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Pollution, green union and network industry

Luciano Fanti and Domenico Buccella

Abstract
In this paper the authors investigate whether and how, in a network industry, the intensity of network effects affect the total pollution under the presence of a union interested to "local" environmental damages (e.g. polluting production processes damaging workers' health and the local environment where workers live). Under monopoly, it is shown that network effects tend to increase, on the one hand, the investments in the cleaning technology but, on the other hand, the polluting output, so that their effects on the total pollution are theoretically ambiguous. In particular, the authors find that total pollution is reduced (resp. increased) with increasing network effects intensity if the market is sufficiently large (resp. small). Moreover the pollution-reducing result of the increasing network effect is more likely when the existing network effects, the union's environmental concerns and the technological efficiency are sufficiently large. These findings are qualitatively confirmed also under different union's preferences, Government's environmental standard and Cournot duopoly, and thus offer interesting empirical as well as policy implications.

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Keywords Network goods; cleaning technology; pollution production; green unions; monopoly; Cournot duopoly

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1. Introduction

The growing relevance of network industries and their fast, constant development is, up to the current stage, one of the most significant stylized fact in contemporary economics. One may simply think the large-scale expansions of devices such as mobile phones and tablets, and computer software. It is immediate to recognize that the utility a single consumer gets from using those goods increases with the number of other users. Noteworthy several companies in network industries produce and assembly their final products in large manufacturing plants (e.g. the several times mentioned in the media Apple's Foxconn plant in China) which, in most of the case, adopt polluting production processes.

The topic of environmental safety has become of great importance on the political as well as popular debate in several industrialised countries, where the presence of unions in imperfectly competitive markets is another stylised fact. In those countries, large manufacturing plants producing local highly pollutant emissions can be usually found in specific sectors of the economy. As a consequence, workers are the most exposed to pollution damages, in the dual role of people participating in the production process and inhabitants living close to the polluting plant.

Despite the evidence of the phenomenon of local environmental damage, the theoretical literature has mainly analysed the environmental damages involving all consumers and having, through transboundary effects, an international scale. Unexpectedly, the study of local damages has been mainly ignored in spite of the fact that: 1) a single giant plant can heavily damage the "local" environment while its "global" impact can be limited; and 2) the workers employed in polluting processes are, by and the large, the most affected people.

As a consequence, not much attention has been devoted to the role organised workers, in the form of a union, play in such polluting milieu. In fact, in recent years, it has been observed, at least in well-identified industries, the rise of "green unions", i.e. unions that have environmental concerns and increasingly interested to "Work Health and Safety" (for a discussion, see e.g. UNEP, 2008, 2011; ILO and UNEP, 2012; ILO, 2013; ITUC, 2014a).

This subject grows in its importance, remarkably in advanced countries. For example, in 2014, after a five months campaign led by environmental labour unions and actionists, Apple decided to remove extremely toxic chemicals (including benzene and n-hexane) from its supplier factories in China. The hi-tech multinational announced that it will "explicitly prohibit the use of benzene and n-hexane" at 22 of its final assembly supplier factories employing nearly 500,000 workers (ITUC, 2014b). Therefore, in a context with a polluting giant plant, this means that workers are "selfish" in having preferences with environmental concerns[1] and instead consumers are not damaged by pollution.[2] Clearly, the presence of active "green unions", via the inclusion of the environmental damage in the wage setting process, affects the output decision and, therefore, will have an impact on the total emission of the manufacturing plant.

The Industrial Organization literature has barely analysed the joint presence of unions and polluting firms (e.g. Barcena-Ruiz and Garzon, 2003, 2009; Barcena-Ruiz, 2011). Moreover, notwithstanding a vast sociological and political literature has documented the unions' sensibility to environmental problems, the study of labour unions caring about environmental safety has been largely neglected.[3] Remarkable exceptions are the contributions of Frederiksson and Gaston (1999) and, recently, Asproudis and Gil-Moltó (2015).[4]

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[1] That is, labour unions are not motivated by ideological reasons, in line with the increasing wave of environmentalism, as some authors have documented by (e.g. Obach, 1999). Nonetheless, for simplicity, we keep here the definition of "green" unions.

[2] This assumption is absolutely realistic. In fact, for example, workers and inhabitants of the polluted environment by a large manufacturing plant are infinitesimal with respect to the pool of all consumers.

[3] For instance, Silverman (2006), Obach (1999) and the works quoted in Asproudis and Gil-Moltó (2015).

[4] This approach with environmentalist unions and firms' pollution abatements could be also related to another recent strand of industrial organization literature focusing on the Corporate Social Responsibility (CSR). In this regard, we can interpret, on the one hand, the unions' care for the environment as an example in which employees have social preferences and, on the other hand, pollution abatements as one reason for profit-seeking companies to invest in socially responsible

Frederiksson and Gaston (1999) include labour market bargaining considerations in a framework with influence-seeking. Those authors show that a union's stance on environmental policy crucially depends on the exposure of its members to the risk of job loss. However, those authors do not focus their analysis on the impact of the union's environmental policy position on the industry outcomes. In a unionised duopoly, Asproudis and Gil-Moltó (2015) investigate, from an industrial organisation perspective, the effects of unions having environmental concerns on firms' technological choices, output and pollution levels, investigating in particular the impact of alternative union structures on firms' technological choices.

However, those authors study the presence of "green unions" in markets in which standard goods are produced while the relationship between the presence of network goods and green unions, on the one hand, and the level of total polluting emissions, on the other hand, has remained so far unexplored.

The present paper aims to answer the following research questions: may the intensity of the network effect in a unionised industry with network goods reduce the total pollution? As known, the network effect increases the consumers' demand and total output. Because the output is polluting, then a summary answer could be negative. However, we show that the network effect also incentivizes the adoption of cleaner technologies. Therefore, the net effect of the presence of network externalities on the industrial pollution is a priori ambiguous. In particular, we show that the answer crucially depends on the size of the product market. This is due to the non-linear effects of the interaction between the market size, on the one hand, and the firms' response to the network intensity in terms of adoption of cleaner technologies and production levels, on the other hand. In particular, the larger the market size is, the larger the differential between the incremental investment in cleaning technologies and the incremental production is (both due to the network effect), so that, for large enough market size, the pollution-reducing effect of the enhanced cleaning

activities. See Kitzmuller and Shimshack (2012), and Schmitz and Schrader (2015) for a recent literature survey on CSR.

technology can outweigh the increased pollution due to the increased production.[5] Moreover, these findings are qualitatively confirmed also under different union's preferences, Government's environmental standard and Cournot duopoly.

Therefore, these results offer some testable implications: for instance, higher pollution should be more frequently observed in industries with 1) low network effects rather than high network effects; 2) a small market dimension rather than a large market; 3) low environmentalist-orientation of the union rather than high environmental concerns. Moreover, it should be more often observed a pollution higher in small network markets than in small standard ones. For a Government interested in reducing the total pollution in network industries, the policy insight is to support the level of environmentalism of the green union.

The remainder of the paper is organised as follows. Section 2 introduces the model with green unions and network goods. Section 3 presents the results of the analysis. Section 4 presents some extensions of the basic model. Section 5 brings the paper to its conclusion with some final observations.

2. The model

The simple network effects mechanism here assumed is that the surplus a firm's client obtains directly increases with the number of other clients of this firm (i.e. Katz and Shapiro, 1985).

