the supply, thus mitigating potential effects on permit price of unexpected shocks or shifts in the cost of pollution.

I aim to shed light on these issues by considering the clarifications and improvements that the experimental investigation tool could bring, by looking at the laboratory as a test bed for the market institution. In order to fill the gap between a theoretical modeled mechanism and an actual economic process that is meant to address fundamental issues of the society, it is paramount to observe and analyze the performance of the mechanism in a context of actual decision problems faced by real people with real incentives, as it happens in a laboratory (Chen

[3] A hard price ceiling designs a firm price level which once is being reached, emissions allowances are released into the market until the price drops back down below it, with no limit on how many allowances are released for dropping the price. In contrast for a soft price ceiling, only a pre-established limited reserve of allowances is released into the market if the superior price target is reached.

and Ledyard, 2006). By managing to emphasize actual behavior in a controlled environment, experimental data may successfully complement numerical simulations, that are only based on some idealized assumptions (Stranlund et al., 2014). Although the cornerstone principles behind emissions trading functioning are elegant and simple, its performance may depend on many design factors and thus the simplified and clear setting of the laboratory allows to isolate and study such complex situations.

Concerning the experimental studies, evidence regarding the impact of price controls have been investigated quite scarcely for the experimental permit markets. Cason and Gangadharan (2006) find that banking diminishes price volatility in the presence of emissions shocks, at the expense of higher emissions and thus the authorities deal with a trade-off when deciding whether to allow banking. Stranlund et al. (2014) present results from laboratory emissions markets that allow for hard price floor and ceiling instruments, but also introduce the possibility of banking permits. Perkis et al. (2016) test the effectiveness of a reserve auction or soft ceiling to control prices in emissions permit markets.

Therefore, the research that I propose has as a main objective to test and analyze in an experimental laboratory setting the effectiveness of introducing hybrid policies in dealing with cost uncertainty in emissions markets, by analysisng the price levels, price volatility, price dispersion, market liquidity, but also considering aggregate emissions evolution. Firstly, we aim to determine the effects of allowing inter-temporal permit transfers in reducing volatility, both forward through banking, and backwards through borrowing allowances and analyzing to what extent does the introduction of these instruments impact pricing behavior. Then, we bring our study to another level, and besides the issue of reducing price variability, we are interested also in the capacity of quantitative trading permit systems to mimic the behavior of a price-based regulatory system, in terms of achieving a certain targeted permits price, by introducing into the market an adjustable permit supply rule in each period, that would consider past cost shocks and price levels, as per Newell et al. (2005).

We develop in a first place a stochastic dynamic model allowing for inter-temporal permit transfer, banking and borrowing, which allows us to draw some qualitative conclusions and fundament our main predictions regarding permit price action and its effects on permits' transferability and emissions level, as per the methodology used by Stranlund et al. (2014). This is important in order to dispose on the conformity of the behavior observed in laboratory with this theory. The contribution of this paper to the existing literature in this field is twofold. Firstly, we examine the effects of introducing the possibility to borrow permits in an emissions permit market for reducing price volatility in combination with banking and secondly, we also consider the impact of a mechanism designed to stabilize prices around a certain given level, through adjusting supply each period. To our knowledge, no experimental studies have yet analyzed the effects of borrowing in emissions permits markets and the consequences on permit prices of introducing an adjustable permit supply rule, meant to ease the attainment of an exogenous imposed price target.

The remainder of this paper is organized as follows. In section 2 we propose a theoretical model of permit emissions market under uncertainty relevant to this study. We present the experimental design in section 3 and develop the predictions in section 4. Section 5 reports the results and section 6 exposes the main conclusions of our findings.

2 Theoretical Model

2.1 The setting

We depict a theoretical model of emissions permit market with inter-temporal permit transfer under uncertainty about the costs of abatement. This formalisation is similar to those of Newell et al.(2005) and Fell et al. (2012), used for making policy recommendations based on simulations of the carbon emissions in the US. In this paper, we follow the method used by Stranlund et al. (2014), in which they use the theoretical model to draw qualitative conclusions about the permit price path and the relationships between prices and emissions levels, prices and inter-temporal permit transfer, to guide the experimental procedure.

We consider a world with competitive markets for permits in every period where firms take prices as given. At the beginning of each period the regulatory authority decides on the number of new permits to issue in order to determine supply and each individual firm chooses its abatement level d_i. Permits represent the right to emit a fixed amount of pollution within a particular period of time. Authorities determine individual initial firm permit supply g_i, $\overline{y}_i$ represents the exogenously determined quantity of goods produced, $C_i(\overline{y}_i)$represents the production cost function, $F_{i,t}(\overline{y}_{i,t},d_{i,t})= \overline{y}_{i,t}$ - $d_{i,t}$ is the permit need function and p_a permit price on the secondary market. Each firm has a quadratic convex abatement cost function $C_i(d_i,\theta)$, where $d_{i,t}$ is the abatement by firm i at time t and θ_t represents a mean zero random shock to the marginal cost function that is the same for all firms and that might be correlated over time. The regulator knows the abatement cost function, but cannot directly observe θ_t. Nevertheless, the regulator can usually infer this value in the next period t+1, due to the previous observed market price and level of abatement in period t.

Therefore, the optimisation problem for the firm becomes:

$$\max_{d_{i,t}} \sum_{t=0}^{T}(1+\mu)^{-1}E_t[\ p_y\overline{y}_{i,t} - C_i(\overline{y}_{i,t}) - C_i(d_{i,t}\,,\theta_t) - pa_t(-g_i+F_i(\overline{y}_{i,t},d_{i,t}))]$$

and the first order condition:

$$-\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} = pa_t\ \frac{\partial F_i(\overline{y}_{i,t},d_{i,t})}{\partial d_{i,t}}$$

Thus, optimizing firms would try to equalise their marginal cost of abatement with the marginal price paid for polluting. In this context there is an inverse relation between the competitive permit price and emissions level.

2.2 Permit Markets with Banking and Borrowing

Banking may take place as firms are given the opportunity to present unused permits for emissions in the current year and, in exchange to obtain permits for the following year from the authorities. In a banking context, each period the firm has to decide on the quantity of permits to be banked at the end of the period. Moreover for each period there is a trading ratio, noted R_t, such as n permits in period t can be exchanged for R_t* n in period t+1. Borrowing may occur when firms get n permits in the current period in exchange for the obligation to return R_t*n permits in the subsequent period. Borrowing would appear in the optimisation problem as a negative value for Bt, but is restricted up to a certain exogenous cap α. The relationship between the stock of the transfered permits at the begining of period $_{t+1}$ and the current period stock of permits $B_{i,t}$ is the following:

$$B_{i,t+1}/R_t = B_{i,t} + g_i + a_i - F_i(\overline{y}_{i,t}, d_{i,t}) \geq \alpha;$$

Moreover, each firm i now deals in each period with a set of decisions concerning the optimal abatement $d_{i,t}$ and banking level $B_{i,t+1}$. These decisions depend and should be based on a series of variables: on the one hand related to the current period, like the realised cost shock θ_t; the market permit price pa_t; the current trading ratio R_t, the initial banking available $B_{i,t}$; and on the other hand information depending on future events, like the future trading ratios R_{t+s} and expectations about future prices $E_t(pa_{\,t+s|s>0})$, which will vary according the the allocation rule established by the regulator. Thus the vector of exogenous variables for the firm is: $\Omega_{i,t} \equiv (pa_t, \theta_t, R_{t+s|s\geq 0}, E_t(pa_{t+s|s>0}))$.Based on this vector of information, the firms' maximization problem can be formulated in a recursive Bellman form, as negative costs plus the expected discounted value of banked permits in the next period.

$$V_t(B_{i,t},\Omega_{i,t}) = \max_{d_{i,t},B_{i,t+1}} [p_y\overline{y}_{i,t} - C_i(\overline{y}_{i,t}) - C_i(d_{i,t}, \theta_t) - pa_t(-g_i + F_i(\overline{y}_{i,t}, d_{i,t}) - B_{i,t} + (B_{i,t+1}/R_t))]$$
$$+ (1+\mu)^{-1} E_t[V_{t+1}(B_{i,t+1}, \Omega_{i,t+1})] + \lambda_t\ (B_{i,t} + g_i + a_i - F_i(\overline{y}_{i,t}, d_{i,t}) - \alpha)$$

the first order conditions become:

$$-\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} - \lambda_t \frac{\partial F_i(\overline{y}_{i,t}, d_{i,t})}{\partial d_{i,t}} = pa_t \frac{\partial F_i(\overline{y}_{i,t}, d_{i,t})}{\partial d_{i,t}}$$

$$pa_t/R_t = (1+\mu)^{-1} E_t\left(\frac{\partial V_{t+1}(B_{i,t+1},\Omega_{i,t+1})}{\partial B_{i,t+1}}\right)$$

$$\lambda_t \geq 0,\ B_{i,t} + g_i + a_i - F_i(\overline{y}_{i,t}, d_{i,t}) - \alpha \geq 0$$

$$\lambda_t(B_{i,t} + g_i + a_i - F_i(\overline{y}_{i,t}, d_{i,t}) - \alpha) = 0$$

After applying the envelope theorem to the maximised expression and using the first order condition, the no-arbitrage condition is obtained (see Appendix B):

$$p_t = \lambda_t + (1+\mu)^{-1} R_t E_t(p_{t+1})$$

This relationship above, describes a Hotelling-type result that is quite standard in the literature on permit markets, indicating that the expected price of permits increases at the rate of discount as a result. If the no-arbitrage condition is not satisfied, an arbitrage opportunity arises in this emissions permit market setting, through the possibiltiy of transferring permits design, until the supply and demand forces in these markets would be re-established by the no-arbitrage condition. Furthermore, this condition determines the price path for the whole market as any change in the current period price would impact the entire price path. Price shocks may be reduced or even eliminated through this condition, by converting them into quantity shocks, moved across periods through the banking mechanism.

