The effect of transaction costs in CO₂ markets: An Agent-Based Model approach

El efecto de los costes de transacción en los mercados de CO₂: un modelo basado en agentes artificiales

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Abstract: The Continuous Double Auction (CDA) is used in the CO₂ markets. High market efficiency (close to 100%) is the most robust result in CDA human-subject experiments. However, the market efficiency decreases when monetary costs are imposed on transactions. In this paper the sensitivity of CDA performance to the imposition of monetary costs on the market is analyzed using an artificial agent-based model approach in order to evaluate the influence of the agents' behaviour. We find that the monetary costs reduce market efficiency according to both the theoretical and the experimental economics results. Moreover, our model provides new behavioural explanations of these effects that have practical value in the design and analysis of CO₂ markets.

Keywords: continuous double auction, co₂ markets, artificial economics.

Resumen: El intercambio en los mercados de CO₂ se realiza mediante una subasta doble continua. Los experimentos en economía experimental han demostrado que la eficiencia en estos mercados es casi del 100%. Sin embargo, la eficiencia disminuye cuando se introducen costes de transacción. En este trabajo analizamos la sensibilidad de estos mercados cuando existen costes de transacción utilizando el modelado basado en agentes, con el objetivo de evaluar la influencia que tiene el comportamiento de los agentes en el mercado. Hemos encontrado que los costes de transacción reducen la eficiencia del mercado, en concordancia con los resultados teóricos y experimentales. Sin embargo, nuestro modelo aporta una nueva explicación relacionada con el comportamiento de los agentes que es interesante considerar para el diseño de mercados de CO₂.

Palabras clave: subasta doble continua, mercados de co₂, economía artificial.

Introduction

Even the common citizen is aware of the difference between value and price. However, she is not so much aware of the fact that the market measures and transforms valuable goods, services or rights into prices. John Stuart Mill showed an early insight into the value of the natural world (Mill, 1848): «Air, for example, though the most absolute of necessities, bears no price in the market, because it can be obtained gratuitously; to accumulate a stock of it would yield no profit or advantage to any one; and the laws of its production and distribution are the subject of a very different study from Political Economy. It is possible to imagine circumstances in which air would be a

part of wealth. If it became customary to sojourn long in places where the air does not naturally penetrate, as in diving-bells sunk in the sea, a supply of air artificially furnished would, like water conveyed into houses, bear a price: and if from any revolution in nature the atmosphere became too scanty for the consumption, or could be monopolized, air might acquire a very high marketable value. In such a case, the possession of it, beyond his own wants, would be, to its owner, wealth; and the general wealth of mankind might at first sight appear to be increased, by what would be so great a calamity to them».

However, the first air pollution trading market took another century and a half to set up, in 1990. It was

introduced by the EPA in the USA and it was applied to the SO₂ emissions of electric utilities. Although, the environmental target was achieved, the EPA's auction was a failure because of its quite particular exchange rules. This failure led to a new design of the CO₂ emissions permits markets as a Continuous Double Auction (CDA).

The CDA is a double sided auction where buyers and sellers announce and accept bids and asks at any time. The information is held separately by many market participants (in the form of privately known reservation values and marginal costs). The Experimental Economics approach has established that fast price convergence and high allocative market efficiency (closed to 100%) are two of the most robust results in CDA markets (Smith 1962). However, the analytical game approach has been unable to explain its properties. Since the early paper by Smith and Williams (1990) little attention has been paid to the transaction cost effects on CDA markets.

A major limitation of Experimental Economics is the lack of control for the human participant's behaviour. Why don't we take a step further to experiment with soft agents that allow us to control the agents behaviour? If the human traders are replaced by software agents, the modeller can control the agents' bidding strategies by specifying their decision rules within an agent-based model.

Agent-Based Models (ABM) *«simulate the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena. The process is one of emergence from the lower (micro) level of systems to a higher (macro) level»*¹. Some facts about ABM are worth mentioning in this short summary.

Complexity comes not only from the number of agents we are dealing with, but from their heterogeneous purposeful and bounded rational behavior. Thus complexity can be drastically reduced and computed with simple behavioral agent's rules with ABM.

ABM incorporate *Social learning*: The process by means of which agent transform information into knowledge is caused and favored by their being exposed to one another in a common environment, in our case, the CDA institution.

ABM are powerful *computational solvers* and they are powerful means to generate emergent patterns that

match the behavior of complex systems. The behavior of the whole may be very flexible, adaptive and robust although their agents may behave with simple, yet heterogeneous decision rules. They are a useful new way to solve problems of choice under resource scarcity and competition let it be in Economics, Management or Natural Resources.