Following Fanti and Buccella (2016) and Buccella and Fanti (2016), we assume that the monopolist firm faces the following linear direct demand:

$$q = a - p + ny \tag{1}$$

[5] Note that the assumption of the clean technology adoption as a fixed cost investment (such as, for instance, an invention which makes the production process less harmful for workers) explains the importance of the market size for the occurrence of the pollution-reducing effect.

where q is the quantity of the goods produced, p is the price, y is the consumers' expectation about monopolist's equilibrium production, and the parameter $n \in [0,1)$ indicates the strength of the network effects (i.e., the higher the value of the parameter is, the stronger the network effects are). From (1), the inverse demand function is obtained:

$$p = a - q + ny \,. \tag{2}$$

In the spirit of the above discussion, to study the link between the presence of a "green" union and welfare outcomes we build a unionised monopoly model with polluting production. Therefore, we assume that there is a private monopoly which produces goods with a polluting production technology. Moreover, each unit of the goods produced generates k unit of pollutant, where $k \in (0,1]$. We also assume the availability of a cleaning technology for the firm, and a union with preferences for an environmental protection. However, following the pioneering model of Asproudis and Gil-Moltó (2015), remark that $k > 0$, that is, a technology that can completely eliminate emissions from production does not exist.

Our assumptions related to the forms of the abatement cost function and the union's utility function strictly follow those of the established literature, and in particular the contribution of Asproudis and Gil-Moltó (2015).

The monopolist may cut emissions and selects its optimal level of pollution which requires a cost of pollution abatement (CA) assumed to be

$$CA = z(1-k)^2, \; z > 0 \,. \tag{3}$$

The form of the CA function shows that the cleaner the technology is, the lower k is. Moreover, the adoption of cleaner technologies requires an increase in the fixed costs, and there are decreasing returns to the investment in technology, i.e. cutting down emission is always costly. Recalling that k is the pollution per unit of output, we may also say that a decrease (resp. an increase) of k is associated with a more (resp. less) efficient abatement technology, in the sense that the identical volume of polluting emission can be abated in a less (resp. more) expensive way. The parameter z up/downsize the total abatement cost and, therefore, it can be interpreted as a measure of the abatement technology's relative efficiency. The parameter z may be also understood as an exogenous index of technical progress. For example, a reduction of z can be exemplified by an exogenous shock such as the launch of a new and cheaper abatement technology.[6]

We assume that a union, having full power in the wage setting, is active in the monopolist firm. As usual, the traditional union (e.g. Pencavel, 1985) has the utility function $V=(w-w^{\circ})l$, where l represents the employment, w is the wage rate per unit of labour, and w° is the reservation wage. Given that we assume constant returns to scale in labour, then it holds that output and employment are equivalent, i.e. $q=l$. As a consequence, we have

$$V=(w-w^{\circ})q. \tag{4}$$

This utility function exhibits the union's interest both for wage and employment levels. Nevertheless, the union may also care about the quality of the environment, as the examples reported in the Introduction section inform us. Following Asproudis and Gil-Moltó (2015), the union is assumed to experience a decrease in its utility in the proportion e per unit of polluting emission. In other words, the parameter e represents the workers' marginal damage from pollution. Analytically, an additional term is introduced into the union's utility function to capture the idea of this environmental damage. Therefore, the union utility becomes:

$$V=(w-w^{\circ}-ek)q. \tag{5}$$

[6] It can be immediately shown that, in equilibrium, the short-run average cost of pollution abatement positively depends on the parameter z in a way that, for example, if z is large, it can be quite costly to adopt highly "green" technologies.

In this regard, the parameter e is a measure of the relative union's orientation towards environmental safety.[7] To ensure non-negativity on output, we assume that $a > e$. Moreover, as usual, and without loss of generality, we set $w^{\circ} = 0$ for analytical convenience.

The game follows this timing. At stage one, the monopolist selects the cleaning technology. At stage two, the union fixes wages. At stage three, following Katz and Shapiro (1985), we impose the additional "rational expectations" conditions, i.e. $y=q$. In the final stage, the monopolist chooses production (and employment), for given consumers' expectations. To obtain a subgame perfect Nash equilibrium, we solve the model making use of the backward induction method.

The monopolist profit function is

$$\pi = (a - q + ny)q - wq - z(1-k)^2 . \tag{6}$$

At the fourth stage, the monopolist's profit maximisation with respect to the quantity leads to:

$$q = \frac{a - w + ny}{2} . \tag{7}$$

Solving (7) by imposing the "rational expectations" condition, $y=q$, the equilibrium quantities at the third stage are:

$$q(w) = \frac{a - w}{2 - n} . \tag{8}$$

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[7] Thus, the term ek in (5) can be interpreted as a non-constant reservation wage which is increasing in the externality produced by work. That is "the higher the environmental damage (e) is or the more polluting the technology used by firm i (k_i) is, the higher the wage that the union will demand to compensate for the disutility caused by pollution" (Asproudis and Gil-Molto, 2015, 170).

At the second stage, substituting (8) into (5), one gets the following wage rate from the union utility maximisation:

$$w = \frac{a + ek}{2}\,. \tag{9}$$

Therefore, substitution of (9) into (8) leads to the output as a function of the cleaning technology

$$q(k) = \frac{a - ek}{2(2 - n)}\,. \tag{10}$$

At the first stage, after substitution of (9) and (10) into (6), the monopolist profit maximisation with respect to the level of the cleaning technology yields the following optimal emission intensity

$$k = \frac{ae - 4z(2 - n)^2}{e^2 - 4z(2 - n)^2}\,. \tag{11}$$

Substituting (11) backwards, the final equilibrium of the game in terms of output is

$$q = \frac{2z(2 - n)(a - e)}{4z(2 - n)^2 - e^2} \tag{12}$$

Total pollution, P, is given by

$$P = kq = \frac{2z(2 - n)(a - e)\left[4z(2 - n)^2 - ae\right]}{\left[4z(2 - n)^2 - e^2\right]^2} \tag{13}$$

Recalling that $k > 0$, the conditions for a maximum as well as for the positivity of all variables boil down to the following set of inequalities:

1) $k > 0 \Leftrightarrow a < a^0 = \dfrac{4z(2-n)^2}{e}$

2) $q > 0, \pi > 0 \Leftrightarrow e^2 < 4z(2-n)^2, e < a < a^0$. (14)

By interpreting the parameter *a* as the size of the market, conditions (14) mean that this should be included in a range, i.e. the feasibility of the model's economy is restricted for a size sufficiently, though not excessively, large of the market. Moreover, the following Remark is here in order.

Remark. The feasibility of the model's economy is reduced under network goods (relatively to standard goods), in the sense that it is required a smaller market dimension and a lower environmental interest of the union (as easily observed by the inspection of conditions (14)).

3. Results

In this section we investigate the influences of network goods on the adoption of cleaning technologies, production and total pollution.

Lemma 1. *Both investment in the cleaning technology and output are increasing at an increasing rate with an increasing network effect (n).*

Proof: $\dfrac{\partial k}{\partial n} < 0$, $\dfrac{\partial^2 k}{\partial n^2} < 0, \dfrac{\partial q}{\partial n} > 0$, $\dfrac{\partial^2 q}{\partial n^2} > 0$.

This lemma shows that the network externality has two contrasting effects on pollution. However, despite the expansion of the polluting production, we are in a position to answer whether and how the network effect may reduce the industrial pollution.