Moreover, an positive relation is depicted between the price of permits in the curent period and the level of tranferred pemits. That is, a higher price implies not only reduced emissions as per our previous conclusion, but also either permits banked for the next period or less permits borrowed in the curent period. Futhermore, as per previous conclusions of Schennach (2000) and Strandlund et al.(2014), according to the magnitude of restriction on borrowing permits, an increased banking phenomena may take place in earlier periods, which implies higher current permit price, but that can later result in falling prices in later periods. As per the no-arbitrage condition, the restriction on borrowing increases the right side of the relation, which implies that the price must also be higher to hold the equality.

2.3 Fixing the price path by adjusting supply

Nevertheless, although it fixes the ratio of prices between periods, the mechanism above does not manage to provide any indication concerning the level of the desired price to be attained. Therefore, having as a depart point a permit transfer design mechanism, which is able to fix the ratio of prices between periods, further policy elements are necessary in order to fix also the price level around a certain target. Setting the price path around a certain exougenously imposed level may represent a beneficial element, as it would establish a clear signal to all agents what the cost of pollution is intended to be.

A deterministic rigid permit supply rule, will not have also a deterministic impact on the price path, such that if for instance a negative cost shock affects the firms, prices on the market will fall due to the fixed supply. Thus, in order to determine permit supply rules that fixes the price path around a certain imposed target pa_t^*, we considered a supply ruled-based mechanisms that depend on the observed cost shocks revealed through the market. Thus, as per the theoretical proposal of Newell et al. (2005), an adjustable supply rule in the presence of cost uncertainty should be:

$$g_0 = g_0^*$$

$$g_{t+1} = g_{t+1}^* \text{ - } R_t[d_t(pa_t^*;\theta_t) - d_t(pa_t^*;0)],\ t \geq 0$$

Therefore, the adjustment to the permit allocation is simply equal to the previous periods aggregate uncertainty-related quantity shock, brought forward one period by the trading ratio. The quantity shock is represented as the abatement that would occur at the desired price allowing for the uncertain shock minus the abatement level at that price absent any shock, such that allocations are adjusted to exactly offset realized cost shocks, based on those prices.

Nevertheless in practice, the regulator does not observe $d_t(pa_t^*;\theta_t)$ or θ_t, but instead must infer their value by observing the actual price and abatement level values. Thus, after making a linear approximation to the first order condition (see Appendix B), the supply rule becomes:

$$g_0 = g_0^*$$

$$\mathrm{g}_{t+1} = g_{t+1}^* - R_t[d_t(pa_t;\theta_t) - d_t(pa_t^*;0) - (pa_t^* - pa_t)\sum_{i=1}^{n}(\frac{\partial^2 C_i(d_{i,t}^*,0)}{\partial^2 d_{i,t}})^{-1}]$$

3 Experimental Design

The experimental design of this study aims transposing into the laboratory the fundamental characteristics of carbon markets, in order to be able to extract effectively the underpinnings of price control mechanisms under analysis. The rules and the parameters used are meant to approach the underlying carbon market characteristics, by using imperfect competition (few heterogeneous agents and different marginal production costs) under a cap-and-trade system and a secondary market structured as a continous double auction.

We conducted 24 experimental sessions with 15 periods in each session, in which six subjects are initially distributed emission rights and then they trade among them these permits in a computerized double auction market. We designed three treatments: Baseline, Permit Transfer

(PT) in which subjects are allowed to bank permits to the next period and to borrow up to a certain limit permits for the current period, and the Permit Transfer with Adjustable Supply (PTAS) treatment, in which we mix the previous characteristics of the PT treatment with an adjustable supply rule of permit distribution at the beginning of each period. The experimental setting is context-free, by using a completely neutral terminology, like calling emissions permits simply coupons or referring to the marginal abatement costs as marginal production costs, in order to avoid potential biases due to individual environmental attitudes.

During the experiment subjects were told that at the begnning of period, they were placed in a market, where they were given an certain number of coupons and a fixed cash amount. Each subject has to produce a certain imposed target of units of a certain good (abatement units). Nevertheless, the production of each unit, incurs a certain cost that will be deducted from subjects' initial cash level. Moreover, the cost of each unit produced may be different from period to another and different from the cost of other units, as the marginal production or abatement cost is an increasing function.

In order to be able to avoid such production costs, subjects are given instead the opportunity to trade coupons (emission permits) on a coupon market, as each coupon they hold will allow them to produce one unit less of the good. Although costs increase as production increases, subjects must nevertheless find a certain "trade-off" between producing and trading coupons, in order to manage to conform to the experiments' compliance rule, such that the sum of the production amount and coupons should equal their individual target of production. Thus, production costs may be avoided by holding coupons, which can be exchanged among subjects during the second and the third phase of the market. Deciding to trade coupons on the secondary market, depends on the difference between the level of coupon prices and the cost required for producing an additional unit of good. Therefore, subjects might choose to sell or buy coupons, if such a transaction turns out to be more profitable rather than producing. Subjects make profits by buying non-given units at a price lower than their cost, and by selling given units at a price higher than their cost.

As per Cason and Gangadharan (2006), the six subjects participating in the experiment are assigned into three groups, with two participants in each type. The three types of subjects in the experiment differ with respect to the values of their marginal production costs, production target, initial cash and coupons received. Such a calibration is meant to control for and exclude potential market power issues, such that, participants with relatively low production costs, net sellers, would be challenged to sell the emission permits originally allocated to them, while the net buyers, which are firms with relatively high costs, should tend to acquire additional coupons.

Each period is divided into five different market stages, except for the Baseline in which we have only four stages (Figure 3 and 4). In the first stage subjects are informed about the quantity of coupons they receive for free, the level of their abatement cost function, the quantity of good they have to provide at the end of the period and the amount of the initial cash. The quantity of the good that has to be provided and the initial cash received will be identical in each period for a given participant but might be different from one participant to another, accoridng to each participant type.

For the Baseline and the PT treatment, the initial quantity of coupons received at the beginning of each period is the same in each period for a given participant, whereas for the PTAS treatment this quantity may vary according to the supply rule [4]. Moreover, for the PT and PTAS treatments, the initial stock of permits may be adjusted upward/downward according to the previous period banking/borrowing decisions of the subject. Therefore, subjects will start the first phase of each period with a certain number of coupons, according to each treatment conditions, and this amount may vary afterward as they will then have then the opportunity to readjust their coupon holdings, by trading them on the subsequent coupon market. However, at the end of each period, the compliance rule must be followed and the total of permits held plus the number of units produced, should be at least equal to the given production target.

Concerning the initial endowment of subjects with emission permits or coupons, for the Baseline and the PT treatment, an aggregate fixed endowment of 42 permits was distributed among subjects, a relatively small number, used for keeping the experiment from becoming too complicated. Player types 1,2 and 3 started each round with 5,7 and respectively 9 permits. In the PTAS treatment, according to the previous period market average price, the number of permits released into the market could differ in each period [5]. By considering also, the marginal

[4] The participants are not informed neither about the way of computing the initial supply amount, in order to avoid that the instructions would turn out to be too complicated, they are only told that if the prices were too low in the previous period, the initial amount of permits distributed would decrease with respect to the previous period, and inversely.

[5] The target price, according to which the initial supply of permits is computed, is not announced to the participants, in order to avoid any potential experimenter demand effects and is represented by the expected equilibrium price of 78 ECU.

costs assignments, coupons were mainly distributed towards the lowest cost producers, whereas the highest cost producers received more initial cash. The aim of this design feature is to induce liquidity and intensify activity into the secondary trading markets, such that those who received more permits, became net sellers, while the others with small initial coupon allotments became net buyers.

Moreover, uncertainty in the control of emissions was introduced in the market, in each treatment, by a mean zero random variation or shock, on the cost function, the same for all participants and that may be correlated across time. Thus, the participants' actual cost level would equal their initial cost function adjusted to the random correlated uniformly distributed shock. The cost shock may take the value -30, 0 or 30 and corresponds to a low cost level (L), medium cost level (M) and a high cost level (H). Each subject type possesses a unique set of marginal costs and permit endowment, which when aggregated together, they actually determine the aggregated market demand for permits, as derived from the avoided abatement costs (Table 6). Considering the 42 permits supplied to the market in every period, competitive permits prices are 108 ECU under High Demand, 78 ECU under Medium Demand, and 48 ECU under Low Demand (Figure 5). Thus, the expected price is 78 ECU because we expect that distribution of the demand shocks that is symmetric.

In the second stage, in each treatment, a screen appears and subjects are required to choose the amount of units they want to produce. According to the level of the production costs of that period, they are also informed about the total production costs incurred by their decision. Afterward, in the third stage, in each treatment, a trading platform is introduced for 2 minutes, such that permits may be redistributed among participants in a secondary market, structured as a double auction permit market, in which participants can adjust their permit holdings by buying and selling permits. The structure of a continuous double auction market is commonly used in economics experiments to generate a competitive trading environment with relatively accurate and rapid price discovery, and which manages to imitate quite closely fundamental mechanisms of real trading platforms. Sellers and buyers are allowed to submit limit orders to sell or buy at any time, or to accept an offer and thus immediately conclude a transaction, as a public order book of all buy and sell offers is available at any time.

A buy order was represented by a quantity and a bid price equal to the maximum a subject was willing to pay for a permit, and a sell order was represented by a specified a quantity and an ask price, which was the minimum the seller could have accepted to receive for a permit. Then, the convergence of the bid and ask prices resulted into the market-clearing price. Buy orders with bid prices higher than the market-clearing price were transacted, as well as sell orders with ask prices below the market-clearing price. After the market-clearing price and transactions had been determined, participants were informed about their new cash and permit holdings.

In the PT and the PTAS treatments, in the fourth stage, subjects were given the oportunity to decide regarding the amount of coupons the want to transfer. Any surplus of permits that subjects detained beyond their production target, could be banked for the next period. If subjects didn't detain any permit beyond their compliance threshold, they weren't able to bank any coupon. Moreover they could also choose to borrow from the next periods' initial provision of permits, but they had to respect a certain borrowing limit. For the PT and the PTAS treatment, they could borrow maximum the number of permits they were given at the beginning of each period and the first period respectively, minus 5 permits, therefore according to their type the limits are of 0, 2 and 4 permits [6]. The next periods' initial quantity of permits given for free, is automatically adjusted with the previous periods' banking or borrowing transfer decision.

