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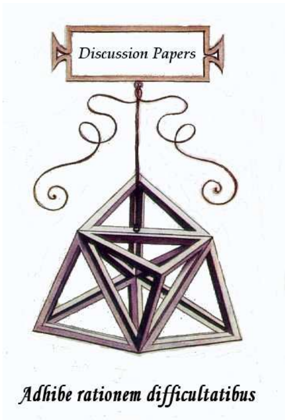

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Environmental standards and Cournot duopoly: a stability analysis.

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Environmental standards and Cournot duopoly: a stability analysis.

Abstract

In this paper the dynamical effects of public environmental policies are investigated in a Cournot duopoly with heterogeneous expectations in a context of limited rationality. It is shown that the introduction of upper limits to emissions always tends to destabilise and generate a chaotic market dynamics.

By contrast the role played by the cost of the abatement technology is more complicated: although in most cases higher costs imply a higher likelihood of stability loss, in some cases increases of such costs when their level is sufficiently low tends to stabilise and in such cases if the market is stable either a decrease or an increase of such costs may lead to a stability loss. The policy implications of these results suggest caution in the use of environmental policies from a market stability point of view.

Keywords Environmental policies; Bifurcation; Chaos; Cournot; Oligopoly;

JEL Classification Q52; C62 ; D43; L13

1. Introduction

Pollution in industrial production as well as environmental public policies are stylised facts that the oligopolistic literature has increasingly investigated.
On the one hand, the literature on the environment has broadly analyzed the environmental policy implemented by governments caring about the environment (see van der Ploeg and de Zeeuw (1992); Barrett 1994; Kennedy 1994; Markusen et al. 1995; Ulph 1996; Katsoulakos and Xepapadeas (1996a,b); Hoel 1997; Markusen 1997; Bluffstone and Panayotou (2000) Bárcena-Ruiz and Garzón 2003, 2006).
On the other hand, the interest on oligopolies under a dynamical point of view has been "renewed" in the recent decades, with the widespread occurrence of chaotic dynamics in "rational" as well as in "bounded rational" contexts.
However, while, on the one hand, the dynamic oligopoly literature has not developed models including environmental standards,[1] on the other hands the literature on the environment has mainly focused its attention on static games. Therefore it may be of interest to extend these studies by considering the dynamical aspects of the existence, on the one hand, of polluting technology and, on the other hand, of environmental standards to control pollution as well as of specific technologies used by producers to abate emissions.
The purpose of this paper is thus to show - in a Cournot duopoly with heterogeneous expectations in a context of bounded rationality - how the environmental policy of governments may affect not only the equilibrium outcomes (as studied by a vast literature, e.g. Barcena-Ruiz and Garzon (2003, 2006)) but mostly the stability and the dynamics of the market. As to the latter we also investigate whether and how different policies caring about the environment such as either the introduction of environmental standards or the fostering of a reduction of the abatement costs may have different dynamical effects.
The main findings are: 1) the introduction of upper limits to emissions always tends to destabilise and generate a chaotic market dynamics; 2) by contrast, the role played by the cost of the abatement technology is more complicated: although in most cases higher costs imply a higher likelihood of stability loss, in some cases increases of such costs when their level is sufficiently low tends to stabilise and in such cases if the market is stable either a decrease or an increase of such costs may lead to a stability loss. The policy implications of these results suggest caution in the use of environmental policies from a market stability point of view.
The paper is organised as follows. Section 2 develops the Cournot model with pollution and environmental standards and presents the two-dimensional

[1] Environmental standards are requirements that set specific limits to the amount of pollutants that can be released into the environment by firms.

dynamic system of a duopoly game with heterogeneous expectations (bounded rational and naïve). Section 3 studies both the steady state and dynamics of the Cournot duopoly, showing explicit parametric conditions of the existence, local stability and bifurcation of the market equilibrium. Section 4 presents numerical simulations illustrating the analytical findings and showing the occurrence of complex behaviours. Section 5 concludes.

2. The model

In order to analyze the market dynamics when there are polluting productions and public rules caring about the environment (such as the setting of an upper limit on emissions), we assume that there are *two* private firms which produce a homogeneous good with the same technology through a polluting production technology.[2] Moreover i) there is a public agency which cares about the environment by choosing an environmental standard to control pollution;[3] 2) each unit of the good produced causes one unit of pollutant; 3) the technology for abating this pollution is disposable to polluting firms, and it is the same for all firms[4]; 4) since both firms produce a homogeneous good with the same polluting technology, then the environmental standard is identical for both firms.