The following total derivative easily shows the mechanisms through which network effects may be pollution-reducing:

$$\frac{dP}{dn} = \overbrace{\frac{\partial q}{\partial n}}^{+} k + \overbrace{\frac{\partial k}{\partial n}}^{-} q .$$

The above expression shows that the sign of the derivative crucially depends on the response of the monopolist in terms of production and cleaning technology to changes in the goods' network intensity.

Result 1. *The network effect always increases (resp. decreases) the total pollution in the case of small (large) values of a, that is small (large) market size. Moreover i) the higher the existing network effect is, the more likely an increase of its intensity may reduce total pollution; ii) the higher both the union's pollution concerns parameters and the technical progress index of the abatement technology (i.e. the lower z) are, the more likely is the occurrence of the pollution-reducing effect.*

Proof: the first part of Result 1 follows from $\frac{\partial P}{\partial n}\underset{<}{>}0 \Leftrightarrow a \underset{>}{<} a^{*} = \frac{4z(2-n)^{2}\left[4z(2-n)^{2}+3e^{2}\right]}{e\left[12z(2-n)^{2}+e^{2}\right]}$, where $a^{*} < a^{0}$; the second part is obtained from $\frac{\partial a^{*}}{\partial n} < 0, \frac{\partial a^{*}}{\partial z} > 0, \frac{\partial a^{*}}{\partial e} < 0$.

Lemma 2. *The larger the market size is, the larger is the differential between the incremental investment in cleaning technologies and the incremental production (both due to the network effect).*

Proof: simple mixed derivatives drive the content of the lemma: $\left|\frac{\partial^2 k}{\partial n \partial a}\right| > \left|\frac{\partial^2 q}{\partial n \partial a}\right|$.

The comment is that, in sufficiently large markets, the total pollution is reduced (rather in contrast to the initial wisdom with regard to the expansive effect of the network) when the production increases with the network effect, thanks to the more intense pollution abatement. Conversely, a small market size discourages investments in a cleaner technology because these are less profitable (given the fixed cost nature of the adoption of a cleaner technology).

Moreover, it is intuitive that the pollution-reducing result of a large network effect is more likely 1) when the union's perceived damage from pollution is higher because the latter tends to expand the pollution abatement (in order to moderate wages) and to reduce employment/output (or to increment employment/output less than the abatement), 2) when abating is cheaper.

Result 1 is rather general and its quantitative implications may be illustrated with some examples (for a fixed $z=1$), as the two Figures below depict. In Figure 1, the upper solid line represents the case with a relatively high value of $a=6$; the intermediate dashed line represents the case with a relatively intermediate value of $a=4.5$; the lower dotted line represents the case with a relatively low value of $a=3$. It is easy to see that for a market size relatively small the total pollution in the presence of increasing network effects either always increases or in any case remains always higher than that of the case of standard goods (i.e. $n=0$) . On the other hand, if the dimension of the market is relatively ample the total pollution may decrease (for high enough network effects) significantly below that produced by industries with standard goods (and even below the level of pollution created by more small industries with the same level of network intensity).

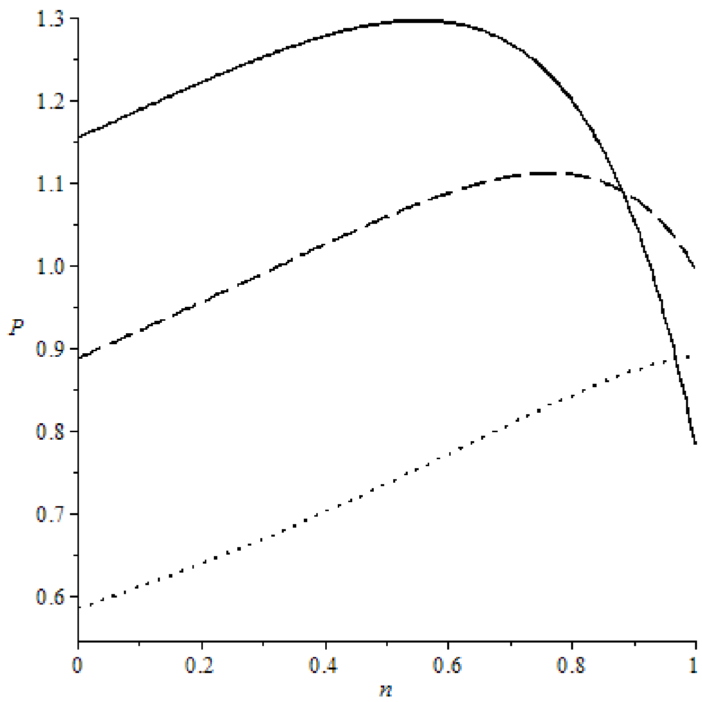

Fig. 1. Total pollution, P, when the network effect (n) increases for three values of the market dimension (a), given e=0.5.

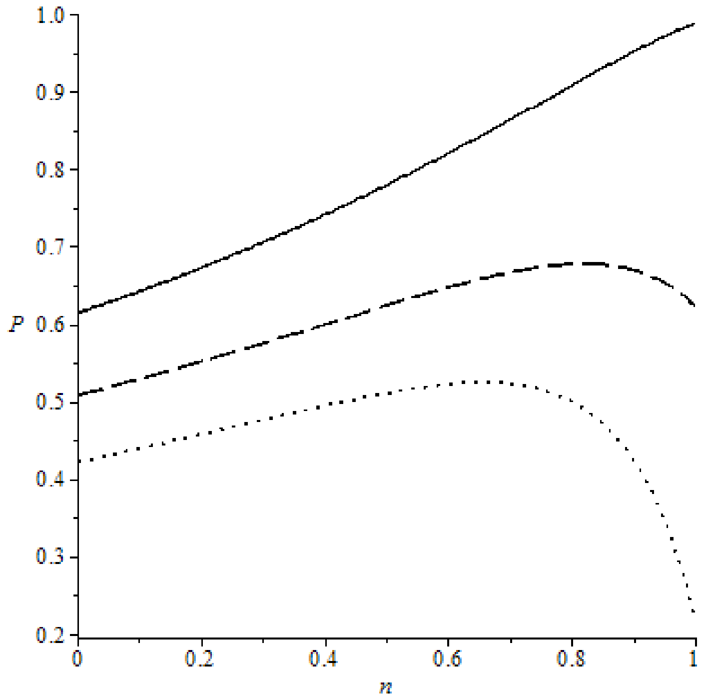

Fig. 2. Total pollution, P, when the network effect (n) increases for three values of the union's environmental concerns (e), given a=3.

In Figure 2, the upper solid line represents the case with a relatively low value of *e=0.4*; the intermediate dashed line represents the case with a relatively intermediate value of *e=0.8*; the lower dotted line represents the case with a relatively high value of *e=1.2*. Figure 2 clearly shows that, in the case of a union rather lowly "environmentalist", the total pollution in the presence of increasing network effects either always increases or in any case remains always higher than that of the case of standard goods, while if the union is relatively adequately "environmentalist" the total pollution may decrease (for high enough network effects) significantly below that produced by industries with standard goods.

