

Fanti, Luciano; Buccella, Domenico

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Pollution, green union, and network industry**Contaminación, sindicato verde e industria de redes*LUCIANO FANTI**
DOMENICO BUCCELLA*****Abstract**

In a network industry, this paper investigates the impact of network effects on 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, on the one hand, network effects tend to increase the investments in the cleaning technology but, on the other hand, increase the polluting output; consequently, the effects on the total pollution are ambiguous. We also find that total pollution reduces (increases) with increasing network effects intensity if the market is sufficiently large (small). Moreover, the pollution-reducing result of increasing network effects appears when the existing network effects, the union’s environmental concerns and the technological efficiency are sufficiently large. These findings are qualitatively confirmed under Cournot duopoly, offering empirical, as well as policy, implications.

Key words: Network goods, Cleaning technology, Pollution production, Green Unions, Monopoly, Cournot duopoly.

JEL Classification: *J51, L12, Q52.*

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** Department of Economics and Management, University of Pisa, Via Cosimo Ridolfi, 10, I-56124 Pisa (PI), Italy. E-mail address: lfanti@ec.unipi.it; tel.: +39 050 22 16 369; fax: +39 050 22 16 384.

*** (Corresponding author), Department of Economics, Kozminski University, Jagiellońska Street, 57/59 – 03301 – Warsaw, Poland. E-mail: buccella@kozminski.edu.pl; tel.: + 48 22 51 92 153.

Resumen

Este documento investiga el impacto de los efectos de la red en la contaminación total bajo la presencia de un sindicato interesado en los daños ambientales “locales” (por ejemplo, contaminar los procesos de producción que dañan la salud de los trabajadores y el medio ambiente local). En régimen de monopolio, se demuestra que, por una parte, los efectos de red tienden a aumentar las inversiones en la tecnología de limpieza pero, por otra, a aumentar la producción contaminante; en consecuencia, los efectos sobre la contaminación total son ambiguos. También encontramos que la contaminación total se reduce (aumenta) con el aumento de la intensidad de los efectos de red si el mercado es lo suficientemente grande (pequeño). Estos hallazgos se confirman cualitativamente bajo el duopolio de Cournot, ofreciendo implicaciones empíricas y políticas.

Palabras clave: Bienes de red, Tecnología de limpieza, Producción de contaminación, Sindicatos Verdes, Monopolio, Duopolio de Cournot.

Clasificación JEL: J51, L12, Q52.

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 assemble 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 cases, adopt polluting production processes generating highly pollutant local emissions.

As a consequence, the topic of environmental safety has become of great importance on the political as well as popular debate in several industrialised countries. In those countries, the presence of trade unions in imperfectly competitive markets, mainly monopolies and oligopolies, is widely observed (Booth, 1995). The present paper aims to answer the following research question: in a network industry with the presence of an environmentally oriented union, may the intensity of the network effect reduce total pollution?

To study the subject of environmental safety is crucial because 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. Up to date, not much attention has been devoted to the role organised workers, in the form of a union, play in such polluting milieu.

Workers were interested in improving their working place in some critical industries, for instance those at contact with asbestos, a cancer-causing agent; they were collectively asking for more protection and this happened prior to the embedment of environmental issues in the bargaining agenda (Henri, 2007). 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), and to promote a “*Green collective bargaining*” which includes the climate change issue during the negotiation processes at the workplace and collective level to tie environmental solutions to social commitment to remodel the economic efficiency of innovative organizations (EPSU, 2017). For example, with regard to the issue of working in a safe and healthy environment, in 2014, after a five-month 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).

Other examples, related to the issue of carbon emissions reduction, are the following. Unions at British Telecom (BT), through the Trade Union Congress’ national GreenWorkplaces Project, put in place an action to “green” the Adastral Park, BT’s research and development headquarters. The main objective is to reduce the Park’s environmental (carbon footprint) impact (TUC, 2010).