As far as Economics is concerned Agent-Based modelling can be considered the *«third way»* to generate explaining models in Economics and it complements the rational reductionism of conventional Economic Theory and the experimental approach either from historical records, Econometrics, or from Experimental Economics with human subjects. ABM simulation in Economics (Artificial Economics) can be viewed as a very elegant and general class of modelling techniques that generalized numerical economics, mathematical programming and micro simulation approaches.

When ABM are populated by autonomous agents whose behaviour is pre-specified and neither adaptive nor strategic, they become micro-simulations. When individual agents are optimizers and there are social planning agents that coordinate or aggregate these individual decisions, the ABM behaves as a general mathematical programming model. But ABM with agents that are heterogeneous, purposeful, bounded rational and interacting over networks, away from equilibrium, go far away from accepted Economic Theory. These facts are already accepted beyond the realm of academia (Farmer and Foley 2009). In Spain The Group InSiSoc (<http://www.insisoc.org/inicio.html>) is working with ABM in alternative fields since the late nineteen's.

In the last decade CDA markets have been extensively studied using an ABM approach, that is, from the micro level to the macro level. The results show that there is high market efficiency even if the artificial agents are zero intelligent (Gode and Sunder, 1993; Licalzi and Pellizari, 2008a; Licalzi and Pellizari, 2008b). However, price convergence and individual surplus depend on the agents' learning (Posada et al, 2006; Gjerstad, 2007, Posada and López, 2008) explaining the paradox that a perfect market does not preclude intensive agents competition. However, in all these CDA models transactions are costless.

Transaction costs are relevant because they are an important feature of these markets, where costs of making offers exist as broker's commissions, travel

¹ http://en.wikipedia.org/wiki/Agent-based_model

costs of reaching markets, costs of writing contracts and search costs of locating and identifying trading partners. In the last decade the effect of transaction cost on permit markets has been examined at the macro level (Stavins 1995).

In this paper we study the sensitivity of CDA performance to the imposition of a monetary cost on transactions from the micro behavioural level to the macro level. The purpose of this paper is to provide new behavioural explanations of the transaction costs effects in the CDA market.

The structure of this paper is the following. In Section 2 the performance of an emission trading market is explained. In Section 3 our agent-based model is described. In Section 4 the model calibration and the simulation scenarios are reported. In Section 5 the market efficiency is analyzed when monetary costs are imposed on transactions and these results are compared to a CDA market with no-monetary costs. Finally, in Section 6 the main conclusions of the paper are reported.

2. The CO₂ market performance

The fact that trade is both a converter of value into prices and a social and individual profit generator has to be remembered every now and then even by prestigious economic newspapers as *The Economist*. It is perhaps opportune to call the reader's attention to the fact that trade can generate wealth even with no physical inputs, but just rights, and to introduce with a simple example, another relevant fact: social efficiency can be achieved for a wide range of the prices that settle the exchange.

Table I shows the data and cost of a clean air policy. There are two power plants with different cleaning air pollution marginal costs, per CO₂ ton and producing 4 tons each. The regulator goal is to limit total air pollution to 4 tns. Each firm is allowed to pollute 2 tns of CO₂ and it should clean up the other 2 tns. No trade is allowed. In this case the cleaning social cost of the 4 CO₂ tns is: $(300=100+200) + (900=300+600) = 1200 \text{ €}$.

An alternative proposal of a wiser regulator will keep the number of permits for each plant but it will allow trading of the permits. Then, the less efficient plant B could make a contract with the other plant: «please, clean a third unit for me and I will pay you for it». The total amount of CO₂ will be kept in four, but the social cost will be: $(100+200+300)$ of plant A and 300

of Plant B. The total social cost is 900 € and a social gain (generated wealth) is $1200 - 900 = 300 \text{ €}$. No goods are traded, just rights.

Table I
Data and cost of a clean air policy

Marginal costs of cleaning a unit of CO ₂	Plant A (€)	Plant B (€)
First unit	100	300
Second unit	200	600
Third unit	300	900
Fourth unit	400	1200

What about the agreed price of the traded permit? It does not matter regarding the social gain: the wrongly named Coase Theorem. But, of course, the total social efficiency depends on the market design and the resulting price depends on the type of trading agents. Even more, for a given market's design the involved transaction costs have an effect on both: total social cost and emissions permits prices. In what follows we provide evidence of these effects using an artificial agent based CDA simulation model.

3. The agent-based CO₂ market model

A tradable permits market for air pollution control is constructed as follows. Tradable permits are issued to firms (more exactly, to facilities of relevant industrial sectors) by each country's National Allocation Plan. These emission allowances are denominated in units of a specific pollutant (for example in tons of CO₂). At the end of period, facilities must own sufficient permits to cover their emissions. This implies that each facility must hold at least as many valid credits as emissions during the compliance period. A penalty is levied if a facility does not deliver a sufficient amount of allowances on time. The payment of a fine does not remove the obligation to achieve compliance, which means that undelivered permits have to be handed in.