4. Extensions

In the next, some extensions of the basic model are concisely discussed. In particular such a model is extended to consider *i)* different union's preferences, *ii)* an environmental standard set by a social-welfare maximising Government, and *iii)* a Cournot duopoly with differentiated product. [8]

4.1 General union utility function

The robustness of the results of the reference framework has been checked assuming a more general union's utility function, which attaches a different weight on the preferences over wages and employment level. Thus, the union's utility function in (5) (setting $w^{\circ}=0$ for analytical simplicity) is modified as follows

$$V^{S}=(w-ek)^{\theta}q^{(1-\theta)}, \tag{15}$$

[8] The analytical details are sometimes omitted to economize on space. Needless to say, those complete results are available from the authors upon request.

where the upper script stands for “sensitivity”. In fact, the parameter $\theta \in [0,1]$ represents the union’s wage sensitivity (or wage orientation): values of $\theta < (>) 0.5$ imply that the union is less (more) concerned about wages and more (less) concerned about jobs.[9] Moreover, it is worth to note that the parameter θ could also be interpreted as a crude measure of the union’s bargaining power in the case of a typical firm-union Nash bargaining over the wage, in the sense that a higher θ would approach a higher union’s power in wage negotiations.[10] Indeed, both the parameter measuring the union’s bargaining power and the parameter θ “will enter the Nash maximand in a mathematically similar way – and we might, in some applications, even choose the alternative interpretation of θ as reflecting the relative bargaining power of the trade union” (Lommerud and Straume, 2012, 184).

From (15), the maximization problem with respect to the wage level yields

$$w^S = a\theta + ek(1-\theta), \tag{16}$$

which shows that the optimal wage the union sets is a linear combination of the market size and the environmental damage. In particular, the more wage-oriented the union is, the less is worried about the environmental damage, and this implies that, in the presence of a wage-oriented union, the firm is less incentivized to reduce such a damage. Substitution of (16) in to the output expression in (8) gives production as a function of the cleaning technology

$$q^S(k) = \frac{(1-\theta)(a-ek)}{2-n}. \tag{17}$$

[9] Note that, when $\theta = 0.5$, this functional form represents the same union’s preferences given by (5). Moreover, the parameter θ may also indirectly represent the degree of 'insider' power, in the sense that the more important insiders into the unions are, the stronger is the union's preference for wages (all else equal) (e.g. Lommerud and Straume, 2012).

[10] In this model the introduction of a bargaining model over wages makes algebraically intractable the solutions. However, even assuming a monopoly union, one can think the parameter θ as a rough measure of the union’s bargaining power.

Substituting (16) and (17) into the monopolist profit function, subsequent maximisation with respect to the level of the cleaning technology leads to the optimal emission intensity

$$k^S = \frac{ae(1-\theta)^2 - z(2-n)^2}{e^2(1-\theta)^2 - z(2-n)^2}. \tag{18}$$

Substituting (18) backwards, the final equilibrium output is

$$q^S = \frac{z(1-\theta)(2-n)(a-e)}{z(2-n)^2 - e^2(1-\theta)^2} \tag{19}$$

Analytical inspection of (18) and (19) reveals that

$$\text{1) } k^S > 0 \Leftrightarrow a < a^{0S} = \frac{z(2-n)^2}{e(1-\theta)^2}$$

$$\text{2) } q^S > 0, \pi^S > 0 \Leftrightarrow e^2 < \frac{2(2-n)^2}{(1-\theta)^2}, e < a < a^{0S}, \tag{20}$$

from which it can be easily derived that the higher is the union's wage orientation, the larger is the feasible market size. Therefore, the wage sensitiveness represents a force that works in an opposite direction with respect to the network effects, in the sense that it tends to expand both the threshold values of the size of the market and the union's environmental interest for which the economy is feasible. A further investigation leads to the following Lemma:

Lemma 3. i) $\frac{\partial k^S}{\partial \theta} > 0, \frac{\partial q^S}{\partial \theta} < 0$; ii) $\frac{\partial k^S}{\partial n} < 0$, $\frac{\partial q^S}{\partial n} > 0$ iii) $\frac{\partial^2 k^S}{\partial n \partial \theta} > 0, \frac{\partial^2 q^S}{\partial n \partial \theta} < 0$.

The content of the part i) of Lemma 3 is expected: in fact, the higher the wage orientation, the higher the firm's costs and, therefore, 1) the lower the selected level of the abatement technology to reduce the fixed costs, 2) the lower the production. Also the part ii) is expected (because the union's preference do not change the role of the network effect already evidenced by Lemma 1). The part iii) says that, since the wage-oriented union is less interested to the environmental damage, then also the pressure of the network effect for reducing such a damage results to be weakened; moreover, since the wage-oriented union lowers output then also the output-increasing role of the network effect is weakened (as a simple visual inspection of (17) reveals). In other words, a wage-oriented union tends to dampen both the opposite effects of the network intensity highlighted in the previous section (e.g. Lemma 1), so that the net effect caused by the wage-aggressiveness on total pollution remains a priori ambiguous. However, the analytical investigation of the relationship between pollution and network reveals a clear-cut effect of the union's wage-orientation on the same, as below shown.

With regard to total emissions, using (18) and (19) it is obtained that

$$P^S = k^S q^S = \frac{z(2-n)(1-\theta)(a-e)\left[z(2-n)^2 - ae(1-\theta)^2\right]}{\left[z(2-n)^2 - e^2(1-\theta)^2\right]^2} \tag{21}$$

It is easy to show that if the network effect is absent (i.e. $n=0$), then the higher the union's wage-orientation is, the lower the pollution level is: this means that the reducing effect of higher wages on quantities overweighs that on the emissions abatement. However, when an increasing network effect is present, the things may change, as below shown:

$$\frac{\partial P^S}{\partial n} \underset{<}{\overset{>}{-}} 0 \Leftrightarrow a \underset{>}{\overset{<}{-}} a^{*S} = \frac{z(2-n)^2\left[z(2-n)^2 + 3e^2(1-\theta)^2\right]}{e(1-\theta)^2\left[3z(2-n)^2 + e^2(1-\theta)^2\right]},$$

with $a^{*S} < a^{0S}$, from which it follows that the higher the union's wage orientation is, the less likely is the occurrence of the pollution-reducing effect, i.e. $\frac{\partial a^{*S}}{\partial \theta} > 0$.

The intuition behind the latter result is as follows. On the one hand, a higher wage orientation moderates the union's perceived damage from pollution and lowers the choice of the abatement technology level, which tends to increase emissions; on the other hand, it decreases employment and output which, in turn, reduces emissions. Moreover, the union's wage-orientation weakens the established positive effects of network on emissions and on emissions abatement; however, it remains to establish which of the two effects is more weakened to reveal whether and how such a wage-orientation affects the relationship between pollution and network. In fact, as displayed in Fig. 3 below (drawn for a fixed levels of $z=1$), while in the absence of network effects the reducing effect of higher wages on quantities overweighs that on the emissions abatement, when the network effect is introduced and is increasing, the emissions abatement may be reduced more than the emissions, as the part iii) of Lemma 3 suggests, and as is clearly illustrated in Fig. 3 below, where (for example with $a=6$ and $e=0.5$) with a more wage-oriented union total pollution is lower when $n=0$ but becomes higher when n is beyond about *0.6*. The role played by the union's preferences on total pollution crucially depends on the intensity of the network effect, as summarized in the next remark.

Remark. When the network effect is not intense, the total pollution is lower if the union is wage aggressive; on the other hand, if the network effect is adequately intense, then the total pollution is lower if the union is employment oriented (see Figure 3 below).