Environmental issues at Électricité de France (EDF), in 2009 the world’s largest producer of electricity, are widely discussed by trade unions at every level, from global to national. EDF operates in several countries: in some of them, as a significant player; in France, almost as a monopolist.¹ In January 2005, EDF signed a global agreement with unions on Corporate Social Responsibility (CSR). In UK, the EDF Company Council is the main union/management consultation body devoted to raise environmental questions; however, regular (quarterly) meetings are also arranged with CSR delegates from the four active unions (GMB, UNISON, Prospect and Amicus, now Unite), to discuss and review sustainability issues and goals. The agreement signed in 2005 covers areas such as fundamental rights, employee relations, community responsibilities, relations with subcontractors. Concerning the environment, EDF committed to guarantee the safety of its facilities to protect local and wider communities, to take model actions in the environmental area, and to promote energy efficiency for clients and within the group. In 2009, the agreement was revised, and the section on environmental issues was reinforced with precise references to counteracting climate change and reducing CO2 emissions. Nonetheless, this global agreement has a direct impact at national level: in fact, it requires that in each country “at a

¹ As of 2017, EDF retains 85.5% of France residential customers (Financial Times, 2018)

minimum” there must be “an annual written review” of progress, which should be sent to the employee delegates in charge of CSR monitoring (TUC, 2014).

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/national damages has been mainly ignored in spite of the fact that: 1) a single giant plant can heavily damage the “local/national” 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.

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. In a context with polluting giant plants, this means that workers are “selfish” in having preferences with environmental concerns² while consumers can be not damaged by pollution.³

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.⁴ Exceptions are the contributions of Frederiksson and Gaston (1999) and, recently, Asproudis and Gil-Moltó (2015) and Fanti and Buccella (2017).⁵

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 Cournot duopoly in which firms produce standard goods, Asproudis and Gil-Moltó (2015) investigate, from an industrial organisation perspective, the effects of unions having environmental concerns on firms’

² 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.

³ This assumption is 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.

⁴ For instance, Silverman (2006), Obach (1999) and the works quoted in Asproudis and Gil-Moltó (2015).

⁵ As the previously discussed EDF case suggests, this approach with environmentalist unions and firms’ pollution abatements could be also related to another recent strand of industrial organization literature focusing precisely on 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 activities. See Kitzmuller and Shimshack (2012), and Schmitz and Schrader (2015) for a recent literature survey on CSR.

decisions about cleaner technologies, output, and pollution levels. Those authors focus on the impact that alternative union structures, i.e., decentralized, and centralized union's wage setting, can have on firms' choices concerning "green" technologies. They show that a decentralized structure provides higher incentives for the investment in cleaner technologies, although emissions may be lower under a centralized structure. Moreover, the impact of the environmental damage parameter on wages and output can be non-monotonic.

Revisiting Asproudis and Gil-Moltó (2015), Fanti and Buccella (2017) investigate in a monopoly context whether and how the presence of a "green" union interested in "local" environmental damages (e.g., polluting production processes damaging workers' health and the local environment where workers live) affects the welfare of single agents—firms, consumers, and workers—and society as a whole. Those authors show that, under monopoly, the union's environmental concerns, depending on the market size, may incentivize or discourage the investments in cleaner technology and rather counter-intuitively, even increase the total environmental damage.

However, the above-mentioned authors study the presence of "green unions" in markets in which standard goods are produced. The main contribution of the present work is to introduce into the analysis the network effects, extending in this sense the framework of Asproudis and Gil-Moltó (2015). In particular, the analysis focuses both on the cases of monopoly and duopoly market structures. Moreover, we do not consider different wage settings in duopoly, but we restrict our attention to the centralized union wage setting in duopoly. In fact, our focus is on the relationship between the presence of network goods and green unions, and the level of total polluting emissions, which has remained so far unexplored.

As known, the network effect increases the consumers' demand and total output. Because the output is polluting, then a summary answer could be that pollution tends to increase. However, the analysis shows that, if the network effects are adequately strong, they incentivize firms to adopt clean technologies and to abate more than the firms in standard industries studied by Asproudis and Gil-Moltó (2015). The net effect of the presence of network externalities on the industrial pollution is *a priori* ambiguous. 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 technology can outweigh the increased pollution due to the increased production.⁶ These findings are qualitatively confirmed also under the Cournot duopoly.