Following Smith (1982), we describe our agent-based market model in terms of the three essential dimensions (I × E × A) of any market experiment: the institution (I) (the exchange rules, the way the contracts are closed, and the information network), the environment (E) (agent endowments and values, resources, knowledge) and the agents' behavior (A).

3.1. The institution: CDA

In a CDA any trader can submit or accept an offer to buy or to sell at any time during the trading period. There are several variations of the double auction exchange rules to simplify its implementation. LiCalzi and Pellizari (2008a) pointed out that the simplifications of the CDA rules matter. We consider that in the market there are selling and buying books and the spread reduction rule is applied. Traders randomly place offers on the books. Orders are immediately executed at the outstanding price if they are marketable. Otherwise, they are recorded on the books and remain valid until either the end of the trading session (that is, without re-sampling) or the agent improves its offer (to buy or to sell).

3.2. The environment

In our agent-based model, traders (firms) exchange single units of tradable permits. Each trader is either a seller (clean firm) or a buyer (pollutant firm). It is initially endowed with a finite number of units (emission allowances) and a private valuation for each unit (marginal reduction cost of pollution).

The environment is stationary (the competitive equilibrium price is the same in every period) in order to study, *ceteris paribus*, the price convergence performance. There are 12 sellers and 12 buyers. Each agent has fifteen units to trade and their valuations are calculated from the following demand and supply: $D(x) = 1535 - 10x$ and $S(x) = 35 + 10x$, respectively (Figure 1). Competitive equilibrium exits at a market price of 785 and a quantity of 75 exchanged. The consumer surplus is 28125 and the producer surplus is 28125 (see Table 2), TC0.

When a monetary cost is imposed, there is a loss of surplus, which reduces the allocative market efficiency. This surplus loss can be calculated theoretically when the monetary cost is imposed on transactions. We consider two amounts of transaction cost: 25 units (TC25) and 50 units (TC50).

As market efficiency is not a univocally defined concept in the economic literature, we make some comments about it. We deal with market efficiency as understood in conventional microeconomics, and following the experimental economics research on market dynamics. We define allocative market efficiency as the total profit actually earned by all the traders divided by the maximum total profit that could have been earned by all the traders (i.e., the sum of producer and consumer surplus) (Smith 1962).

Table 2
Theoretical results

	TC0	TC25	TC50
Equilibrium quantity	75	72,5	70
Equilibrium price	785	785	785
Consumer/producer surplus	28125	26281.5	24500
Market efficiency	1	0.9344	0.8711

3.3. The agent behaviour

In CDA markets traders face three non-trivial decisions: How much should they bid or ask? When should they place a bid or an ask? And when should they accept an outstanding order? Bidding strategies corresponds to particular answers for these decisions. LiCalzi and Pellizari (2008) pointed out that

Figure 1
Market environments

learning greatly improves the allocative efficiency in CDA. Therefore, we consider GD and K bidding strategies which are related to the financial terms: active (who submits market orders) and inactive (who only accepts the orders submitted).

3.3.1. Active agents

Active agents learn to decide on how much should they bid or ask, and they submit their orders 25 times the percentage. The GD bidding strategy (for more details, Gjerstad and Dickhaut 1998) is the most sophisticated learning designed for CDA. Each agent chooses the offer that maximizes his expected surplus, defined as the product of the gain from trade and the probability for an offer to be accepted. GD agents modify this probability using the history. The history memory is the only parameter of this bidding strategy (its value is 8 following Gjerstad and Dickhaut 1998).

3.3.2. Inactive agents

The only decision the inactive agents take is: when they should accept an outstanding order? They can use either the GD bidding strategy (Gjerstad and Dickhaut 1998) or the K bidding strategy.

- When an active agent use the GD bidding strategy, they accept an outstanding offer to sell if it is less than its calculated offer to buy (submitted or not) and they accept an outstanding offer to buy if it is greater than its calculated offer to sell (submitted or not).
- Kaplan (K) is the simplest learning that has been designed for CDA. It was the winner in the tournament of Santa Fe Institute in 1993 (Rust et al. 1993). The basic idea behind the Kaplan strategy is: «wait in the background and let others negotiate. When an order is interesting, accept it». K agents accept an outstanding order when one of the following conditions take place: they have a minimum profit (between 1%-3%), the ratio orders is between 0.0125 and 0.0375), or the time is out (between 5%-15%).

4. The simulations

Each run consists of a sequence of ten consecutive trading periods, each one lasting 100 time steps. We have analyzed the following twenty three scenarios (see Table 3) that accommodate a symmetric environment with:

- Two kinds of learning agents (GD and K) with four alternative market populations: 100%GD-0%K, 75%GD-25%K (buyers), 62,5%GD-37,5%K (buyers), and 50%GD-50%K (buyers).
- Different amount of monetary costs on transaction (25 versus 50) in order to compare the results with a no-monetary cost case, TC0.