If the goal is to reduce total pollution, then the policy implication is that in sectors with strong network externalities the presence of a union employment oriented should be preferred, while in sectors with low network effects is preferable a wage oriented

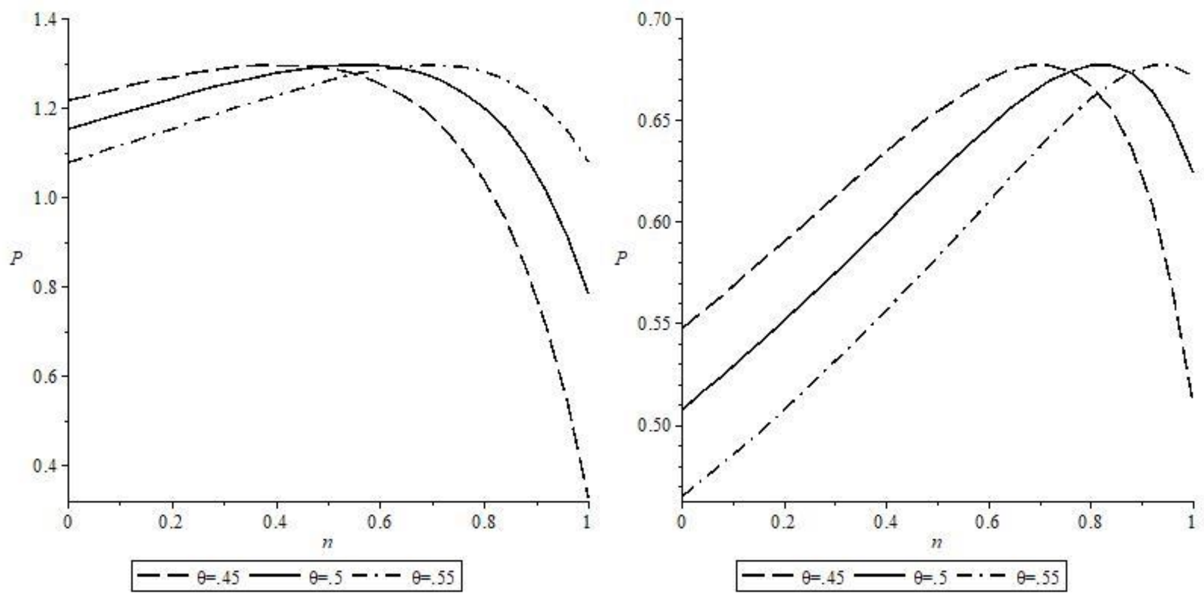

Fig. 3. Total pollution, P^S, when the network effect (n) increases for three values of the wage orientation parameter (θ). Left box: a=6, e=0.5; Right box: a=3, e=0.8.

union. For example, in Figure 3, left box, if $n = 0.1$ the total pollution is $P = 1.14$ when the union is relative wage oriented, and $P = 1.23$ when the union is relative employment oriented: on the other hand, if $n = 0.8$ the total pollution is $P = 1$ if the union is employment oriented and $P = 1.27$ if the union is wage oriented.

To sum up, the presence of network may still increase or reduce pollution, confirming the result of the previous section, but the higher the union's wage-orientation is, the less likely the network effect tends to reduce pollution.

4.2 Government's choice of the "environmental standard"

The model has been also extended to the case in which, rather than the firms, it is the Government that selects the abatement level (the "environmental standard") firms have to adopt in order to maximize the social welfare. In this case, using (9) and (10), it is obtained that the union utility, the profits and the consumer surplus (defined as $CS = \frac{(1-n)q^2}{2}$) are, respectively

$$V=\frac{(a-ek)^2}{4(2-n)},\ \pi=\frac{(a-ek)^2}{4(2-n)^2}-z(1-k)^2,\ \ CS=\frac{(1-n)(a-ek)^2}{8(2-n)^2}.$$

As a consequence, the social welfare is given by $SW=V+\pi+CS$. Maximization of social welfare with respect to k leads to

$$k^G=\frac{(3ae-32z)n-7ae+32z+8n^2z}{8n^2z+(3e^2-32z)n-7e^2+32z} \qquad (22)$$

where the upper script G stands for "Government". The positivity condition for (22) is ensured by the following inequalities:

$$1)\ e^2<\frac{4z(14-6n)(2-n)^2}{(7-3n)^2}$$

$$2)\ k^G>0\Leftrightarrow a<a^{0G}=\frac{8z(2-n)^2}{e(7-3n)}. \qquad (23)$$

A straight forward observation of a^{0G} and a^0 in (14) (see condition 1) reveals that, if the Government fixes the socially optimal cleaning technology, the market size feasibility is smaller than in the case in which the firm selects the level of cleaning technology to adopt, i.e. $a^{0G}<a^0$. Substitution of (22) into the expression for quantity leads to

$$q^G=\frac{4z(2-n)(a-e)}{8n^2z+(3e^2-32z)n-7e^2+32z} \qquad (24)$$

Having assumed that $a>e$, and recalling (23), also the positivity of quantity is ensured. Then, it is natural to compare the levels of polluting production and pollution abatement in the two cases of the choice of the cleaning technology by

Government and by firm. First, a direct comparison of k and k^G shows that $k > k^G$: the Government chooses a higher level of the abatement technology with respect to the firm. Second, a direct comparison of q and q^G shows that $q < q^G$: the output is higher when the Government chooses the abatement technology, because firms may produce more being higher the investment in cleaning technology.

The rationale for these comparative results is that the Government, on the one hand, reduces the emissions more than the firm because it is careful of the workers' utility (while the firm is careful only of the pollution damaging workers to the extent that the consequent higher wages damage own profits); however, on the other hand, it increases production because - considering the overall social welfare - has to take into account also the welfare of consumers that are not directly affected by pollution and can be interested in adequately large levels of output that lead to a lower market price.

Now, it is natural to ask for the role played by the network effect on the pollution when the cleaning technology is chosen by the Government and compare it with that of the case of cleaning technology chosen by firm. Therefore, the following holds:

Lemma 4: i) $\frac{\partial k^G}{\partial n} < 0$ and $\frac{\partial q^G}{\partial n} > 0$; ii) $\left|\frac{\partial k^G}{\partial n}\right| > \left|\frac{\partial k}{\partial n}\right|$ and $\frac{\partial (q^G - q)}{\partial n} < 0$.

Hence, as expected, the network effect still favours both the pollution abatement and polluting production; however, the former effect is more intense under the Government's cleaning decision, while the latter tends to become similar between the two cases when the network effect becomes more intense.

In other words, for an increasing network effect the abatement becomes more large under the Government's cleaning decision while the polluting output becomes very similar regardless of whether the cleaning decider is the Government or the firm. As a consequence, in the overall, we expect that the pollution-reducing effect of the network intensity is more likely under the Government's cleaning decision.

The total pollution level is the following:

$$P^G = k^G q^G = \frac{4z(2-n)(a-e)[8n^2 z + (3ae - 32z)n - 7ae + 32z]}{[8n^2 z + (3e^2 - 32z)n - 7e^2 + 32z]^2}. \quad (25)$$

Therefore, from (25), it is obtained that

$$\frac{\partial P^G}{\partial n} \underset{<}{\overset{>}{-}} 0 \Leftrightarrow a \underset{>}{\overset{<}{-}} a^{*G} = \frac{8z(2-n)^2(3e^2 n - 8n^2 z - 9e^2 + 32nz - 32z)}{e(48n^3 z + 3e^2 n - 312n^2 z - 7e^2 + 672nz - 480z)}.$$

It is straightforward to demonstrate that $a^{*G} < a^{0G}$, showing that the pollution-reducing effect of an increasing network intensity is more likely under the Government's cleaning decision, as above discussed.