⁶ 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

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 monopoly model with green unions and network goods and presents the results of the analysis. Section 3 develops the duopoly model. Section 4 briefly discusses the policy implications. Section 5 brings the paper to its conclusion with some final observations and an outline of the potential future lines of research with regard to this subject.

2. THE MONOPOLY 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 inverse demand function:

$$(1) \quad p = a - q + ny$$

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).

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 eliminate emissions from production does not exist.

workers) explains the importance of the market size for the occurrence of the pollution-reducing effect.

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

$$(2) \quad CA = z(1 - k)^2, z > 0$$

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.⁷

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 the assumption of constant returns to scale in labour, output and employment are equivalent, i.e. $q=l$.

This utility function exhibits the union's interest both for wage and employment. Nevertheless, the union may also care about the quality of the environment, as the examples reported in the Introduction 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:

$$(3) \quad V = (w - w^\circ - ek)q$$

In this regard, the parameter e is a measure of the relative union's orientation towards environmental safety, and the term ek in (3) can be interpreted as a non-constant reservation wage which increases in the externality work produces. To

⁷ 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.

ensure non-negativity on output, we assume that $a > e$. Moreover, as usual, and without loss of generality, we set $w^o = 0$ 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), the “rational expectations” realize, 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

$$(4) \quad \pi = (a - q + ny)q - wq - z(1 - k)^2$$

At the fourth stage, the monopolist chooses the quantity to maximize profits, and the subsequent imposition at the third stage of the “rational expectations” condition, $y=q$, leads to the equilibrium quantities

$$(5) \quad q(w) = \frac{a - w}{2 - n}$$

At the second stage, substituting (5) into (3), the union utility maximisation yields the wage rate:

$$(6) \quad w = \frac{a + ek}{2}$$

with $\frac{\partial w}{\partial a} > 0$, $\frac{\partial w}{\partial e} > 0$, and $\frac{\partial w}{\partial k} > 0$. The intuition behind these comparative statics are as follows. First, the higher the market size, the higher the consumers’ willingness to pay; therefore, the union can fix a higher wage to catch a larger share of the monopoly rent. Second, the higher the environmental damage is, the higher the wage the union claims to compensate the disutility of pollution. Third, the cleaner the technology the monopolist uses, the lower the wage the union can claim as a compensation for the disutility caused by pollution (Asproudis and Gil-Moltó, 2015).

Making use of (5) and (6), at the first stage, the monopolist’s profit maximisation with respect to the cleaning technology leads to the optimal emission intensity

$$(7) \quad k = \frac{4z(2 - n)^2 - ae}{4z(2 - n)^2 - e^2}$$

Substituting (7) backwards, the final equilibrium of the game in terms of output is

$$(8) \quad q = \frac{2z(2-n)(a-e)}{4z(2-n)^2 - e^2}$$

Total pollution, P , is given by

$$(9) \quad P = kq = \frac{2z(2-n)(a-e)[4z(2-n)^2 - ae]}{[4z(2-n)^2 - e^2]^2}$$

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:

$$(10) \quad \begin{aligned} 1) \quad k > 0 &\Leftrightarrow a < a^0 = \frac{4z(2-n)^2}{e} \\ 2) \quad q > 0, \pi > 0 &\Leftrightarrow e^2 < 4z(2-n)^2, e < a < a^0 \end{aligned}$$

By interpreting the parameter a as the size of the market, conditions (10) 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. The following Remark follows.

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 (10)).

2.1. 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 in the network effect (n) at an increasing rate.*

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

This lemma shows that the network externality has two contrasting effects on pollution. In fact, the monopolist's emissions are given by $P = kq$, with both k and q that depend on the network effects, n : a positive impact on emissions via output expansion, but a negative impact on them via the monopolist's incentive to choose a "greener" technology. Despite the expansion of the polluting production, we are able 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:

$$\frac{dP}{dn} = \frac{\overline{\partial q}}{\partial n} k + \frac{\overline{\partial k}}{\partial n} q.$$

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 $\frac{\partial P}{\partial n} > 0 \Leftrightarrow a < a^*$ $\frac{\partial P}{\partial n} < 0 \Leftrightarrow a > a^* = \frac{4z(2-n)^2 [4z(2-n)^2 + 3e^2]}{e [12z(2-n)^2 + e^2]}$, where $a^* < a^0$; the second part is obtained from $\frac{\partial a^*}{\partial n} < 0, \frac{\partial a^*}{\partial z} > 0, \frac{\partial a^*}{\partial e} < 0$.