Table 3
Scenarios of simulation

	TC0	TC25	TC50
100% GD-0%K	E11	E12	E13
75% GD-25%K (buyers)	E21	E22	E23
62,5% GD-37,5%K (buyers)	E31	E32	E33
50% GD-50%K (buyers)	E41	E42	E43

5. Main results

We analyzed the CDA market efficiency performance. We use E11, E12, and E13 scenarios as the reference benchmark because the market performance is excellent in terms of price convergence and efficiency. A comparison of the graphics of Figure 2 (on the left, E11, E12, and E13 scenarios) shows that introducing monetary costs on transactions reduce the allocative market efficiency. Our results confirm expected theoretical and experimental results:

- The efficiency is lower when a monetary cost is imposed (TC25 and TC50) than when there is not monetary cost (TC0).
- The lowest efficiency in all scenarios is achieved when the transaction cost is 50 (TC50).

However, there is a new result overlooked by Economic Theory. The efficiency loss not only depends on the source of the transaction cost but it heavily depends on the agents' learning as well. This result is just an extension of previous results obtained when there were no transaction costs. Posada et al (2006) first demonstrated that, when the costless market is populated by K agents, and more clearly if they are on one side of the market (making bids or asks), market efficiency decreases and price convergence is not achieved. The efficiency decreases as the percentage of K agents increases in the market. There is a wide gap when this percentage goes from 37,5% to 50%. Moreover, the effect of behaviour is stronger than

Figure 2
Average efficiency per period of a market

the effect of transaction cost in the extreme case where only sellers submit offers to the markets due to all buyers are K agents (that is in E41, E42, and E43 scenarios, see Figure 2 on the right).

A comparison of the graphics of Figure 2 shows that the presence of inactive agents drastically reduces the allocative market efficiency. K agents are parasitic on the intelligent agents to trade and to obtain profit. When most of the traders in the market use a K bidding strategy, the market performance is poor in terms of price convergence and efficiency. However, its performance in terms of individual agents' profits is excellent. Our explanation relies on agents' learning skills.

The sample averages per run efficiency and the sample standard deviations per run are reported in Table 4. As it can be seen, market efficiency depends of the type of traders if we take in consideration transaction costs.

6. Conclusions

Experimental Economics allows a deep analysis of microeconomic markets and inspires new empirical bases for testing theories, institutional design and, behavioural explanations of market dynamics.

As pointed out more than 150 year ago by Mill (1848), by creating a market, in this case for CO₂ permits rights, we can reveal the value of clean air, and assign a price to this good. The CDA experiments with artificial agents have provided a thinner resolu-

tion and alternative explanations of price dynamics and social and individual efficiency for a wide range of AxExI microeconomic settings. When realistic assumptions are added to the CDA, such as transaction costs and agents with heterogeneous behaviour, Artificial Economics can be very useful to inspire explanations of the observed behaviour. Our results confirm both expected theoretical effects and experimental results, and they indicate new behavioural explanations of market dynamics. The behavioural effect is stronger than the effect of transaction cost in the extreme case where only sellers submit offers to the markets due to all buyers being K agents

This result is similar when the transaction costs are imposed on the submissions (Posada and Hernández 2010). The consequence for market policy design is that if monetary costs are imposed, it should be on the transactions, because monetary costs on submissions reinforce the parasitic feature of the K agents.

As we show, Artificial Economics models are a necessary companion of Experimental Economic experiments. With artificial agents, the experimental results' robustness can be checked against alternative controlled agents' behaviour with reliability and at low cost, providing detailed explanations of the limitation and scope of Experimental Economics results.

A final conclusion is in order: Up to now, Economic Theory has been fed by Econometric and Mathematical models from historical real data and more recently Experimental Economics with humans has been welcome as the «second way» to the making

Table 4
Market efficiency

Traders	TC0	TC25	TC50
100% GD-0%K Market average (standard deviation)	0,9993 (0,000212)	0,9337 (0,000191)	0,8672 (0,000226)
75% GD-25%K (buyers) Market average (standard deviation)	0,9894 (0,00365)	0,9153 (0,00641)	0,006411 (0,00496)
62,5% GD-37,5%K (buyers) Market average (standard deviation)	0,9587 (0,0131)	0,9027 (0,0119)	0,8223 (0,0151)
50% GD-50%K (buyers) Market average (standard deviation)	0,3791 (0,00719)	0,3784 (0,00561)	0,3560 (0,00454)

of Economics. As these and related papers show the time has come for a «*third way*»: Artificial Economics (Experiments with soft agents) to be accepted as an endogenous generator of Economic Theory and as an innovative teaching tool.

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