Remark. As expected, the total pollution is lower if the Government establishes the "environmental standard". However, it is worth to note that, in the presence of network effects, the total pollution is significantly reduced with respect to the case in which the firm decides the level of emission's abatement (see Figure 4 below).

The policy implication is that, in sectors with strong network externalities, if the Government selects the abatement level (the "environmental standard"), the pollution reduction effect due to the network intensity is decisively more pronounced than in the case the firm chooses it. For example, looking at Figure 4, with standard goods (i.e. $n = 0$), the total pollution is $P^G = 0.9$ (Government) and $P = 1.29$ (firm). However, when $n = 0.9$, $P^G = 0.58$ and $P = 1.64$. Therefore, if the objective is to reduce the pollution, the Government's introduction of an "environmental standard" is rather successful. Figure 4 below shows the key (quantitative) difference between the models in which the Government selects the level of the technology adoption and that in which the firm chooses that level.

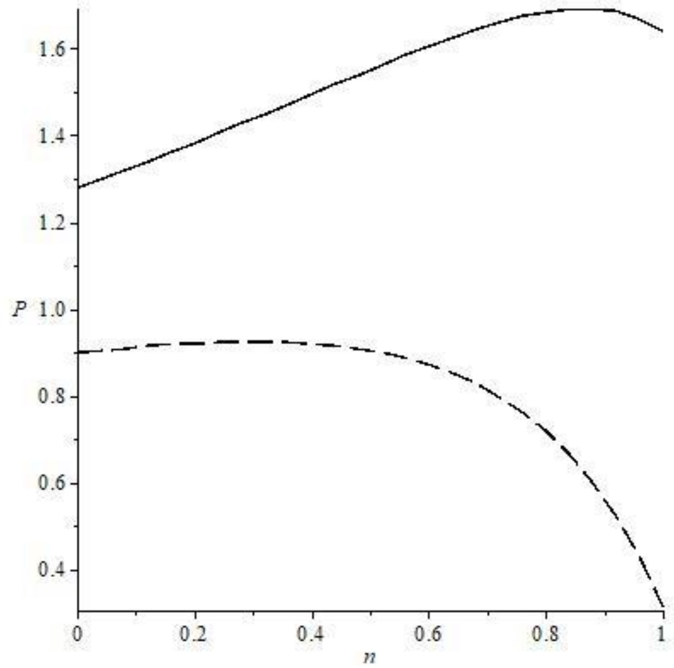

Fig. 4. Levels of total pollution, P^G and P, when the network effect (n) increases, for given a=6, e=0.3, z=1. Legend: solid line, technology level chosen by the firm; dashed line, technology level chosen by the Government.

Summarizing, the qualitative results obtained in the reference framework are confirmed also under this model's specification.

4.3 The duopoly case

Following the established literature (for instance, Hoernig 2012; Chirco and Scrimitore, 2013; and Battacharjee and Pal, 2014 develop a model of duopoly with network externalities), we consider a Cournot oligopoly with two unionized firms indicated by $i, j = 1, 2$ with $i \neq j$ producing heterogeneous goods. We assume that each duopolist firm faces the following inverse linear direct demand:

$$p_i = a - q_i - \gamma q_j + n(y_i + \gamma y_j) \tag{26}$$

where q_i is the quantity of the goods produced by firm *i*, p_i is the price, y_i is the consumers' expectation about firm i equilibrium production, and the parameter $\gamma \in (0,1)$ indicates the degree of product substitutability.

Each firm *i* may reduce emissions and choose its optimal level of pollution which entails a cost of pollution abatement (CA_i) assumed to be

$$CA_i = z(1-k_i)^2, \qquad z > 0. \tag{27}$$

We assume a centralised union,[11] which monopolistically fixes an uniform wage for workers of both firms. Keeping in-altered the motivations and simplifications discussed in the previous section for the monopoly case, the industry-wide union's utility function in the duopoly context becomes:

$$V = wq_i + wq_j - ek_iq_i - ek_jq_j. \tag{28}$$

The timing of the game is as follows. In the first stage, each firm non-cooperatively chooses the cleaning technology. In the second stage, the industry-wide union sets a common wage for both firms. The remaining stages are unaltered. We solve the game by backward induction to obtain a subgame perfect Nash equilibrium.

The profit function of firm *i* is

$$\pi_i = (a - q_i - \gamma q_j + n(y_i + \gamma y_j))q_i - wq_i - z(1-k_i)^2. \tag{29}$$

[11] This assumption under duopoly is the most coherent with the case of monopoly firm, because in the case of firm-specific unions in duopoly also the strategic effect of the inter-union competition over the wages would has been introduced, thus potentially obfuscating the comparison between monopoly and duopoly with regard to the relationship between network effects and pollution which is the focus of this paper. Of course also the assumption of firm-specific unions (made for instance by Asproudis and Gil-Molto, 2015, in their context) is worth to be explored in future works.

At the last stage, the firm's profit maximisation with respect to the quantity leads to the following output level, as a function of the output expectations:

$$q_i = \frac{(a - w - \gamma q_j + n(y_i + \gamma y_j))}{2}. \tag{30}$$

Solving the system composed by (30) and its counterpart for *j*, and imposing the "rational expectations" condition, $y=q$, the equilibrium quantities at the last stage are:

$$q_i(w) = \frac{a - w}{I}, \text{ where } I = 2 - n + \gamma(1 - n). \tag{31}$$

At the second stage, substituting (31) into (28), the following wage rate is obtained from the union utility maximisation:

$$w = \frac{2a + e(k_i + k_j)}{4}. \tag{32}$$

Therefore, substitution of (32) into (31) leads to the output as a function of the cleaning technology

$$q_i(k_i k_j) = \frac{2a - e(k_i + k_j)}{4I}, \tag{33}$$

and substitution of (33) into (29) yields profits, again as a function of the cleaning technology

$$\pi_i(k_i, k_j) = \frac{\left[2a - e(k_i + k_j)\right]^2}{16I^2} - z(1 - k_i)^2. \tag{34}$$

At the first stage, each firm *i*'s profit maximisation with respect to the level of the cleaning technology yields the following reaction functions in terms of the emission intensity

$$k_i(k_j) = \frac{e(2a - ek_j) - 16zI^2}{e^2 - 16zI^2}. \tag{35}$$

By solving the system composed by (35) and its counterpart for *j*, the following optimal emission intensity at the equilibrium is obtained

$$k_i = k_j = k^D = \frac{ae - 8zI^2}{e^2 - 8zI^2}, \tag{36}$$

where the upper script *D* denotes the duopoly case. Substituting (36) backwards, the final equilibrium of the game in terms of output is

$$q_i = q_j = q^D = \frac{4zI(a-e)}{8zI^2 - e^2} \tag{37}$$

Total pollution, *P*, is given by

$$P^D = 2k^D q^D = \frac{8zI(a-e)(8zI^2 - ae)}{\left(8zI^2 - e^2\right)^2}. \tag{38}$$

Recalling that $k > 0$, the conditions for a maximum as well as for the positivity of all variables boil down to the following set of inequalities:

i) $k^D > 0 \Leftrightarrow a < a^{\circ D} = \dfrac{8zI^2}{e}$

ii) $q^D > 0, \pi^D > 0 \Leftrightarrow e^2 < 8zI, e^{\circ D} < a < a^{\circ D}$ (39)

The analysis of the effect of network consumption externalities on the adoption of cleaning technologies, production, and total pollution under a duopoly leads to the following results and considerations.