A first conclusion arising from Result 1 is intuitive: if the market size is not sufficiently large, the monopolist is not incentivised to invest in efficient cleaner technology. Consequently, the firm's total emission level is not reduced. Moreover, the presence of network externalities induces the firm to adopt a cleaner technology for a market size smaller than in an industry that produces standard goods.

Second, the derivative of the emissions with respect to the size of the network externality can be positive or negative depending on the strength of the network effect, n , provided that the market size is large enough. Specifically, there is a critical value of the size of the market a^* before (beyond) which emissions are increasing (decreasing) in the intensity of the network effect. The intuition behind this result is as follows. As the analytical inspection of total derivative $\frac{dP}{dn}$ shows, n has a positive effect on emissions via output expansion, but a negative effect via the technology choice. An increase in the network effects leads the monopolist to expand output which, as known, has a twofold impact on a firm's revenues. On the one hand, the positive direct effect due to the increase in production, and this leads to more emissions. On the other hand, there is the negative, indirect price effect. When the network

effects are strong, the negative price effect becomes relevant, and this second effect can outweigh the former; to increase profitability, the monopolist invests more in cleaning technologies which has the effect of reducing wages, and therefore reducing the operative costs.

Lemma 2. *Provided that $a \geq a^*$, the larger the market size is, the larger is the differential between the marginal benefit on the environment due to the investment in cleaning technologies and the marginal damage due to production expansion (both generated by the network effect).*

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

When the market size is sufficiently large, the increase in production levels due to the network effect, total pollution decreases thanks to the more intense investment in technologies related to pollution abatement. This contrasts with the common wisdom concerning the output expansion effect on pollution due to network externalities. 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, and the small impact in reducing operative costs, i.e., wages.

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 (to moderate wages) and to reduce employment/output (or to increment employment/output less than the abatement), 2) when abating is cheaper.⁸

3. THE DUOPOLY MODEL

In the next, we analyse a Cournot duopoly with differentiated product.⁹ Following the established literature (for instance, Hoernig 2012; Chirco and Scrimatore, 2013; and Battacharjee and Pal, 2014), we consider a Cournot oligopoly with two unionized firms indicated by $i, j = 1, 2$ with $i \neq j$ producing

⁸ In the Appendix B, we have tested some extensions of the basic monopoly model. In particular we have considered 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) an environmental standard set by a social-welfare maximising Government: 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 selects it, and the network externalities significantly intensify the total pollution reduction effect. These models' specifications confirm the qualitative results obtained in the basic framework here presented.

⁹ The analytical details are sometimes omitted to economize on space. Needless to say, the complete results are available from the authors upon request.

heterogeneous goods. We assume that each firm in this duopoly faces the following inverse linear direct demand:

$$(11) \quad p_i = a - q_i - \gamma q_j + n(y_i + \gamma y_j)$$

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

$$(12) \quad CA_i = z(1 - k_i)^2, \quad z > 0.$$

We assume a centralised union,¹⁰ which monopolistically fixes a 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:

$$(13) \quad V = wq_i + wq_j - ek_i q_i - ek_j q_j.$$

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

$$(14) \quad \pi_i = (a - q_i - \gamma q_j + n(y_i + \gamma y_j))q_i - wq_i - z(1 - k_i)^2.$$

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:

$$(15) \quad q_i = \frac{(a - w - \gamma q_j + n(y_i + \gamma y_j))}{2}.$$

¹⁰ 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 have been introduced, thus potentially obfuscating the comparison between monopoly and duopoly regarding 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-Moltó, 2015, in their context) is worth to be explored in future works.