As a consequence of the environmental standard, the producers have to abate pollution emissions to comply with this upper limit. This abatement requires a positive cost. If the government sets the environmental standard e and producer i chooses the output level q_i producer i has to abate emissions by $(q_i - e)$ and thus the total cost of pollution abatement (CA) for the i-firm is assumed to be, as usual, $CA_i = k\frac{(q_i - e)^2}{2}$, $k>0$. (1)

We assume for simplicity that both firms have a constant marginal cost of production which is normalized to zero and, as usual, a linear inverse demand function for the homogeneous good, which is

$$p = a - \left(q_i + q_j\right) \qquad (2)$$

The profit function of firm i is

$$\pi_i = (a - q_i - q_j)q_i - k\frac{(q_i - e)^2}{2} \qquad (3)$$

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[2] For a duopoly model with pollution in a static context see, for instance, Barcena-Ruiz and Garzon, (2003, 2006).

[3] Alternatively, it could be assumed environmental taxes which are also increasingly implemented by public agencies (European Environment Agency, 2000). This is left for further research.

[4] Given the dynamical focus of this paper in a context of disequilibrium dynamics and limited information, we abstract from the choice of "optimal" environmental standards by public agency, as is the rule in the static duopoly games literature. Therefore we study the effects of exogenously given (rather than endogenously optimally chosen) environmental standards.

From the profit maximisation by firm $i=\{1,2\}$, the marginal profits are obtained as:

$$\frac{\partial \pi_1(q_1,q_2)}{\partial q_1}=a-2q_1-kq_1-q_2+ek\,, \tag{4}$$

$$\frac{\partial \pi_2(q_1,q_2)}{\partial q_2}=a-2q_2-kq_2-q_1+ek\,. \tag{5}$$

The reaction or best reply functions of firms 1 and 2 are computed as the unique solution of Eqs. (4) and (5) for q_1 and q_2, respectively, and they are given by:

$$\frac{\partial \pi_1(q_1,q_2)}{\partial q_1}=0 \Leftrightarrow q_1(q_2)=\frac{1}{2+k}[a+ek-q_2], \tag{6}$$

$$\frac{\partial \pi_2(q_1,q_2)}{\partial q_2}=0 \Leftrightarrow q_2(q_1)=\frac{1}{2+k}[a+ek-q_1] \tag{7}$$

Now, the forecasts as regards the behaviour of the competitor are crucial in order to make the optimal (rational) output choice. In fact, starting from a definition of the dynamic adjustment process in a Cournot duopoly such that each firm forecasts the quantity its rival will choose in the current period, and that then the firm chooses as its own quantity the output level that will maximize its own profit if its rival's quantity turns out to be as forecasted, then it follows that how one firm infers the choices of the other firm is the key factor for determining dynamical outcomes. Two polar cases of firm's inference have been considered in the literature: on the one side the original Cournot (1838) conjecture that the quantity each firm forecasts for its rival is the quantity the rival was observed to have chosen in the preceding period (i.e. Cournot-naïve expectations),[5] and on the other side that each firm perfectly infers the quantity chosen by the other firm (of course, in such a case any adjustment (disequilibrium) dynamics is prevented). However to consider firms able to perfectly infer the choices of the other firms may be rather unrealistic, for instance because information in the market usually is incomplete. It seems more realistic to consider mechanisms through which each firm form their expectations on the decisions of the rival firm.
However, it must be noted that even in the case of assumption of full information and a "rational" formation of expectations it has been shown that under the existence of a Markov-Perfect Equilibrium (MPE) in the sense of Maskin and Tirole (1987, 1988a, 1988b) *i)* the dynamic process of the agents playing alternately will be an orbit of a map similar to a Cournot tatonnement,

[5] Under the assumption of Cournot-naïve expectations, Theocharis (1960) has shown for the standard case with linear demand and cost functions in a homogenous (quantity adjusting) duopoly that the adjustment process always converges to the Nash-Equilibrium. After that, the case with naive expectations has been deeply analyzed taking in consideration alternative features of the demand and cost functions, (see, for instance, Puu, 1997), discovering complicated dynamic specifically due to the non-linearity introduced in the alternative demand and cost functions.

and *ii)* as the discount rate converges to zero the set of MPEs converges to the best reply function of the one-shot game of Cournot (Dana and Montrucchio, 1986, 1987).[6] Therefore this leads to the consequent relevant conclusion that, since the mathematical structures both of the dynamic process under "rational" strategies and MPE, and of the adjustment dynamic process under "myopic" strategies – such as the Cournot-naïve expectations - are similar, then the analysis of the dynamical properties of a adjustment dynamic process such as the Cournot tatonnement may be sufficiently general for predicting the dynamical outcomes of a duopolistic Cournot competition.