In the last stage, in each treatment, subjects were informed about their results of the period, their monetary and permit balance, costs incurred, earnings realised in the current period and their accumulated earnings. Moreover, they were informed about their compliance state for the period and the number of periods of non-compliance they have accumulated up to that point [7].

The experimental sessions were conducted in the experimental laboratory of GATE (Groupe dAnalyse et de Thorie Economique) in Lyon, France and the experiment was programmed using the Z-Tree software (Fischbacher, 2007). Subjects were recruited from the undergraduate student population by email using the software hroot (Bock, Nicklisch, Baetge, 2012). We recruited a total of 144 subjects, all of them students. Before beginning the 15 periods, subjects underwent a training round, that consisted of a comprehension questionnaire regarding the session instructions and a series of two periods of practice, that were not considered for the final payment. For

[6] Such paremeters chosen are intended to allow us to test our main predictions regarding price stability, and not necessarily for easying participants' task of being compliant.

[7] As compliance behaviour is not our main interest in this paper, but as non-compliance was possible during the experiment, we chose to discourage any potential speculative behaviour, by excluding the participants non-compliant for more than 2 periods from the session and paying them only the participation fee.

each session, the experimental conditions used in the practice periods were identical to the one used in the actual session, but the parameters were different. Participants received a 5 Euros show-up fee and average earnings were of 22 Euros (St. dev = 4.5). Sessions lasted in total approximately 2 hours.

4 Main Predictions

The theoretical setting that we propose and the characteristics of our experimental design are envisaged to allow us to draw several qualitative conjectures concerning the effects of permit transfer across periods and of a PTAS rule, in terms of permit price action and price control. If agents cannot transfer permits and hedge against the price risk, as per the Baseline, prices could plummet due to negative emissions shocks and unavoidable sell-offs, but also spike following positive cost shocks. As a consequence of a cost shock, permit prices are under pressure, if market participants cannot use intertemporal permit tranfer, such that prices could drop (spike) as a consequence of negative (positive) emissions shocks and as the period ends, net sellers just throw close to expiry permits on the market. Thus, the relationship between cost shocks and permit prices is stronger without any other additional price control instruments and we should observe higher price volatility and price dispersion in the Baseline case.

Firstly, in the PT treatment, when banking and borrowing is allowed, as per the theoretical predictions previously derived, the price volatility should be reduced relative to the Baseline levels and the permit price path significantly smoothed, promoting price stability and consistency. Permit transfer would allow a shift of abatement across time in a cost effective manner, as a hedging reaction against the risk of cost shocks and price uncertainty. On the one hand, the possibility to bank unused permits allows the creation of a provision of permits for insuring against potential cost spikes, and they no longer have to dump unused permits on the market at the end of the period, whereas the possibility to borrow dissipates to a certain extent, depending on the value of the cosntraint put on borrowing, the upward pressure existing on prices in case of of positive cost shocks.

Furthermore, as per the elements previously depicted in the theoretical section, in case of a positive multiplier, there is a positive relationship between the current permit price and the size of the transferred permits at the end of the period, such that a higher price in the current period implies more permits transferred, either banked especially in the case of net sellers or borowed when reffering to net buyers. This is expected to result in lower permit prices in the next period, when more permits were banked in the current period, and inversely in the case of borowing.

Last but not least, as per the no-arbitrage condition revealed in the theoretical section and as per the results that several previous works have already put forward results regarding the behavior of a permit market on which only banking is allowed, according to which despite a certain degree of reduced volatility, price level is relatively high in early periods, due to permits reserves that are build up by subjects, and then it falls over time by the end of the period (Stranlund et al., 2014; Cason and Gangadharan, 2010). Thus we conjecture that introducing also the possibility to borrow, smooths prices series and balances potential last periods drop in prices and holds up prices in later periods, depending on the level of the borrowing constraint.

Concerning the PTAS treatment, trades should eventually converge towards the target price level, and we conjecture that combining permit transfer with the PTAS price control tool, leads to an increased price control effectiveness, managing a replication of price based mechanisms effects. In the case of this treatment, all previous elements discussed for the PT treatment apply, but as the PTAS rule price controls and permit transfer are complementary measures for controlling price volatility, combining these measures would lead to lower price volatility than the PT mechanism alone. Moreover, as per the theoretical supply mechanism described, the price path would more significantly be stabilized around the wanted pice target. Such tools have the advantage over pricing policies, that they do not require any monetary transfers between the government and the regulated firms, thereby avoiding a politically unattractive aspect of price-based policies.

5 Results

In this section we analyze the impact of the mechanisms proposed in terms of the effects on the average price levels, between-period price volatility, within-period price dispersion and the traded volume. Moreover, the effects that arise in terms of the evolution of the aggregate emissions level and emissions volatility is considered. The analysis is organized around three main time intervals during each session. Therefore, we analyze separately the first two periods in order to be able to distinguish for potential beginning learning effects (Periods 1-2), we consider Periods 3-12 as the main trading interval and we also consider independently the last three periods of the session in order to account for any possible end of the game effect (Periods 13-15).

Regarding the price action analysis, firstly, we report the summary statistics obtained after computing for each treatment and time interval average prices, between-period price volatility, and within-period price dispersion. Average prices are calculated as the mean of all transactions for a given group in a given period. Price volatility is calculated as the absolute difference between the average price for a group between periods t and t-1. Price dispersion is calculated as the mean absolute difference between each trading price and that periods average price. The volume traded represents the mean number of transactions per period for a given group, and taking into account the fact that only one permit could be traded per transaction, the volume traded actually represents the mean number of permits traded on the market.

We also conduct a non-parametric analysis reporting the significance levels from pair wise Mann-Whitney rank-sum tests comparing each treatment and the Baseline, and from Wilcoxon Signed Rank tests comparing mean price values to the expected equilibrium value. In the non-parametric tests, the mean value obtained for a group of subjects represents one independent observation. We also complement the analysis with an econometric analysis of the price evolution, for which we use linear random effects models for identifying the determinants of the average price level, price volatility and dispersion. We allow for clustering at the group level and we include dummy variables for treatment, time interval interaction variables and a variable that accounts for the magnitude of the cost shock. Regarding the evolution of emissions level, we conduct a similar analysis as per the description above for the price change, with the ammendament that we do not include Baseline emission levels, because these are constant at 42 units per period.

Prices

Average Prices

As per Table 1, firstly one may note that in the Baseline environment the average price level decreases across periods from 107.98 in the first period to 89.27 in the main trading interval, to descend more abruptly as expected towards the end of the session to 50.63. Such an environment is quite restrictive if we account for the random cost shock that takes place on the market and the fact that subjects are unable to use inter-temporal permit transfers. Therefore, we expected a more difficult price discovery and convergence towards the competitive price. The average price is significantly different from the equilibrium prediction (Wilcoxon sign ranked test p=0.078 for all periods and p=0.012 for the Periods 3-12), but nevertheless the average price across all periods are within 5% of the theoretical prediction and 15% for the middle time interval, suggesting that even such environment is quite competitive. With respect to the other treatments, the mean prices appear to differ significantly from the PTAS Treatment across all periods and for the median interval (Mann-Whitney test, p= 0.077 and p=0.015 respectively). If we refer to pair wise comparisons with respect to the PT Treatment, differences are significant only for the median interval (Mann -Whitney test, p=0.049).

When subjects are allowed to transfer permits from one period to another, both by banking and by borrowing, in the first price interval the average price level decreases across periods from 107.51 in the first period to 83.32 in the main trading interval, to descend more abruptly as expected towards the end of the session to 55.67. As per other previous literature studies (Strandlund et al., 2014; Cason and Perkins, 2015), in which only banking is allowed, average prices are found to be significantly higher with respect to the Baseline, especially in the first periods due to the fact that subjects are able to make banking provisions. In our study, taking into account the fact that subjects are also able to borrow permits, price evolution seems to be smoothed and the average price level is not significantly different with respect to the Baseline (Mann-Whitney test p = 0.309 for all periods). Such results are also sustained by the Wald chi square tests that confirm the non-significance between the average prices between the Baseline context and the PT treatment (Table 5). Nevertheless, the average price is significantly different from the equilibrium prediction for the main trading interval Periods 3-12 (p=0.044), but we find a less convincing convergence and less significant values for all periods (Wilcoxon sign ranked test p=0.426). Drop in permit prices towards the end of the session is expected and the significant regression coefficients confirm this, as subjects know with certainty that the session would end after the 15th period and that any unused permits won't have any redemption value (Table 3 and Table 5).

In the third treatment, subjects have the possibility to transfer permits from one period to another, both by banking and by borrowing. Additionally the initial amount of permits received at the beginning of each period may change according to the previous period price level. If the average price was lower in the previous period than the targeted price value (that is the same as the predicted equilibrium price) the number of permits initially received would be lower and inversely (according to the permit supply rule described in section 2 and 3). As per Table 1, in the first price interval the average price level is lower with respect to the Baseline and the PT Treatment level (99.75), and continues to decrease up to 80.32 in the main trading interval and to 50.93 at the end of the session. As per the regression results and the Wald chi square test (Table 3 and 5), the average price is significantly lowered with respect to the Baseline in the main trading interval. This significant difference is confirmed by the Mann -Whitney test (p= 0.077 for all periods and p=0.015 for the main trading interval) for the Baseline, but we find no significance regarding differences in the average prices with respect to the PT treatment (p=0.395 for all periods and p=0.289 for the main trading interval).

As a result of the fact that now the initial supply of permits is adjusting according to the previous period price action, the price level is significantly smoothed around the imposed target equilibrium price. Wilcoxon sign ranked test values show no significant difference between the average permits prices and the target price neither for all periods (p=0.954), nor for the main trading interval (p=0.575). Fluctuations in the initial supply corroborated with the permit inter-temporal PT possibility, successfully stabilize prices around the desired price. The banking behavior is also significantly different with respect to the PT treatment (p=0.004), as the amount of permits banked is higher than in the PT treatment, taking into account the fact that there is no restriction on the maximum number of permits that can be banked.