Remark. The feasibility of the duopoly model is enlarged with respect to that of monopoly under network goods (relatively to standard goods), in the sense that the duopoly is workable with a larger market dimension and a higher environmental interest of the union (as easily observed by $a^{\circ} < a^{\circ D}$, $e^{\circ} < e^{\circ D}$).

Preliminarily, we may compare the levels of polluting output and cleaning technology obtained under Cournot duopoly and monopoly, respectively.

Lemma 5. Total quantity, as expected, is larger under duopoly than monopoly, i.e. $2q^D > q$.

Lemma 6. Firms invest in cleaning technology more under monopoly than duopoly, i.e. $k^D > k$.

Proof: The proof is straightforwardly obtained by comparison of the two values and omitted here for brevity.

The reason for the result that the unitary abatement of pollution is lower under duopoly is the following: i) at the intermediate stage, the union chooses the wage for given values of k_i, k_j, and the wage is increasing in both parameters; ii) therefore, since firms strategically choose their own level of *k*, each firm is less motivated to reduce its own pollution in order that the union reduces its wage claim because the latter reduction depends also on what will be the rival firm's choice of *k*. Moreover the following holds.

Corollary 1: The higher the product differentiation is, the closer between them the investments in cleaning technology are; however, in any case, also with total product differentiation ($\gamma = 0$), it holds that $k^D > k$ (i.e., Result 1).[12]

This is because, when $\gamma \to 0$, firms tend to be independent, that is, to become two unrelated monopolies. However, although unrelated in the product market, firms remain related in the labour market. Indeed, the crucial role played by the wage setting in the choice of *k* under duopoly is witnessed also by the fact that each independent monopoly sets an investment in cleaning technology (for the same strategic reasons above mentioned) lower than in the case of a single monopolist. The rationale for this result is that the industry-wide wage depends jointly on (the sum of) the abatement choices, and it is unaffected by the degree of market competition.

While the above mentioned facts (lower pollution abatement and large output in duopoly than monopoly) imply that the total pollution is always higher under duopoly than monopoly, the relationship between the network effect and the pollution remains qualitatively the same in both market structures. Indeed, from (36) and (37) it is easy to see that the network effect tends to increase both production and abatement of pollution, in line with the case of the monopoly, so that the effect of the network externalities on pollution is ambivalent also under duopoly. However, the following holds:

Result 2. *Under duopoly the network effect always increases (resp. decreases) the total pollution in the case of small (large) values of a, that is small (large) market size.*

Proof: Result 2 follows from $\frac{\partial P^D}{\partial n} \gtrless 0 \Leftrightarrow a \lessgtr a^{*D} = \frac{8zI^2(8zI^2+3e^2)}{e(24zI^2+e^2)}$.

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[12] The corollary follows by $\frac{\partial(k^D - k)}{\partial\gamma} < 0$ and $(k^D - k)\big|_{\gamma=0} > 0$.

Result 2 qualitatively confirms Result 1.

Moreover, we also state the following:

Result 4. *The network effect induces a pollution reduction under duopoly when the market size is larger than under monopoly, that is* $a^{*} < a^{*D}$.

On the other hand, as stated in the above remark, also the threshold value of the market size ensuring the feasibility of the market model is larger under duopoly than monopoly. However, we can see that, in the overall, the parametric set for which the pollution-reducing effect appears is larger under duopoly than monopoly, and this difference shrinks with an increasing product differentiation.

Result 5. *i) The network effect reduces pollution more under duopoly than monopoly; ii) the more differentiated the products are, the weaker the statement in part i) is.*

Both parts i) and ii) follow from a simple visual inspection of the parametric regions which depict the signs of the relationship between network effect and level of pollution, comparing - as regards the part i) - Fig. 5 a) duopoly and Fig. 5 b) monopoly, and - as regards the part ii) - Fig. 6 a) $\gamma=1$ and Fig. 6 b) $\gamma=0.05$, below.[13] Indeed, Fig. 5 neatly shows that the feasibility and, more importantly, the parametric region where the relation "more network externality-less pollution" holds are larger under duopoly. As Fig. 6 shows, the product differentiation tends both to reduce the threshold levels of the market size and to shrink the parametric areas making them close to (but always larger than) those of the monopoly case. This is intuitive because the higher the product differentiation is the more duopoly tends to monopoly.

[13] Obviously a more formal proof – omitted here for brevity - of the statement of the Result 5 could be obtained evaluating the parametric areas A and B either under duopoly and monopoly, respectively, (Fig. 5) or with γ=1 and γ=0.05, respectively, (Fig. 6) through the corresponding integrals; however, in this case, the visual inspection provides a self-evident result.

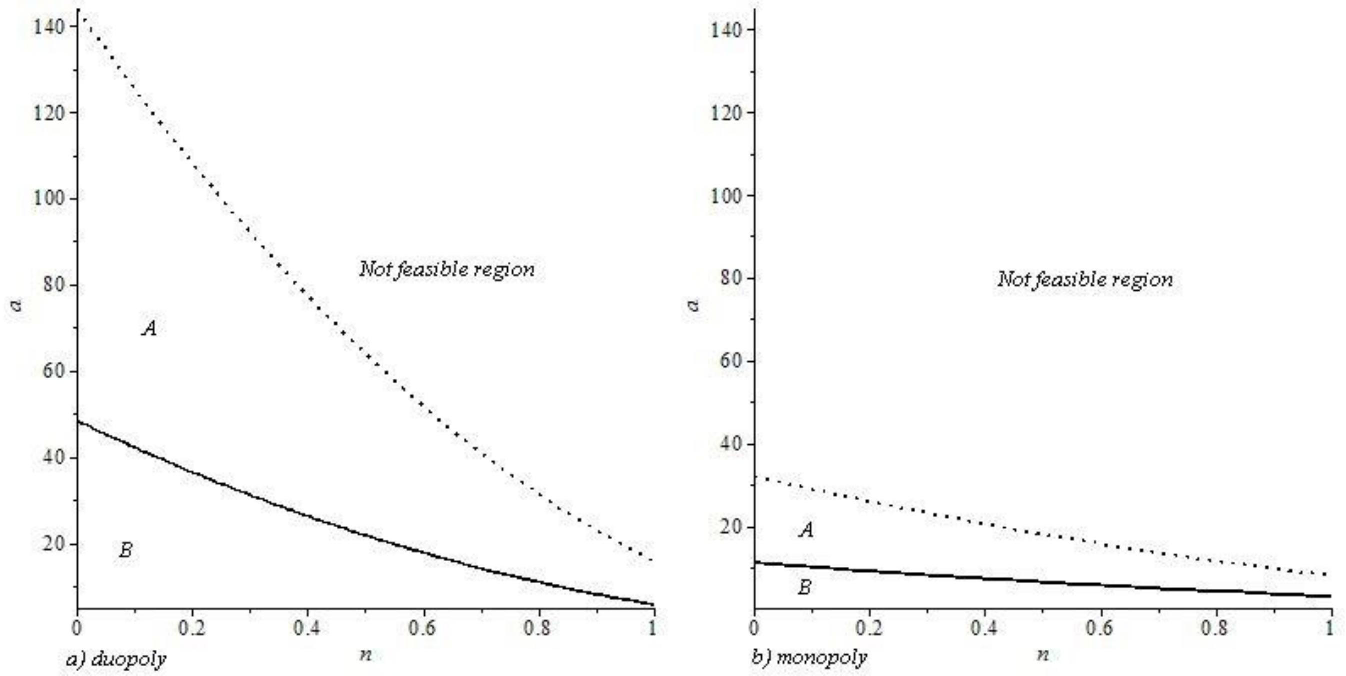

Figure 5: Plots of the regions with opposite effects of the network externalities on total pollution, in the plane (n,a). Parameter set: z=1, e=0.5, γ=1. The curves represent: i) a^{*D} (solid line) and $a^{\circ D}$ (dotted line) in a) duopoly; ii) a^{*} (solid line) and a° (dotted line) in b) monopoly. Legend: a)duopoly: A= region in which $\frac{\partial P^D}{\partial n} < 0$, B= region in which $\frac{\partial P^D}{\partial n} > 0$; b) monopoly: A= region in which $\frac{\partial P}{\partial n} < 0$, B= region in which $\frac{\partial P}{\partial n} > 0$.