In any case, more recently, several works have considered perhaps more realistic (although in a context of limited information) mechanisms through which players form their expectations on the decisions of the competitors, based on standard models of formation of expectations already existing in economic theory, but "renewed" at the light of the novelties of the dynamical systems theory (e.g. chaos): *i)* "adaptive" expectations, according to which expected values are successively revised in the same direction resulting from the difference between the actual and the expected values (where the latter are a weighted average of all actual values in the past, with the weight decreasing with time)[7]; *ii)* "bounded rational" expectations according to which the firm, having incomplete knowledge of market, decides to increase (decrease) its quantity if it has a positive (negative) marginal profit (for instance, this adjustment mechanism has been suggested by Dixit (1986))(e.g. Leonard and Nishimura, 1999; Den Haan, 2001; Agiza and Elsadany, 2003; Bischi et al., 2010).

Therefore, following the recent above mentioned literature, we assume that each firm forecasts the quantity its rival will choose in the current period in a context of limited information and bounded rationality. In particular, in accord with, for instance, Zhang et al., 2007; Tramontana, 2010; Fanti and Gori, 2012), we assume that the duopolists do not adopt the same decision mechanism, but they are heterogenous: the one adopts the bounded rational expectations, the other adopts Cournot-naïve expectation. Thus, we assume that firm 1 is bounded rational and firm 2 is naïve. Therefore, given these types of expectations formation, the two-dimensional system that characterises the dynamics of a Cournot duopoly with pollution is the following:

$$\begin{cases} q_{1,t+1} = q_{1,t} + \alpha q_{1,t}\left[a - (2+k)q_{1,t} - q_{2,t} + ek\right] \\ q_{2,t+1} = q_{2,t} = \dfrac{a + ek - d q_{1,t}}{2+k} \end{cases} \quad . \tag{8}$$

[6] These authors, through the adoption of the concept of MPE, have allowed for dynamic responses within an infinite horizon duopoly game, showing that any pair of smooth reaction functions could be the MPE of some game, and hence any behavior (including complicated ones) is possible also in the context of full information and "rational" firms.

[7] The existence, stability and uniqueness of the Cournot-Equilibrium under adaptive expectations has been largely studied by Okuguchi (1976).

3. Local stability analysis of the unique positive Cournot-Nash equilibrium

From an economic point of view we are only interested to the study of the local stability properties of the unique positive output equilibrium, which is determined by setting $q_{1,t+1} = q_{1,t} = q_1$ and $q_{2,t+1} = q_{2,t} = q_2$ in (8) and solving for (non-negative solutions of) q_1 and q_2, that is:

$$q^*_1 = q^*_2 = q^* = \frac{a+ek}{3+k}, \tag{9}$$

The Jacobian matrix evaluated at the equilibrium point (9) is the following:

$$J = \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix} = \begin{pmatrix} 1-\dfrac{\alpha(2+k)(a+ek)}{3+k} & \dfrac{-\alpha(a+ek)}{3+k} \\ -\dfrac{1}{2+k} & 0 \end{pmatrix}. \tag{10}$$

The trace and determinant of the Jacobian matrix (10) are respectively given by:

$$T := Tr(J) = J_{11} + J_{22} = \frac{3+k-\alpha(2+k)(a+ek)}{3+k}. \tag{11}$$

$$D := Det(J) = J_{11}J_{22} - J_{12}J_{21} = \frac{-\alpha(a+ek)}{(3+k)(2+k)}, \tag{12}$$

so that the characteristic polynomial of (10) is:

$$G(\lambda) = \lambda^2 - tr(J)\lambda + \det(J), \tag{13}$$

whose discriminant is $Q := [Tr(J)]^2 - 4Det(J)$.

We now study the local stability properties of the Cournot-Nash equilibrium Eq. (9) by means of well-known stability conditions for a system in two dimensions with discrete time (see, e.g., Medio, 1992; Gandolfo, 2010), which are generally given by:

$$\begin{cases} (i) \quad F := 1 + T + D > 0 \\ (ii) \quad TC := 1 - T + D > 0 \\ (iii) \quad H := 1 - D > 0 \end{cases}. \tag{14}$$