Solving the system composed by (15) and its counterpart for j , and imposing the “rational expectations” condition, $y=q$, the equilibrium quantities at the last stage are:

$$(16) \quad q_i(w) = \frac{a-w}{I}, \text{ where } I = 2-n+\gamma(1-n)$$

At the second stage, substituting (16) into (13), the following wage rate is obtained from the union utility maximisation:

$$(17) \quad w = \frac{2a+e(k_i+k_j)}{4}$$

Making use of (16) and (17), one gets the output as a function of the cleaning technology, and subsequent substitutions into (14) yields profits, again as a function of the cleaning technology

$$(18) \quad \pi_i(k_i, k_j) = \frac{[2a - e(k_i + k_j)]^2}{16I^2} - z(1 - k_i)^2$$

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

$$(19) \quad k_i(k_j) = \frac{e(2a - ek_j) - 16zI^2}{e^2 - 16zI^2}$$

By solving the system composed by (19) and its counterpart for j , the following optimal emission intensity at the equilibrium is obtained

$$(20) \quad k_i = k_j = k^D = \frac{8zI^2 - ae}{8zI^2 - e^2}$$

where the upper script D denotes the duopoly case.

Comparing eq. (20) here with eq. (20) concerning the identical context in Asproudis and Gil-Moltó (2015), one can easily derive that $k_i^{NI} \leq k_i^{SI}$ if $n^T \geq \frac{1+2\gamma}{2(1+\gamma)}$, where “ NI ” stands for network industry while “ SI ” stands for standard industry. Note that the threshold value of the network effect, n^T , is independent of the market size, the union's orientation toward the environment, and technology efficiency. In other words, the presence of network externalities induces firms to invest more in cleaner technology if the network effects are adequately strong. The forces that lead to this result mirror those of the monopoly case.

Substituting (20) backwards, the final equilibrium of the game in terms of output is

$$(21) \quad q_i = q_j = q^D = \frac{4zI(a-e)}{8zI^2 - e^2}$$

Total pollution, P , is given by

$$(22) \quad P^D = 2k^D q^D = \frac{8zI(a-e)(8zI^2 - ae)}{(8zI^2 - e^2)^2}$$

A comparison of the emission levels per firm here (i.e. half of the value in the expression (22)) with those regarding the same framework in Asproudis and Gil-Moltó (2015), reveals that $k_i^{NI} q_i^{NI} \leq k_i^{SI} q_i^{SI}$ if $n \geq n^{TT}(a, e, \gamma)$, where the threshold value of the network effect, $n^{TT}(a, e, \gamma)$, has an extremely analytical complex form. To derive some qualitative conclusions, we have performed a set of numerical simulations, whose graphical analysis (see Appendix B) led to the following conclusions. When the cleaning technology is not efficient, the pollution network industries generate is higher than the one in standard industries. However, when the available “green” technology is efficient, then network industries pollute less than standard ones if the network externalities are adequately high.

The mechanism that leads to this result is like the one described above concerning the cleaning technology choice. When the cleaning technology is inefficient, the output expansion effect due to the network externalities yields high pollution levels. However, the technology inefficiency does not induce firms to adopt it to reduce wages: therefore, pollution remains relatively high. On the other hand, when the “green” technology is sufficiently efficient, when the network effects are strong, the negative price effect on revenues is relevant. Firms are incentivized to invest more in cleaning technologies; these lead both to the reduction of the firms’ operative costs and emissions. Therefore, pollution can be lower than in standard industries, provided that the network effects are adequately strong.

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:

$$(23) \quad \begin{aligned} i) \quad k^D > 0 &\Leftrightarrow a < a^{\circ D} = \frac{8zI^2}{e} \\ ii) \quad q^D > 0, \pi^D > 0 &\Leftrightarrow e^2 < 8zI, e^{\circ D} < a < a^{\circ D} \end{aligned}$$

3.1. Results

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 3. As expected, total quantity is larger under duopoly than monopoly, i.e. $2q^D > q$; however, firms invest more in cleaning technology 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).¹¹

This is because, when $\gamma \rightarrow 0$, 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

¹¹ The corollary follows by $\frac{\partial(k^D - k)}{\partial\gamma} < 0$ and $(k^D - k)|_{\gamma=0} > 0$.

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 (20) and (21) 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.*

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

As for the case of monopoly, if the market size is not adequately large, the duopolistic firms have no incentives to invest in “green” technologies, and therefore total emissions do not reduce. The forces at work that lead duopoly firms to make the output and abatement choices such that Result 2 arises mirror those of the monopolist firm in Result 1. However, a further analytical inspection reveals the next result.