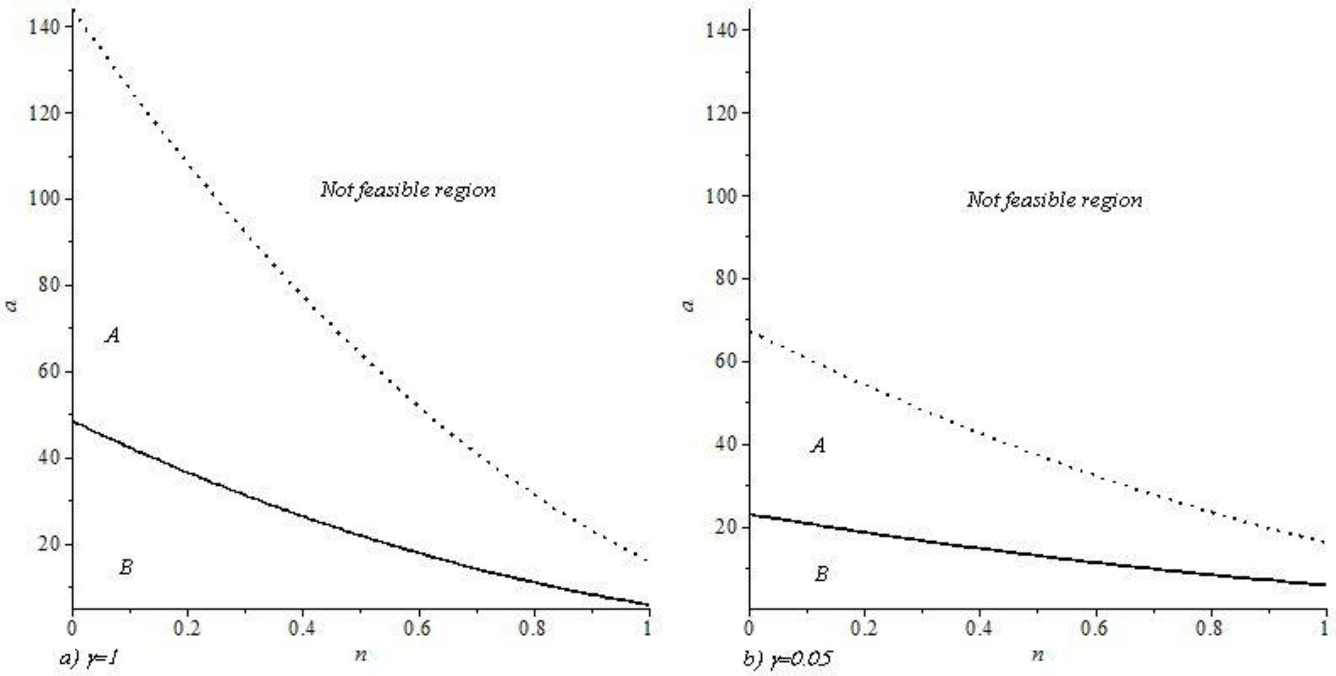

Figure 6: Plots under duopoly of the regions with opposite effects of the network externalities on total pollution in the plane (n,a), for products perfect substitutes (left box: a) γ=1) and strongly differentiated (right box: b) γ=0.05). Parameter set: z=1, e=0.5. The curves represent a^{*D} (solid line) and $a^{\circ D}$ (dotted line). Legend: a) γ=1: A= region in which $\frac{\partial P^D}{\partial n} < 0$, B= region in which $\frac{\partial P^D}{\partial n} > 0$; b) γ=0.05: A= region in which $\frac{\partial P}{\partial n} < 0$, B= region in which $\frac{\partial P}{\partial n} > 0$.

To sum up, the results discussed in the previous section for the case of a monopoly firm, are qualitatively confirmed also in the case of duopoly both with homogeneous and differentiated products.

5. Concluding Remarks

In a network industry, this paper has investigated whether and how the intensity of the network effects affects the total pollution when in the manufacturing plant a union interested to “local” environmental damages, that is polluting production processes damaging workers’ health and the local environment where workers live, is active. In the local monopoly model proposed, the paper has shown that, on the one hand, the network effects tend to increase the investments in the cleaning technology; however, on the other hand, network externalities increase the polluting output as well. Therefore, the impact of network externalities on the total pollution is in principle ambiguous. However, the analysis has shown under which conditions total pollution increases/decreases. In particular, we have shown that total pollution decreases (resp. increases) with an increasing intensity of the network effects if the size of the market is adequately large (resp. small) because, in this case, the incentivising (dis-incentivising) effect of adopting the cleaner technology outweigh the polluting effect due to output expansion. Moreover, it has been shown that the pollution-reducing result of the increasing network effects is more likely to appear when the existing network effects, the union's environmental concerns and the technological efficiency are adequately large. Therefore, given a Government interested in reducing the total pollution in network industries, the policy insight is to give support to the environmentalism of the green union. The reference framework has been extended to different model’s specifications, and precisely to 1) the case of a more general union utility function with different wage sensitivity. It has been found that if the network effect is weak, a wage oriented union leads to a relatively low pollution level than an employment oriented; the opposite holds true if the network effect is strong; 2) the Government selection of the level of technology adoption. In this case, the key finding is that if the Government establishes the “environmental standard” then the total pollution is lower than when the firm select it, and the network externalities significantly intensify the total pollution reduction effect; and 3) a duopoly market structure with differentiated products. It has been shown that the network effect reduces pollution more under duopoly than monopoly, and the more the goods are differentiated, the weaker the reduction effect on pollution is.

To sum up, the qualitative findings of the basic model have been confirmed also under those extensions, providing a first robustness check**.**

Nonetheless, as future lines of research, the present model can be extended to *i)* a more competitive (oligopoly) market structures and alternative modes of competition (Cournot vs. Bertrand), to investigate the condition under which different strategic contexts in the product market can change the results obtained under monopoly and Cournot duopoly; *ii)* an analysis of different bargaining agendas between the firm(s) and the union(s), relaxing the assumption of a monopoly union; *iii)* an analysis of different workers' pay systems such as the piece rate pay and the profit-sharing scheme, relaxing the assumption of a fixed wage system; *iv)* an investigation of how the organizational form of the company has an impact on total pollution (e.g. the presence of a manager to whom the firm’s owners delegate decisions about the amount of sales/production levels and/or the adoption of cleaner technologies or the case for cross-ownership); *v)* the analysis of the introduction of public policies such as tax/subsidy environmental policies.

Compliance with Ethical Standards:

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