The violation of any single inequality in (15), with the other two being simultaneously fulfilled leads to: (*i*) a flip bifurcation (a real eigenvalue that passes through -1) when $F = 0$; (*ii*) a fold or transcritical bifurcation (a real eigenvalue that passes through $+1$) when $TC = 0$; (*iii*) a Neimark-Sacker bifurcation (i.e., the modulus of a complex eigenvalue pair that passes through 1) when $H = 0$, namely $Det(J) = 1$ and $|Tr(J)| < 2$. For the particular case of the Jacobian matrix (10), the stability conditions stated in (14) can be written as follows:

$$\begin{cases} (i) \quad F = -\dfrac{\alpha(a+ek)(2+k)^2 - 2(2+k)(3+k)}{(2+k)(3+k)} > 0 \\ (ii) \quad TC = -\dfrac{\alpha[1-(2+k)(a+ek)]}{2+k} > 0 \\ (iii) \quad H = \dfrac{(2+k)(3+k) - \alpha(a+ek)}{(2+k)(3+k)} > 0 \end{cases} \qquad (15)$$

From (15) it can easily be seen that while conditions (*ii*) is always fulfilled, condition (*i*) and (*iii*) can be violated. Therefore, the Cournot-Nash equilibrium $q^*_1 = q^*_2 = q^*$ can loose stability through either a flip or a Neimark-Sacker bifurcation. The stability condition (*i*) in (15) represents a region F in the (α,e) plane, i.e., the speed of adjustment and the environmental standard, bounded by the economic model assumption $\alpha, e > 0$. Therefore, the following equation $\mathrm{B}(\alpha)$, i.e. the numerator of F in (15), represents a bifurcation curve at which the positive equilibrium point $q^*_1 = q^*_2 = q^*$ looses stability through a flip (or period-doubling) bifurcation, that is:

$$\mathrm{B}(\alpha) := -\alpha(a+ek)(2+k)^2 - 2(2+k)(3+k) = 0. \qquad (16)$$

A simple inspection of Eq. (16) leads to the following remarks.

Remark 1. *The bifurcation curve* $\mathrm{B}(\alpha)$ *intersects the horizontal axis at*

$$\alpha = \alpha^F = \frac{2(2+k)(3+k)}{(a+ek)(5+k^2+4k)}. \qquad (17)$$

Furthermore, the market equilibrium q^* *is stable (*$\mathrm{B}(\alpha) > 0$*) when* $\alpha < \alpha^F$

Moreover, the following equation $N(\alpha,\gamma)$, i.e. the numerator of H in (15), represents a bifurcation curve at which the positive equilibrium point q^* looses stability through a Neimark-Sacker bifurcation, that is:

$$N(\alpha,e) := (2+k)(3+k) - \alpha(a+ek) = 0. \qquad (18)$$

A simple inspection of Eq. (18) leads to the following remark.

Remark 2. *The bifurcation curve* $N(\alpha,e)$ *intersects the horizontal axis at* $\alpha = \alpha^H := \dfrac{(2+k)(3+k)}{(a+ek)}$ *and the market equilibrium* q^* *is stable (*$N(\alpha,e) > 0$*) when* $\alpha < \alpha^H$. (19)

Given that the Nash equilibrium may become unstable either via flip or via Neimark–Sacker bifurcation (as shown in Remark 1 and 2)), we have to check which one occurs before the other one, starting from a stability situation and increasing the value of α.

Then the following Remark holds:

Remark 3: *the equilibrium market q* may loose stability only through a flip bifurcation*. This Remark straightforwardly follows from the simple observation that $\alpha^F < \alpha^H$.[8]

Therefore we have established that, also in this duopoly model with pollution a sufficiently high speed of adjustment may destabilise, as expected, the Cournot-Nash equilibrium.

However, we must investigate which is the dynamic role of our parameters of interest, that is the environmental standard and the cost of abatement technology which are the novelty of our duopoly dynamic analysis.

Let's begin with the environmental standard: by solving (16) for the environmental standard level, we may claim that

Remark 4. *The bifurcation curve* $\mathrm{B}(e)$ *intersects the horizontal axis at*

$$e = e^F = \frac{a\alpha(k^2+4k+5)-2(k^2+5k+6)}{ak(5+k^2+4k)}. \qquad (20)$$

Furthermore, the market equilibrium q^* *is stable (*$\mathrm{B}(e)>0$*) when* $e<e^F$.

Therefore remark 3 establishes that the introduction of a higher environmental standard may destabilise the Cournot-Nash equilibrium.

From an economic point of view, Remark 3 constitutes a policy warning about the peril of introducing higher upper limits to emissions for what concerns the stability of the market in which the pollutant firms produce.