Price Volatility

The previous conclusions reached regarding the evolution of the average prices are confirmed by the results obtained regarding the between periods price volatility. As per Table 1, price volatility is decreasing in the Baseline and PT treatment across periods, between the main trading interval Periods 3-12 and Periods 13-15, but this effect is significant only for the Baseline case (p=0.063), whereas for the PTAS condition, the price volatility is relatively the same in the two cases. Furthermore, the non-parametric analysis that we carried out across treatments, reveals the positive impact that introducing an inter-temporal permit PT mechanism and its combination with an PTAS rule implies, as it manages to significantly reduce price volatility with respect to the Baseline case (p <0.001 for both the PT and the PTAS treatment). Nevertheless, the difference that the adjustable rule is able to make in terms of volatility, when comparing the PT vs. the PTAS treatment, is not significant (p=0.467 for all periods and p=0.447 for Periods 3-12). These results are further sustained by the regression analysis and the Wald chi square test values obtained by assessing the significance of differences in the regression estimates (Table 3 and Table 5). Thus, both the PT and the PTAS Treatment significantly decrease price volatility compared to the Baseline values. Even if the negative impact of latter is higher, as per the previous observation we made, the difference between the two treatments is not significant (Table 5).

Price Dispersion

Introducing a price control mechanism, both though the possibility to bank or borrow permits in the PT treatment and its combination with the additional flexible supply mechanism in the PTAS treatment, has a positive impact on the reduction of price dispersion relative to the Baseline (p=0.023 and p=0.074, respectively). This is confirmed by the results of the regression we ran, which show that both the PT and the PTAS treatment realize a significant diminution of price dispersion, with a higher impact corresponding to the latter one. The significant differences in the estimated price dispersion values further enhance these results, as according to the Wald chi square test results for the main price interval (Table 5).

However, as per the outcomes of the non-parametric analysis, again, differences between the two treatments are not significant (p=0.256). Nevertheless, if we focus on the results of the linear regression, in the last interval Periods 13-15, there seems to be a significant increase effect in the price dispersion in the PTAS condition (Table 3 and 5). Thus, adding a mechanism that aims to achieve a certain price target, in spite a successful accomplishment of the price evolution towards the desired target, might imply some undesired side effects in terms of increase price dispersion. Under the Baseline, price dispersion follows a clear ascendant pattern across periods and trading intervals, unlike the other treatments in which the evolution of this indicator is rather negative.

Traded Volume

We consider the traded volume of permits as a proxy for the level of liquidity existent on the permits market, which is a very important premise for the well-functioning of a market. As per Table 1, the volume of permits traded increases over time between Periods 3-12 and Periods 13-15 for both the PT and the PTAS treatments (p=0.499 and p=0.107, respectively), whereas for the Baseline case the liquidity seems to decrease in the final periods (p=0.611). Across treatments, we register a very significant augmentation effect of the trade volume of permits between the Baseline and the PT and between the Baseline and the PTAS treatment ($p<0.001$ for comparisons for all periods and also for the main time intervals). Nevertheless, differences are not significant between the PT and the PTAS treatment (p=0.198).

The regression results and the results of the Wald chi square test support the conclusions obtained according to the non-parametric analysis (Table 3 and 5). Thus, both the PT and the PTAS treatment have a significant positive effect on the volume of permits traded on the market, the latter having the most powerful impact. As expected, the magnitude of the cost shock that is randomly applied each period, negatively influences the number of permits traded.

Emissions

Aggregate Emissions

Table 2 suggests that in all treatments, aggregate emissions significantly increase over time intervals, as they double from 26.93 in the first time interval to 60.33 for the PT Treatment and go from 32.12 to 51.37 in the PTAS condition. This time effect, seems to be the automatic reverse result of the decreasing evolution of mean prices, that we discussed above.

However, differences across time intervals are not significant between the Baseline emissions level and the PT Treatment (p=0.929 for the main trading interval) and for the PTAS Treatment (p=0.723 for the main trading interval), which suggests that the discussed price controls do not have a negative effect on aggregate emissions level. When checking for significance across treatments, we find no significant differences when comparisons are made across all periods (p=0.959). Turning towards the econometric analysis, we get more evidence regarding the previous remarks we made. Therefore, it appears that there is a significant time interval increase for the PT and the PTAS treatment increase significantly over time (Table 4). The effect is even higher if the initial supply of permits is adjustable as the potential stock of permits that can be transferred from one period to another can be even higher.

Emissions Volatility

Table 2 suggests that for the PT treatments, emissions volatility increase over time intervals, with a significant effect from the main trading interval to the last periods ($p<0.001$), whereas for the PTAS treatment although an increase trend over the three trading intervals is no longer valid, the significant increase in volatility in the last periods is maintained (p=0.017). A significant increase in volatility are registered for the non-parametric analysis between the Baseline volatility (that is 0 as emissions don't change over periods in this case) and the treatments emissions volatility ($p<0.001$ for both treatments), but there are no significant difference beteween the two treatments (p=0.111), which indicates that in spite of the effectiveness in reducing price volatility, the proposed price controls may lead also to a significant increase in emissions volatility, but such effects should not necessarily be surprising as offering the possibility to transfer permits from one period to another is highly likely to produce such effects. These elements are confirmed by the econometric analysis, as per Table 4, emissions volatility is significantly lower in the PT treatment with respect to the PTAS, but effects are more significant in the PT case for the extreme intervals.

6 Conclusion

In this paper, we use experimental emissions trading markets to investigate the effects of two types of instruments for dealing with the negative effects of price risk, as a results of potential shocks that might affect abatement costs. The first instrument under analysis is represented by an inter-temporal permit transfer mechanism, according to which, on the one hand market participants have the opportunity to bank for the next period any surplus of permits accumulated beyond their target compliance objective, and on the other hand, they can also borrow a limited amount of permits from the next period to the current trading period. The second instrument represents a mix between the previous permit transfer mechanism and an adjustment of the initial supply rule, such that the initial amount of permits that is put at the disposal of the participants at the beginning of each period, would change according to the previous periods' price level in order to drive current price towards a targeted imposed level.

As per the results obtained, introducing the possibility to bank and borrow permits from one period to another, yields some important benefits in terms of the reduction of price volatility, price dispersion and significantly increases market liquidity. Unlike other studies in the field that only refer to the effects of banking permits in emissions permits markets and that observe significantly higher level of prices especially in early period that fall over time (Strandlund et al, 2014), we observe that introducing the option of borrowing permits, although with some restrictions, would lead to flatter price series, as the reverse inter-temporal transfer instrument has the potential to balance the price increase effects deriving from the accumulation of banking reserves. To our knowledge, the effects of borrowing haven't yet been studied in the laboratory, but our results suggest the fact that complementing banking with the possibility of a controlled borrowing instrument, represents an efficient mechanism of controling the price path and reducing the price risk.

Such remarks are also valid when referring to the effects of the second price instrument that contains also the adjustable supply rule. However, although both instruments behave effectively in producing more stable price paths within and between time periods, the PTAS mechanism manages to produce stronger effects in terms of attaining a price convergence towards the targeted equilibrium price level. In other words, banking and borrowing manage to stabilize the price path, whereas adding also a permit supply rule straightforwardly manages to settle the price path around the desired target price level.

Furthermore, while the proposed price control mechanisms don't seem to produce any negative effects on the aggregate emission level, it appears that in terms of emissions volatility a trade-off appears such that, despite the positive effects regarding the impact on the price volatility and price dispersion, such instruments also imply an increase in the emissions volatility. Such elements are in line with the previous results obtained in the literature regarding the impact of introducing the possibility to bank permits across periods (Cason and Gangadharan, 2006; Perkis et al., 2016).

Therefore, we believe that this experimental study reveals some important aspects relevant for the design of emission permit markets. The elements we put under discussion, open further avenues of research into the effects of imposed price stabilization mechanisms on carbon markets. Moreover, the results obtained might represent a useful instrument in the process of designing more effective permit markets and for supporting transition operations of such mechanisms from the lab into the field.

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Appendix A

Table 1: Mean Permit Price, Volatility, Dispersion and Traded Volume by Treatment and Period Interval

	Baseline			Permit Transfer Treatment			Permit Transfer with Adjustable Supply		
	Periods 1-2	Periods 3-12	Periods 12-15	Periods 1-2	Periods 3-12	Periods 12-15	Periods 1-2	Periods 3-12	Periods 12-15
Average Permit Price	107.98 (46.13)	89.27 (41.65)	50.63 (44.32)	107.51 (53.93)	83.32 (27.89)	55.67 (19.34)	99.74 (28.34)	80.30 (9.83)	50.92 (17.19)
Between Period Price Volatility	32.05 (13.04)	67.32 (25.39)	33.49 (22.47)	51.67 (70.14)	19.11 (13.65)	17.82 (6.68)	28.88 (32.54)	19.13 (9.35)	19.14 (6.12)
Within Period Price Dispersion	18.27 (12.26)	28.98 (14.89)	31.57 (21.95)	14.23 (18.66)	9.41 (10.37)	9.4 (6.34)	20.53 (18.42)	7.71 (2.86)	10.55 (4.38)
Volume Traded	4.62 (1.59)	5.16 (1.23)	4.08 (0.52)	6.12 (0.88)	8.58 (1.39)	9.86 (3.96)	5.75 (0.35)	9.62 (1.23)	12.08 (2.72)

Standard deviations in parentheses. Price volatility is defined as the mean absolute difference in the mean price for a given group between periods t and t1. Price dispersion is defined as the absolute difference between each trading price in a period and that periods mean price. The volume traded represents the average number of permits traded for a given time interval.