Result 3. *The network effect induces a pollution reduction under duopoly when the market size is larger than under monopoly, that is $a^* < a^{*D}$.*

Proof: Result 3 follows from simple comparison.

As stated in the previous remark, the threshold value of the market size ensuring the feasibility of the model is larger under duopoly than monopoly and Result 3 is strictly connected to that finding. Overall, the parametric set for which the pollution-reducing effect appears is larger under duopoly than monopoly. Nonetheless, this difference shrinks with an increasing product differentiation: in fact, as goods become more differentiated, each firm acts like a monopolist for its own product. The intuition behind these findings is straightforward.

Total output in a duopoly industry is typically larger than in a monopoly due to the firms’ rivalry. The presence of network effects pushes outward the duopoly firms’ reaction functions, i.e., $\frac{\partial q_i(q_j)}{\partial n} > 0$, so that the equilibrium point is farther from the origin in the output space than in an industry with standard goods: the relevant market size increases. As for the monopoly, the total derivative $\frac{dP}{dn}$ reveals that n has a positive effect on emissions via output expansion, but a negative effect via the technology choice. An intensification of the network externalities induces

each firm to increase production which has a double impact on revenues: 1) the positive direct effect due to the increase in production, magnified by competition, and this leads to more emissions; 2) the negative, indirect price effect, also this magnified by increased competition. When network externalities are adequately strong, the negative price effect, now amplified by duopoly competition, becomes significant, and offset the direct output effect. As a consequence, to improve profitability, firms invest more in “green” technologies to curb the union’s wage demand, and thus cut their operative costs.

Result 4. *Provided that the available technology is not extremely efficient: 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.*

Proof: See Appendix A.

Concerning part i), the intuition behind this finding is that, in the presence of an efficient technology, the monopolist faces a substantial reduction in its “green” investment; moreover, it is more incentivized to choose higher abatement levels to reduce operative costs than a duopoly firm. As regards part ii) of Result 4, this finding is intuitive because the higher the product differentiation is, the more a duopoly tends to a monopoly. 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.

4. POLICY CONSIDERATIONS AND EMPIRICAL IMPLICATIONS

To derive some policy implications, we consider the case of a benevolent social planner whose aim is to maximize social welfare.

The social planner’s optimization problem is to choose the output and the abatement level that maximize the following expression:

$$SW = \pi + V + CS$$

i.e., the sum of the monopolist profits, the union utility (which embeds the environmental damage) and the consumer surplus in the case of monopoly and

$$SW = \pi_i + \pi_j + V + CS$$

in the case of duopoly. As in Asproudis and Gil-Moltó (2015), we obtain that the social optimum is characterized by output and investment levels higher than the market ones (underproduction and underinvestment), with network externalities expanding these discrepancies.¹²

¹² Analytical details are available upon request from the authors.

However, the findings of this work suggest the following policy insights. If the government has the objective of improving the environmental quality through emissions reduction, it should prop up the demand facilitating the customers' access to the network of compatible products (e.g. in the case of telecommunications, installing repeaters in zones with feeble signal). This would expand the market size to such an extent that firms are incentivized to invest in "green" technologies, therefore reducing total pollution. Therefore, the government's interest would coincide with that of the environmentally oriented union. Moreover, the government should design the proper regulations to incentivize the firm's adoption of clean technologies.

Moreover, this work also suggests the following empirically testable implications: 1) in network industries, environmental unions should be broadly seen active in large plants serving adequately large markets; the role of the network externalities is that of increasing the relevant market size; and 2) in network industries with sufficiently intense externalities, the presence of "green unions" should induce firms having a large pool of consumers (that network externalities crucially contribute to expand) to allocate more resources for investments in "green" technologies than firms producing standard (i.e., no network) goods.