Now we analyse the stability role played by the cost parameter of the abatement technology disposable for firms. Let's rewrite the flip bifurcation boundary curve (16) in terms of the cost parameter, k:

$$\mathrm{B}(k) := -A_1k^3 + A_2k^2 + A_3k + A_4 = 0 \qquad (21)$$

where $A_1 = -e\alpha;\ A_2 = 2-\alpha(a+4e);\ A_3 = 10-\alpha(4a+5e);\ A_4 = 12-5a\alpha$.

The boundary curve (21) may have up to three real solutions for *k*. However, through an application of the Descartes'rule we claim the following remark:

Remark 5. *The bifurcation curve* $\mathrm{B}(k)$ *is a cubic polynomial which tends to minus infinity and has only one positive solution for* $k = k_1^F$ *when* $\frac{12}{5a} < \alpha$, *two positive solutions (if real) for* $k = k_1^F$ *and* $k = k_2^F$ *(* $k_1^F > k_2^F$ *) when* $\frac{12}{5a} < \alpha < \frac{10}{4(a+1.25e)}$, *no positive solutions when* $\alpha > \frac{10}{4(a+1.25e)}$

[8] The proof of Remark 3 straightforwardly derives from $\alpha^F - a^H = \frac{(2+k)(3+k)(1-4-k^2-4k)}{(a+ek)(5+k^2+4k)} < 0$.

Furthermore, the market equilibrium q^* *is: 1) stable (* $B(k)>0$ *) when: i)* $k<k_1^F$ *for* $\frac{12}{5a}<\alpha$*; ii)* $k_2^F<k<k_1^F$ for $\frac{12}{5a}<\alpha<\frac{10}{4(a+1.25e)}$, *and 2) always unstable when* $\alpha>\frac{10}{4(a+1.25e)}$.

Proof: Firsly, we establish the sign of coefficients of the cubic polynomial (21): $A_1<0;\ A_2 \begin{smallmatrix}>\\=\\<\end{smallmatrix} 0 \Leftrightarrow \alpha \begin{smallmatrix}<\\=\\>\end{smallmatrix} \frac{2}{a+4e};\ A_3 \begin{smallmatrix}>\\=\\<\end{smallmatrix} 0 \Leftrightarrow \alpha \begin{smallmatrix}<\\=\\>\end{smallmatrix} \frac{10}{4(a+1.25e)};\ A_4 \begin{smallmatrix}>\\=\\<\end{smallmatrix} 0 \Leftrightarrow \alpha \begin{smallmatrix}<\\=\\>\end{smallmatrix} \frac{12}{5a}$.
Secondly we apply the Descartes' Theorem, as depicted in the table below: the first and second lines prove part *1i)*; the third line proves the part *1ii)*; the fourth line proves part *2)*. Q.E.D.

Sign of Coefficients	*Roots*
$A_1<0; A_2>0; A_3>0; A_4>0$	*Only 1 positive root*
$A_1<0; A_2<0; A_3>0; A_4>0$	*Only 1 positive root*
$A_1<0; A_2<0; A_3>0; A_4<0$	*2 positive roots (if real)*
$A_1<0; A_2<0; A_3<0; A_4<0$	*No positive roots*

Remark 5 shows that the cost parameter of the abatement technology plays a complicated dynamical role: although when the speed of adjustment is sufficiently low higher costs imply a higher likelihood of stability loss, in the case of a speed of adjustment included in a intermediate window it happens that increases of such costs when their level is sufficiently low tends to stabilise. This result highlights not only the peril of high abatement costs, but also picks up the parametric conditions under which the converse is true: too low abatement costs may menace the market stability, and in such a case if the market is stable then either a decrease or an increase of such costs may lead to a stability loss.

4. A numerical illustration

The main purpose of this section is to show that the qualitative behaviour of the solutions of the duopoly game with heterogeneous players (described by the dynamic system (8)) can generate, in addition to the local flip bifurcation and the resulting emergence of a two-period cycle implied by Remark 3, complex behaviours. To provide some numerical evidence for the chaotic behaviour of system (8), we present several numerical results, including bifurcations diagrams, basin of attraction and strange attractors.

According with the aim of the paper, we take the environmental standard e and the cost parameter k as the bifurcation parameters. As regards the bifurcation analysis with respect to e, we choose the following parameter set only for illustrative purposes: $\alpha = 0.335$, $a = 7$ and $k = 1.5$.