Table 2: Mean Aggregate Emissions and Volatility by Treatment and Period Interval

	Permit Transfer			Permit Transfer with Adjustable Supply		
Treatment	Periods 1-2	Periods 3-12	Periods 12-15	Periods 1-2	Periods 3-12	Periods 12-15
Mean Aggregate Emissions	26.93 (2.38)	42.1 (4.17)	60.33 (2.91)	32.12 (3.53)	42.9 (4.53)	51.37 (12.9)
Between Period Mean Aggregate Emissions Volatility	3.37 (5.12)	5.11 (3.75)	10.37 (7.89)	5,00 (0.88)	3.81 (4.49)	7.95 (8.92)

Standard deviations in parentheses. Emissions volatility is defined as the mean absolute difference in the mean aggregate emissions level for a given group between periods t and t1.

Figure 1: Mean Permit Prices across all periods for all treatments

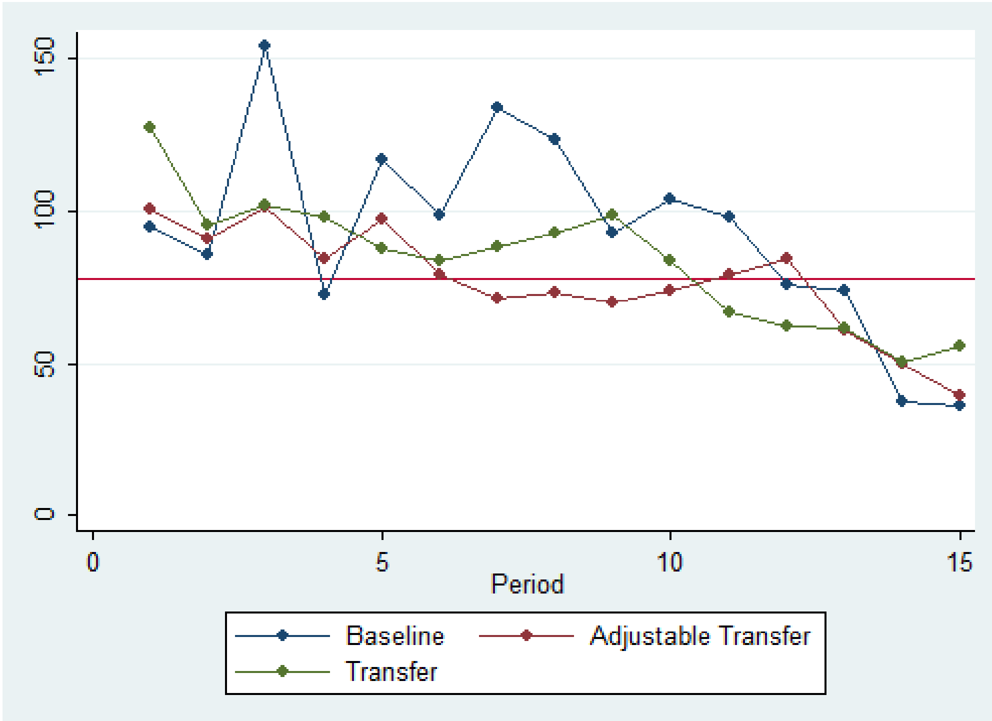


Figure 2: Mean Aggregate Permits Transfers

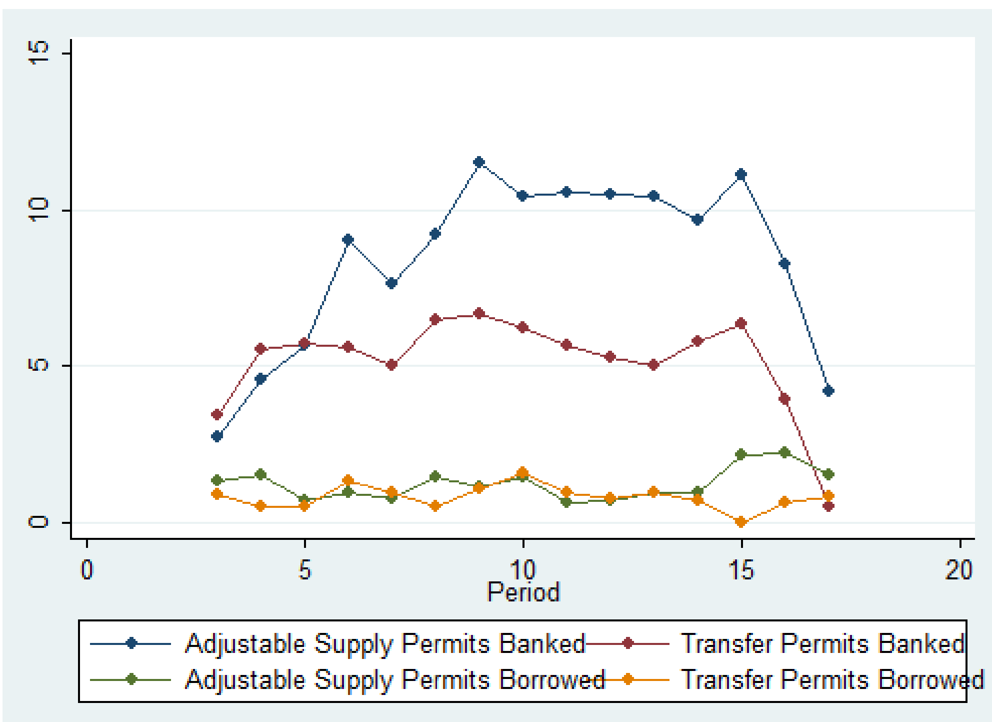


Table 3: Linear Random Effects Models of Permit Prices, Volatility and Dispersion

Dependent variable	Permit price	Price Volatility	Price dispersion	Volume Traded
Constant	99.337***	73.316***	24.563***	4.087***
	(8.471)	(11.263)	(5.188)	(.635)
PT Treatment	-14.123	-55.898***	-14.628**	3.896***
	(11.711)	(12.164)	(6.041)	(1.496)
PTAS Treatment	-18.406*	-56.791***	-16.907***	5.559***
	(10.279)	(11.564)	(5.245)	(1.195)
Shock Magnitude	.646***	.203**	.029	-.029***
	(0.114)	(0.093)	(0.035)	(.011)
Periods 1-2 *Baseline	-2.05	-32.348**	-2.204	.210
	(16.691)	(12.694)	(8.511)	(.724)
Periods 1-2 *PT Treatment	35.752**	57.949**	1.789	-2.294**
	(17.819)	(26.563)	(4.089)	(1.022)
Periods 1-2 * PTAS Treatment	17.340**	23.971***	7.033***	-4.005***
	(8.201)	(8.469)	(2.506)	(1.278)
Periods 13-15 *Baseline	-48.044***	-27.252	-8.837**	-.388
	(7.609)	(21.861)	(3.53)	(.871)
Periods 13-15 *PT Treatment	-35.766***	-1.605	-4.537	1.931***
	(8.683)	(5.568)	(2.685)	(.735)
Periods 13-15 * PTAS Treatment	-19.831**	5.038	6.555***	1.928
	(9.989)	(4.048)	(2.262)	(1.601)
Observations	360	360	360	360
Groups	24	24	24	24

***, ** and * indicate significance at the 1% , 5%, and 10% level.

Table 4: Linear Random Effects Models of Emissions and Emissions Volatility

Dependent variable	Aggregate Emissions		Emissions Volatility	
	Coefficient	*St. error*	*Coefficient*	*St. error*
Constant	42.05***	1.415	19.284***	1.716
PT Treatment	.825	7.222	-8.962***	2.179
Shock Magnitude	.054	.045	-.012	.039
Periods 1-2 *PT Treatment	-9.941**	5.021	12.554***	3.592
Periods 1-2 * PTAS Treatment	-14.917***	3.888	9.294**	3.826
Periods 13-15 *PT Treatment	7.946	5.66	5.344**	1.826
Periods 13-15 * PTAS Treatment	19.227***	2.731	-.711	2.499
Observations	240		240	
Groups	16		16	

***, ** and * indicate significance at the 1% , 5%, and 10% level.

Table 5: Treatment Differences

	Treatment Difference	Periods 1-2	Periods 3-12	Periods 13-15
Price	**Baseline – PT**	-23.679	14.123	1.845
	Baseline – PTAS	-0.984	18.406*	-9.807
	PT- PTAS	22.695	4.283	-11.652
Price Volatility	**Baseline – PT**	-34.399	55.898***	30.251*
	Baseline – PTAS	0.472	56.791***	24.501*
	PT- PTAS	34.871	0.892	-5.75
Price Dispersion	**Baseline – PT**	10.635	14.628**	10.328**
	Baseline – PTAS	7.67	16.907***	1.515
	PT- PTAS	-2.965	2.279	-8.813**
Traded Volume	**Baseline – PT**	-1.392	-3.896***	-6.215***
	Baseline – PTAS	-1.344	-5.559***	-7.875***
	PT- PTAS	0.047	1.663	-1.663
Aggregate Emissions	**PT- PTAS**	-5.801	0.825	10.456***
Emissions Volatility	**PT- PTAS**	-5.702	-8.962***	-2.907

Values in the table are the difference in estimated regression coefficients between treatments. Wald chi-squared tests were used to test the null hypothesis of no difference between estimates. ***, ** and * indicate significance at the 1% , 5%, and 10% level.