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. 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 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 relaxation of the assumption that product substitutability is identical to product compatibility (Naskar and Pal, 2020); *ii*) consider the case of responsive expectations, that is, firms can commit to the level of their quantities because consumers believe that the announced level of quantities are equal to the actual network size (Katz and Shapiro 1985, Appendix A; Amir and Lazzati, 2011); *iii*) 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; *iv*) an analysis of different bargaining agendas between the firm(s) and the union(s), relaxing the assumption of a monopoly union. Moreover, given that the workers' health risks are a main concern for the union, this issue may appear in the unions' bargaining agenda. Thus, the union could negotiate with firms about the clean technology; *v*) 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; *vi*) 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); *vii*) the analysis of the introduction of public policies such as tax/subsidy environmental policies.

APPENDIX A

A.1. Proof of Result 4, Part i)

To prove analytically part i) of Result 4, it suffices to evaluate, through the corresponding integrals in the (n, a) – space, the difference between the parametric areas below the curves $a^{oD} = \frac{8zI^2}{e}$ and $a^{*D} = \frac{8zI^2(8zI^2 + 3e^2)}{e(24zI^2 + e^2)}$ under duopoly, and $a^0 = \frac{4z(2-n)^2}{e}$ and $a^* = \frac{4z(2-n)^2[4z(2-n)^2 + 3e^2]}{e[12z(2-n)^2 + e^2]}$ under monopoly, respectively, and to show that the former area is larger than the latter one.

Let us define those differences as “Emissions Reducing Area” (ERA):

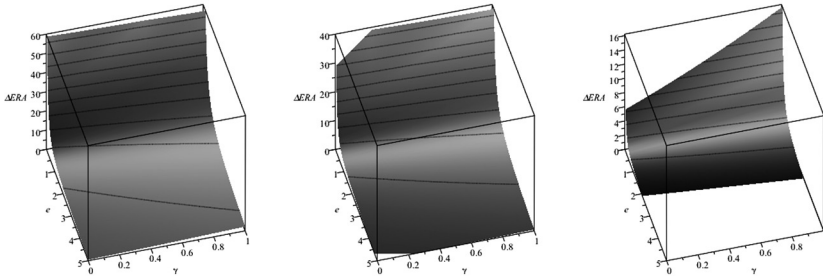


Fig. A1: Plots of the function ΔERA in the plane (e, γ) , for different technological levels: left box, $z = 1$; center box, $z = .5$; right box, $z = .1$. Legend: grey area, $\Delta ERA > 0$; white area, $\Delta ERA < 0$.

$$\begin{aligned}
 ERA^D &= \int_0^1 \frac{8zI^2}{e} dn - \int_0^1 \frac{8zI^2(8zI^2 + 3e^2)}{e(24zI^2 + e^2)} dn = \\
 &= \frac{2}{27e\sqrt{e^2z(1+\gamma)^2}} \left(- \left(\arctan \left(\frac{2z(2+\gamma)(1+\gamma)\sqrt{6}}{\sqrt{e^2z(1+\gamma)^2}} \right) - \arctan \left(\frac{2z(1+\gamma)\sqrt{6}}{\sqrt{e^2z(1+\gamma)^2}} \right) \right) e^4 \sqrt{6} \right. \\
 &\quad \left. + 12\sqrt{e^2z(1+\gamma)^2} (e^2 - 2\gamma^2z - 10\gamma z - 14z) \right) \\
 ERA^M &= \int_0^1 \frac{4z(2-n)^2}{e} dn - \int_0^1 \frac{4z(2-n)^2[4z(2-n)^2 + 3e^2]}{e[12z(2-n)^2 + e^2]} dn = \\
 &= \frac{4 \left(e^3 \sqrt{3} \arctan \left(\frac{2\sqrt{z}\sqrt{3}}{e} \right) - e^3 \sqrt{3} \arctan \left(\frac{4\sqrt{z}\sqrt{3}}{e} \right) + 6e^2 \sqrt{z} - 42z\sqrt{z} \right)}{27e\sqrt{z}}
 \end{aligned}$$

where D and M stand for duopoly and monopoly, respectively. Let us also define $\Delta ERA = ERA^D - ERA^M \stackrel{>}{<} 0$. The analytical expression of ΔERA is not of direct

interpretation; however, graphical representations reported above indicate that there exists a critical threshold of $z < 1$, $z^T(\gamma, e)$ such that $\Delta ERA = 0$ in the relevant parametric space. For another visual inspection of Result 4, see also Section B.2.2 of Appendix B.