Figure 1 depicts the bifurcation diagram for e. The figure clearly shows that an increase in the upper limit for emissions implies that the map (8) converges to a fixed point for $0 > e > 0.064$. Starting from this interval, in which the positive fixed point (9) of system (8) is stable, Figure 1 shows that the equilibrium output undergoes a flip bifurcation at $e^F = 0.643$. Then a stable two-period cycle emerges for $0.064 > e > 1.34$. As long as the upper limit for emissions is further raised it is observed: *i)* a four-period cycle, *ii)* cycles of highly periodicity and *iii)* a cascade of flip bifurcations that ultimately lead to unpredictable (chaotic) motions, interspersed by some sizable windows of periodic dynamics, as clearly displayed in the enlarged view of Figure 2. As another example of the occurrence of chaos, the phase portrait of Figure 3 depicts the shapes of both the strange attractor and basin of attraction, which is fractal, for $e = 2.63$.

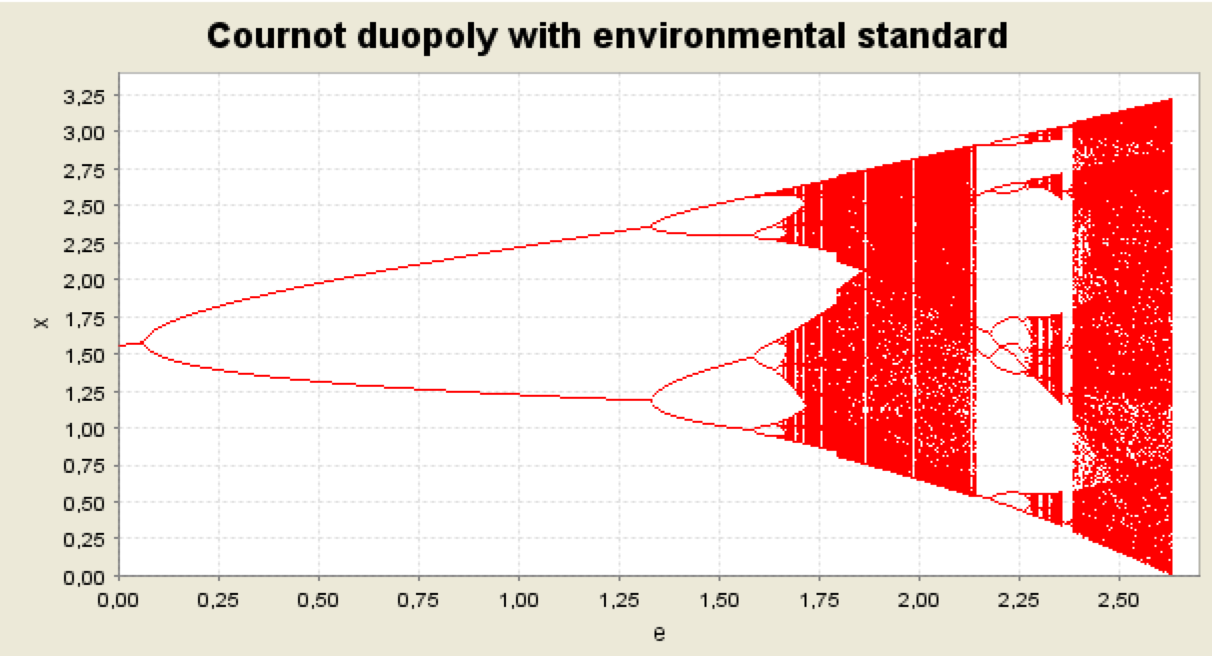

Figure 1. *Bifurcation diagram for* e. Initial conditions: $q_{1,0} = 0.03$ and $q_{1,0} = 0.01$.