Figure 3: Sequence of events in the Baseline Treatment

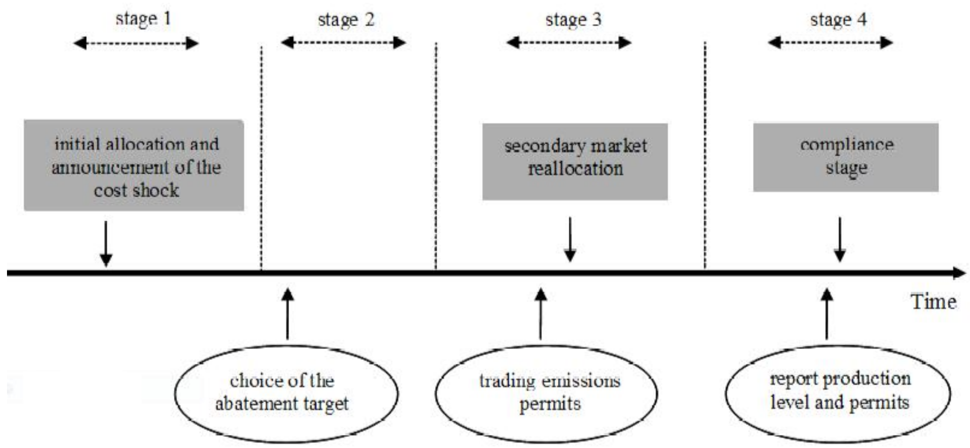


Figure 4: Sequence of events in the PT and the PTAS Treatment

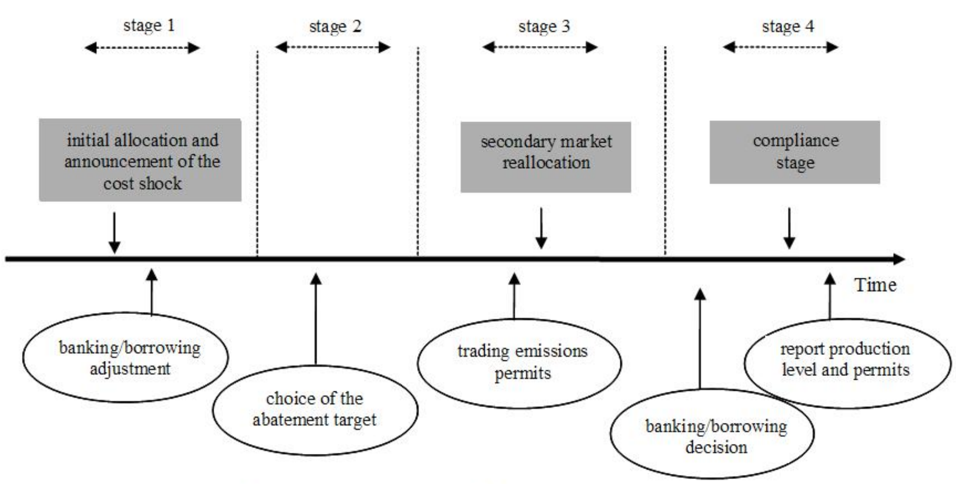


Figure 5: Competitive Permit Prices

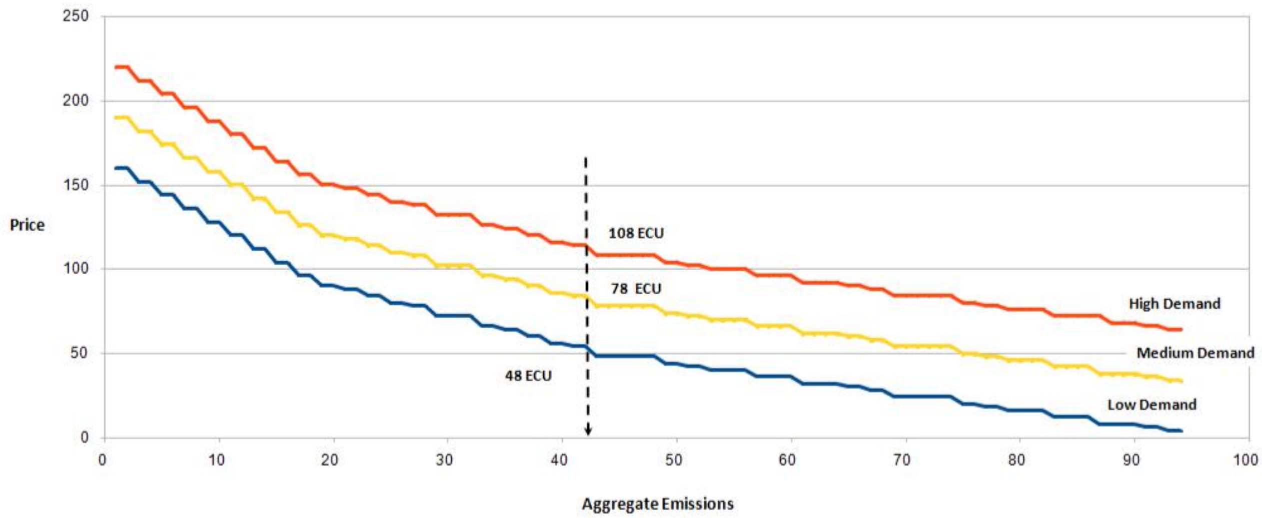


Table 6: Values of the marginal abatement costs

	Marginal Abatement Costs								
Units of Abatement	Type 1			Type 2			Type 3		
	L	M	H	L	M	H	L	M	H
1	8	38	68	6	36	66	4	34	64
2	16	46	76	12	42	72	8	38	68
3	24	54	84	18	48	78	12	42	72
4	32	62	92	24	54	84	16	46	76
5	40	70	100	30	60	90	20	50	80
6	48	78	108	36	66	96	24	54	84
7	56	86	116	42	72	102	28	58	88
8	64	94	124	48	78	108	32	62	92
9	72	102	132	54	84	114	36	66	96
10	80	110	140	60	90	120	40	70	100
11	88	118	148	66	96	126	44	74	104
12	96	126	156	72	102	132	48	78	108
13	104	134	164	78	108	138			
14	112	142	172	84	114	144			
15	120	150	180	90	120	150			
16	128	158	188						
17	136	166	196						
18	144	174	204						
19	152	182	212						
20	160	190	220						

Appendix B. Prof Section 2

For section 2.2, knowing that the permit need function is $F_{i,t}(\overline{y}_{i,t}, d_{i,t}) = \overline{y}_{i,t} - d_{i,t}$, we may simplify the first order conditions to :

$$\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} - \lambda_t = pa_t$$

Moreover, from the first order conditions we have:

$$\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} - \lambda_t = (1+\mu)^{-1} R_t E_t\left(\frac{\partial V_{t+1}(B_{i,t+1},\Omega_{i,t+1})}{\partial B_{i,t+1}}\right)$$

Using the envelope theorem we obtain:

$$E_t\left(\frac{\partial V_{t+1}(B_{i,t+1},\Omega_{i,t+1})}{\partial B_{i,t+1}}\right) = (1+\mu)^{-1} R_t\ E_t\left(E_{t+1}\left(\frac{\partial V_{t+2}(B_{i,t+2},\Omega_{i,t+2})}{\partial B_{i,t+2}}\right)\right) + E_t(\lambda_{t+1})$$

From the first order condition we obtain:

$$E_{t+1}\left(\frac{\partial V_{t+2}(B_{i,t+2},\Omega_{i,t+2})}{\partial B_{i,t+2}}\right) = \frac{(1+\mu)^{-1}}{R_t} \left(\frac{\partial C_i(d_{i,t+1},\theta_{t+1})}{\partial d_{i,t+1}} - \lambda_{t+1}\right)$$

Therefore, we obtain:

$$\left(\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} - \lambda_t\right)\frac{(1+\mu)}{R_t} = (1+\mu)^{-1} R_t E_t\left(\left(\frac{\partial C_i(d_{i,t+1},\theta_{t+1})}{\partial d_{i,t+1}} - \lambda_t\right)\frac{(1+\mu)}{R_t}\right) + E_t(\lambda_{t+1})$$

If we simplify, we obtain:

$$\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} = \lambda_t + (1+\mu)^{-1} R_t E_t\left(\frac{\partial C_i(d_{i,t+1},\theta_{t+1})}{\partial d_{i,t+1}}\right)$$

Knowing that at equilibrium the permit price equal the cost of abatement, we obtain the non arbitrage condition:

$$p_t = \lambda_t + (1+\mu)^{-1} R_t E_t(p_{t+1})$$

For section 2.3, knowing that the permit need function is $F_{i,t}(\overline{y}_{i,t}, d_{i,t}) = \overline{y}_{i,t} - d_{i,t}$, we simplify again the first order conditions to :

$$\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} - \lambda_t = pa_t$$

We have to rewrite $d_t(pa_t^*;\theta_t) - d_t(pa_t^*;0)$:

$$\mathrm{d}_t(pa^*_t;\theta_t) - d_t(pa^*_t;0) = d_t(pa_t;\theta_t) - d_t(pa^*_t;0) - ((d_t(pa_t;\theta_t) - d_t(pa^*_t;\theta_t))$$

After making a linear approximation to the first order condition we have:

$$\frac{\partial C_i(d_{i,t},\theta_t)}{\partial d_{i,t}} \text{ - } \lambda_t = \frac{\partial C_i(d^*_{i,t},\theta_t)}{\partial d_{i,t}} - \lambda_t + (d_t(pa_t;\theta_t) - d_t(pa^*_t;\theta_t))(\frac{\partial^2 C_i(d^*_{i,t},\theta_t)}{\partial^2 d_{i,t}})$$

Thus:

$$\mathrm{d}_t(pa_t;\theta_t) - d_t(pa^*_t;\theta_t)) = (pa^*_t - pa_t)(\frac{\partial^2 C_i(d^*_{i,t},\theta_t)}{\partial^2 d_{i,t}})^{-1}$$

Appendix C. Instructions PT Treatment

Thank you for participation to this experiment in economics. According to the decisions you will make during the experiment, you may earn some money that will be paid to you in cash at the end of the session. During the experiment your earnings are expressed in Experimental Currency Unit (ECU). These ECU will be converted to real Euros at the end of the experiment, at a rate of 1500 ECU = 1 Euro. Along with the other earnings you might accumulate in this experiments, you will receive a show up fee of 5 Euros.

The experiment consists of 17 periods. The first two periods represent practice periods, that won't be taken into consideration for determining your final earnings. The sum of your earnings for the next 15 periods will represent your total earnings for this experiment.

During the experiment you will be part of a group of 6 participants, all presents in this room. You will remain in the same group with the same 5 other participants for the whole experimental session. In each period, each participant will have to produce a certain quantity of a good. Producing this target is absolutely compulsory. If you don't comply to this target quantity for three periods during the 15 paying periods, you will be excluded from the experiment, you will loose all the earnings that you have accumulated up to that point and you will only be given the participation fee.

In order to provide the production target, you have the choice between producing units of a good with a certain production cost or use coupons (a coupon corresponds to the provision of a unit of the good) such that:

number of units produced + number of coupons available at the end of the period = production target

Each participant receives several coupons at the beginning of each period. At each period a market for exchanging coupons is organised. The participants will be able to sell and buy coupons on this market.For each participant, the stock of coupons not used for a period may be saved for the next period. It is also possible to borrow coupons from one period to another.

In the following sections, each stage of each period will be presented in detail.

Stage 1. The Announcement

At the beginning of each period, each participant is informed about:

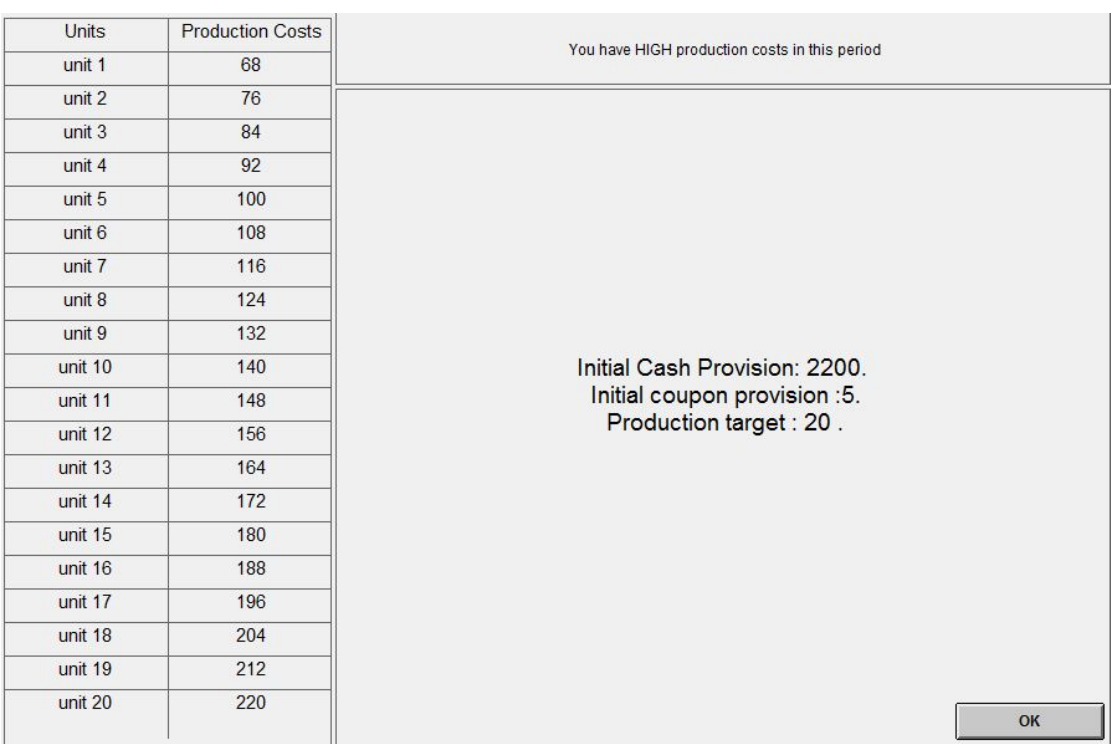
1. the production target of the good that has to be provided in the current period;

2. the initial provision of coupons received for using in the current period. To this provision will be added the coupons saved from the previous period or will be substracted the amount of coupons borrowed in the previous period.The initial provision of coupons adjusted with the saved or the borrowed coupons from the previous period, will give you the total stock of coupons available to use for the period.

3. the initial amount of cash received for the current period. This initial provision of cash will allow you to pay your production costs and your buys during the period;

4. the production costs for each unit. These costs may change from one period to another (high cost, medium costs, low costs) and may be different from one participant to another. The cost of a unit is increasing with the number of units produced(the cost of the first unit produced is lower than the cost of the 2nd unit, which is lower than the cost of the 3rd unit etc.).

Figure 1: Screen shot Stage 1



Units	Production Costs
unit 1	68
unit 2	76
unit 3	84
unit 4	92
unit 5	100
unit 6	108
unit 7	116
unit 8	124
unit 9	132
unit 10	140
unit 11	148
unit 12	156
unit 13	164
unit 14	172
unit 15	180
unit 16	188
unit 17	196
unit 18	204
unit 19	212
unit 20	220

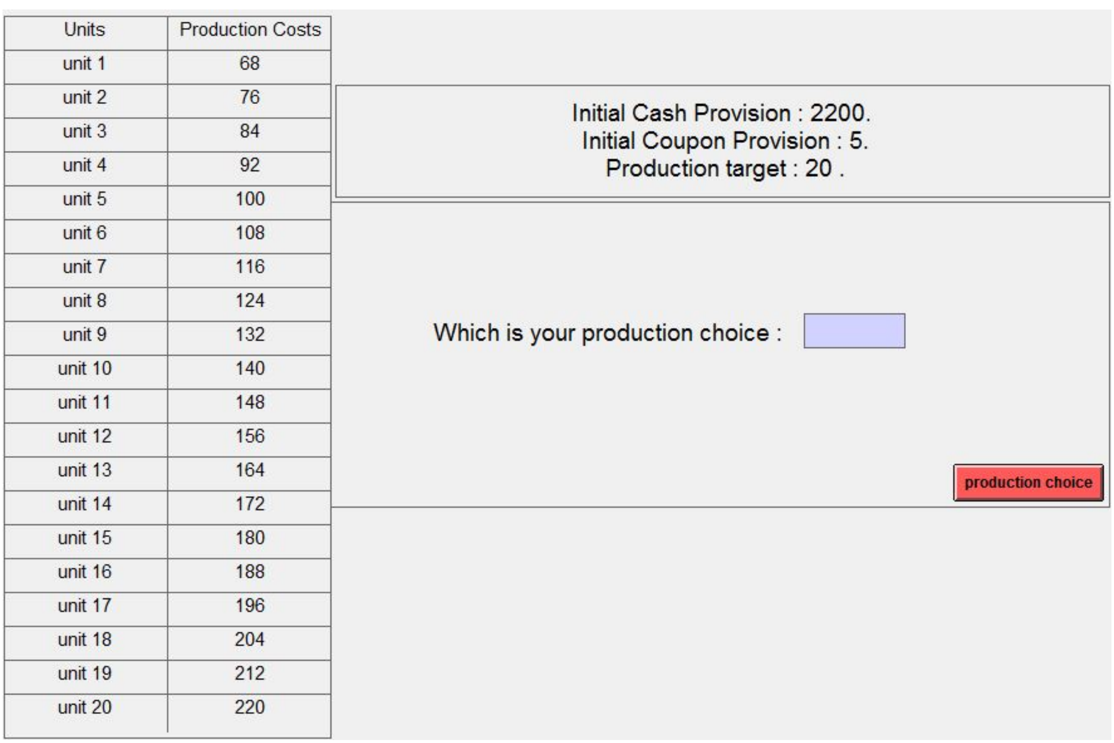
Observation:

The quantity of the good that has to be provided, the initial provision of coupons and cash will be identical in each period for a given participant but might be different from one participant to another.

Stage 2. The Production Decision

At this stage you need to decide the number of production unit. You need to pay production costs in case when you are going to produce asset units. Your production cost will be shown in the left side of your screen as displayed in the print-screen bellow. The cost shown on your screen corresponds to the cost generated by the production of an extra asset unit. For instance, the first unit which you will produce it will cost you 68 ECU, the second 76 ECU, and so on...If you decide to produce 3 units your total production costs will be 68+76+84= 228 ECU.

Figure 2: Screen shot Stage 2



Units	Production Costs
unit 1	68
unit 2	76
unit 3	84
unit 4	92
unit 5	100
unit 6	108
unit 7	116
unit 8	124
unit 9	132
unit 10	140
unit 11	148
unit 12	156
unit 13	164
unit 14	172
unit 15	180
unit 16	188
unit 17	196
unit 18	204
unit 19	212
unit 20	220

Stage 3.Coupon Market

During this stage an exchange market of coupons is opened for 2 minutes.

Buy a coupon

There are two ways to buy a coupon:

- Either by accepting the sale offer displayed on the left side of the screen by clicking on the "buy" button.

- Or by proposing an offer to purchase by indicating the purchase price in the box on the right side of the screen.

If there is already a buy offer placed in the market, you must propose an offer at a higher price to replace current offer. The transaction will take place as soon as another participant accepts the offer by clicking on the "sell" button. It is possible to make a buy offer or to accept a sell offer at any time during the opening of the market. In case of purchase, the amount of cash is reduced by the amount of the purchase price and your stock of coupons increases by one unit.

Sell a coupon

There are two ways to sell a coupon:

- Either by accepting an offer to buy displayed on the right side of the screen by clicking on the "sell" button.

- Or by proposing an offer of sale indicating in the box on the right side of the screen your price of sale.

If there is already a sell offer in the market, it is necessary to propose an offer at a lower price to take the place of the current offer. The sale will take place as soon as another participant accepts the offer by clicking on the "buy" button. It is possible to make an offer to sell or accept a buy offer at any time during the opening of the market. In case of sale, the amount of available cash is increased by the amount of the selling price and your stock of coupons decreases by one unit.

Why to buy coupons

You can decide to buy coupons on the market because the coupons help you avoid producing units of good and increase your profit of the period. If for instance, at the beginning of the period, you have a stock of 7 coupons and your production target is 10 units, you must produce 3 more units. If the production cost of the 3rd unit is 300 ECU and you anticipate that you can buy a coupon in the market at less than 300 ECU, you can choose to produce only 2 units and buy the third unit on the market for less than 300 ECU. If you buy the coupon in the market at 250 ECU you will realize in this way a profit of 50 ECU.