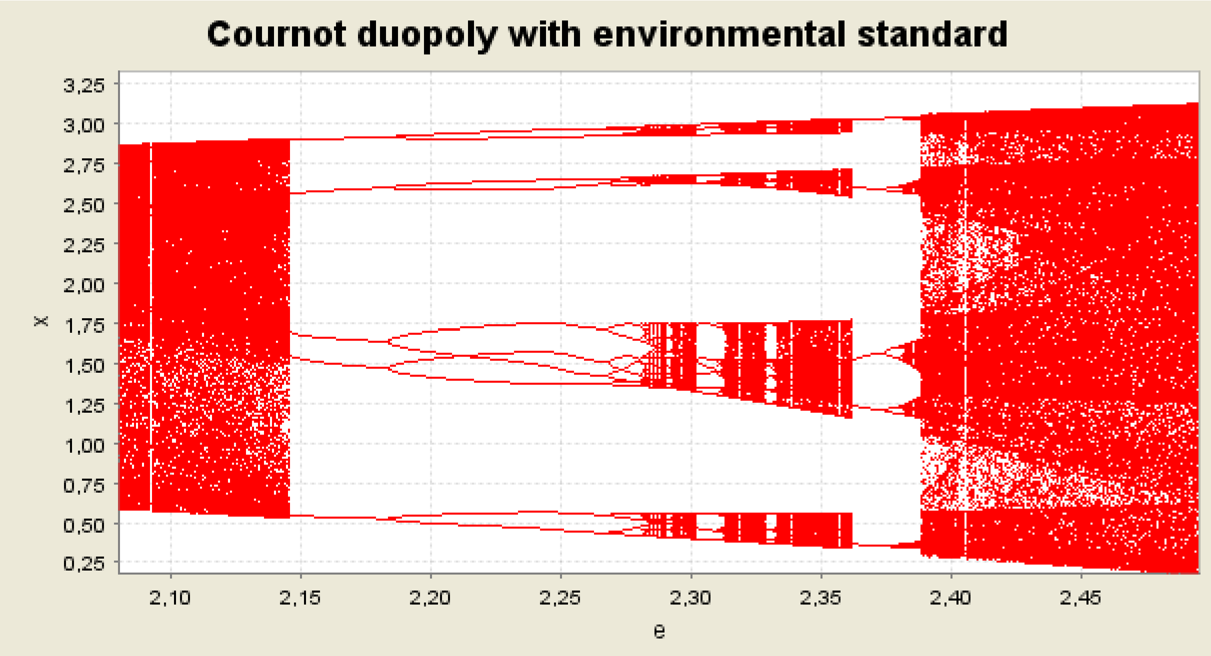

Figure 2. *An enlarged view of the Bifurcation diagram in fig. 1.*

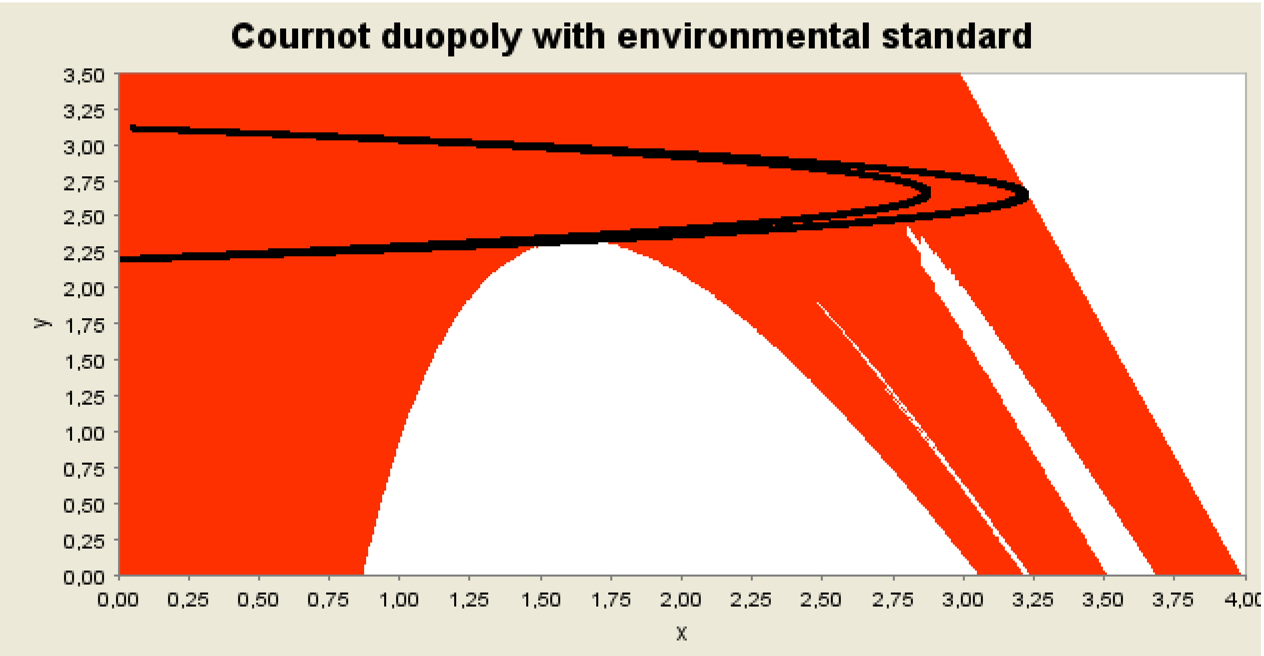

Figure 3. *Basin of attraction and strange attractor* ($e = 2.63$).

Now we address the issue of the role of the abatement cost parameter, k. As analytically shown by Remark 5, k may play multiple roles, among which the most intriguing for firms and policy-makers is that, when the market is stable under a sufficiently low k, a change of k in any direction may destabilise the industry equilibrium. The following numerical simulation aims to exemplify such a case.

Figure 4 displays the bifurcation diagram for k, under the following parameter set: $\alpha = 0.801$, $a = 3$ and $e = 0.03$. This set corresponds to the content of the part *1ii*) of Remark 5, which predicts the appearance of a twofold flip bifurcation for varying values of the abatement cost parameter (i.e. one period-doubling and one reverse period-doubling bifurcation): in fact the diagram shows that 1) the market system is stable for $k_2^F = 0.095 < k < k_1^F = 0.42$ and 2) starting from a cost value included in this interval either an increase or a decrease of such a cost may cause a stability loss.

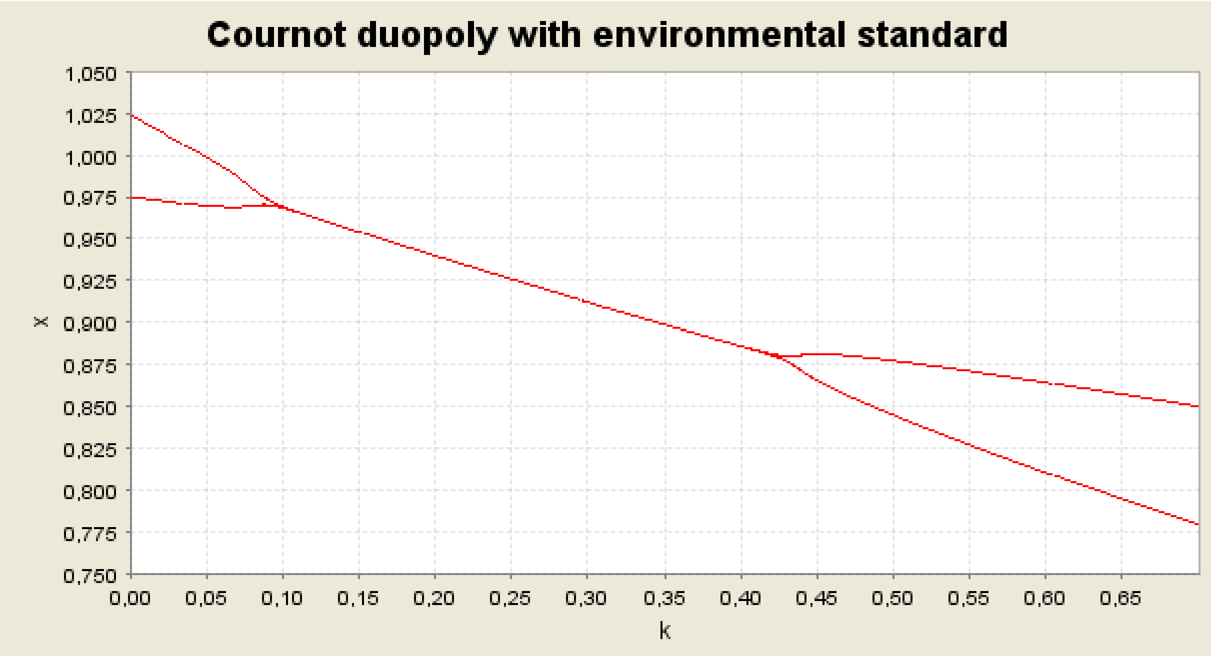

Figure 4. *Bifurcation diagram for* k . Initial conditions: $q_{1,0} = 0.03$ and $q_{1,0} = 0.01$.

5. Conclusions

Motivated by the observation that so far the oligopolistic literature on the one hand analyzed the environmental policy in a static context, while on the other hands the dynamic analyses have abstracted from environmental issues, this paper analyzes, to fill this gap in the literature, whether and how two public policies – the use of environmental standards and the fostering of a reduction of the abatement costs – affect the dynamics of the market.

We show that the introduction of upper limits to emissions - in a Cournot duopoly with heterogeneous expectations in a context of bounded rationality - always tends to destabilise and generate a chaotic market dynamics. This finding reveals a possible unpleasant trade off between the effects of environmental standards in a static and in a dynamic context.

By contrast the role played by the cost of the abatement technology is more complicated: when the cost is sufficiently high, an its further increase implies a higher likelihood of stability loss, however when the cost is sufficiently low and the market is stable either a decrease or an increase of such a cost may lead to a stability loss. The policy implication of this finding is that policy makers should be cautious in fostering the reduction of abatement costs.
To sum up, our findings, notwithstanding the caveat that the strategic context is not fully rational, shed some light on the possibly complicated dynamical effects of environmental policies.

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