Why to sell coupons

In the same way you can decide to sell coupons on the market to increase your profit of the period. If you hold 7 coupons and you have a production target of 10 units, you must produce another 3 units. You can decide to sell a coupon on the market and produce 4 units if you think the coupon selling price is higher than the production cost of the 4th unit. If the production cost of this 4th unit is 400 ECU and you sell the coupon with 450 UME, you will realize a profit of 50 UME.

Figure 3: Screen shot Stage 3

Stage 4. Transfer Decision

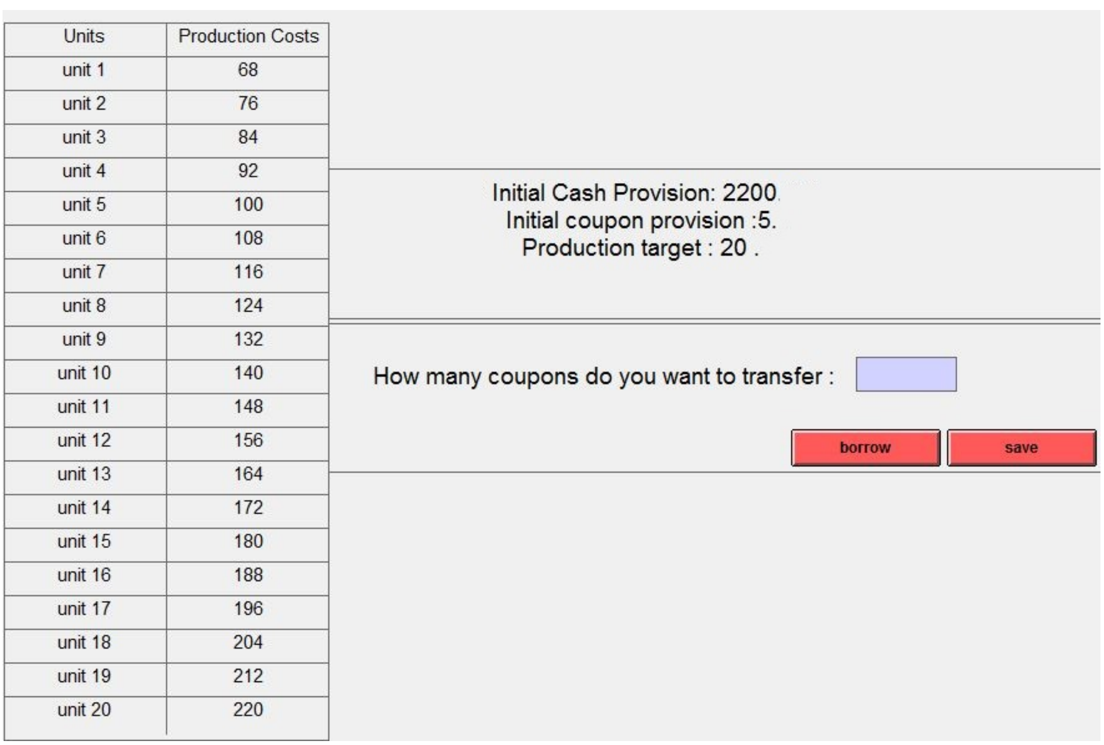
At the beginning of this stage, each participant is informed about the stock of coupons available after selling and buyings that took place on the market. Two situations are therefore possible:

- The stock of coupons available plus the number of produced units is inferior to the production target.

In this case, you have the opportunity to borrow coupons from the initial provision of coupons of the next period and use them for being copmliant with the production target of the current period. The number of coupons borrowed may be minimum 0 and maximum the initial provision of coupons that you have the right to receive in each period minus 5. For example, if your initial provision of coupons in each period is of 8 coupons, you can borrow maximum 8-5 = 3 coupons in this period from the next one. The number of coupons borrowed will be substracted automatically from the initial provision of coupons of the next period. If you don't want to borrow any coupon choose 0 and pres the borrow button.

- The stock of coupons available plus the number of produced units is superior or equal to the production target.

Figure 4: Screen shot Stage 4



In this case, you have the opportunity to save the surplus of coupons and transfer them for the next period. The number of coupons saved may be comprised between 0 and the surplus if coupons detained. For example, if your production target is 10 units, your production choice is of 8 units and you detain a stock of 5 coupons, you have thus a surplus of 3 coupons beyond your production target. You can therefore save maximum (8+5)-10 = 3 coupons in the current period for the next period.

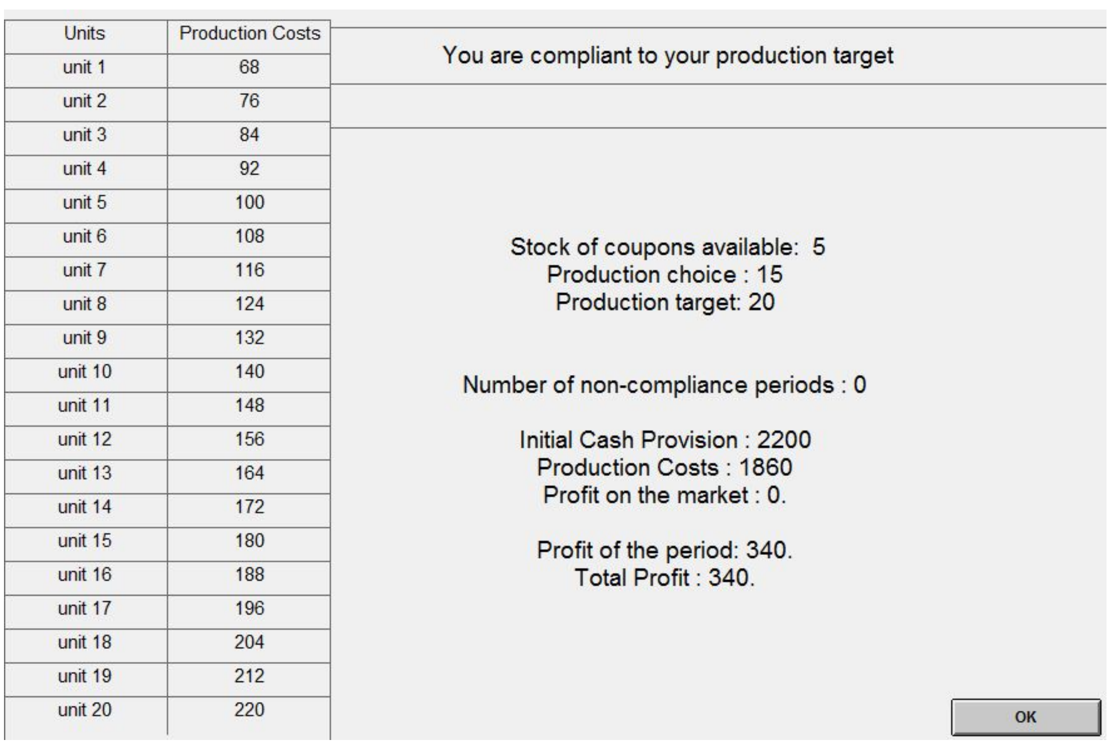
The number of coupons saved will be added automatically to the initial provision of coupons of the next period. If you don't want to save any coupon choose 0 and pres the save button.

Stage 5. Results for the period

The results of the period will be displayed on the screens of each participant.

At the end of this stage, each participant will be informed on the stock of coupons available at this stage of the period after the market; his choice of production and its quantity to be supplied. If the available coupon stock plus the number of units produced is less than the quantity to be provided for the period, you will be declared non-compliant with your production target.

Figure 5: Screen shot Stage 5



If you are unable to provide the requested quantity for three periods, you will be excluded from the experience, you will lose any accumulated earnings up to that time and you will only earn the participation fee. So, you have the right to be non-compliant with your quantity to provide for maximum two periods during the experiment.

If the stock of coupons plus the number of units produced is greater than or equal to the quantity to be supplied for the period you are in compliance with your quantity to be supplied.

You will also receive information about your profit for the period and your accumulated profit. Your accumulated profit is equal to the sum of the profits of each period since the beginning of the session. The amount of your profit in ECU at the end of the period is given by the following formula:

Profit of the period = initial cash provision for the period - production costs + earnings from potential selling of coupon - expenditures with potential coupon purchases

Summary

In each period every participant must provide a certain amount of goods. In the case of non-supply of the required quantity for three periods, the participant is excluded from the experience and loses all his earnnings with the exception of his participation fee.

To provide the required quantity, participants have the choice between producing with a known cost of production or using coupons, with each coupon providing a unit with no production cost.

During each period, participants can buy and sell coupons on a coupon market or they can save coupons from the current period for the next period, or on the contrary borrow coupons from the next period to the current one.

Final note

The experiment includes a second part which begins after the end of the last period. The winning of this second part will be added to the winnings of the first game. We will then ask you to answer a few questions before leaving the room.

Please review these instructions. If you have any questions - now or during the experiment, please call us by pressing your call button. We will answer you in private.

Quiz

1. The composition of your group will remain the same during the 15 periods :

True False

2. The total sum of your profits in the 15 periods will determine your gain for this session :

True False

3. Let's suppose that you are assigned the production costs of Figure 1 from the instructions. If you decide to produce 5 units, which will be your total production costs ?

____

What if you decide to produce 7 units?

____

4. Let's suppose that you are assigned the production costs of Figure 1 from the instructions and that you have a production target of 15 units. At the beginning of each period you also receive a fixed amount of 6 coupons.

a) In order to comply with your target you decide to produce 7 units of good and buy 2 coupons on the market. Are you compliant in this situation? (Explain)

a) OUI b) NON

....

b) If you receive an initial fixed amount of cash of 2000 ECU and you buy the first coupon with 200 ECU and the second with 300 ECU, which will be your profit of the period?

....

5. Let's suppose that you are assigned the production costs of Figure 1 from the instructions and that you have a production target of 12 units. At the beginning of each period you also receive a fixed amount of 5 coupons.

a) In order to comply with your target you decide to produce 7 units of good and buy 4 coupons on the market. Are you compliant in this situation? (Explain)

a) OUI b) NON

....

b) If you receive an initial fixed amount of cash of 1500 ECU and you buy each coupon with 100 ECU, which will be your profit of the period?

....