A.2. Proof of Result 4, Part ii)

Differentiating the expression of the emissions reducing area w.r.t. to the degree of product differentiation it is obtained

$$\frac{\partial ERA^D}{\partial \gamma} = \frac{1}{ez(1+\gamma)^3[e^2+24z(2+\gamma)^2]} \left(\begin{aligned} & -2[e^2+24z(2+\gamma)^2]e^2\sqrt{e^2z(1+\gamma)^2}\sqrt{6} \\ & \left(\arctan\left(\frac{2z(2+\gamma)(1+\gamma)\sqrt{6}}{\sqrt{e^2z(1+\gamma)^2}}\right) - \arctan\left(\frac{2z(1+\gamma)\sqrt{6}}{\sqrt{e^2z(1+\gamma)^2}}\right) \right) \\ & +24z[96(1+\gamma)(\gamma+\frac{5}{2})(2+\gamma)^2z^2+4e^2(1+\gamma)(\gamma+\frac{5}{2})z+e^4](1+\gamma)^2 \end{aligned} \right)$$

whose analytical expression is not of immediate interpretation; however, the graphical representations reported below indicate that the sign of derivative is positive provided that the value of the technological efficiency index is not too low. When the technology is efficient, there is a critical threshold of $z < 1$, $z^{TT}(\gamma, e)$ such that $\frac{\partial ERA^D}{\partial \gamma} = 0$ in the relevant parametric space.

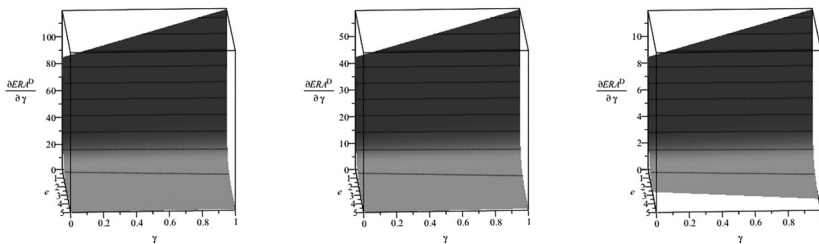


Fig. A2: Plots of the function $\frac{\partial ERA^D}{\partial \gamma}$ in the plane (e, γ) , for different technological levels: left box, $z = 1$; center box, $z = .5$; right box, $z = .1$. Legend: grey area, $\Delta ERA > 0$; white area, $\Delta ERA < 0$.

APPENDIX B: SUPPLEMENTAL MATERIAL

B.1. Numerical examples of Result 1

Result 1 is rather general and its quantitative implications may be illustrated with some examples (for a fixed $z=I$), as the two Figures below depict. In Figure B.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).

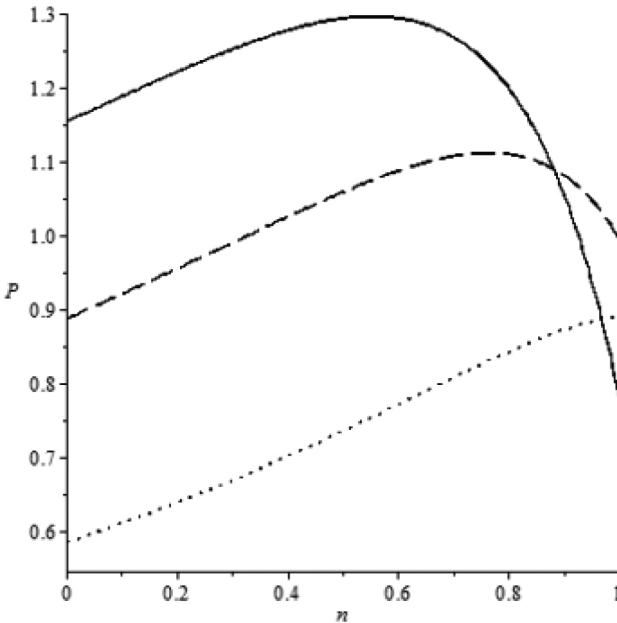


Fig. B.1. Total pollution, P , when the network effect (n) increases for three values of the market dimension (a), given $e=0.5$.

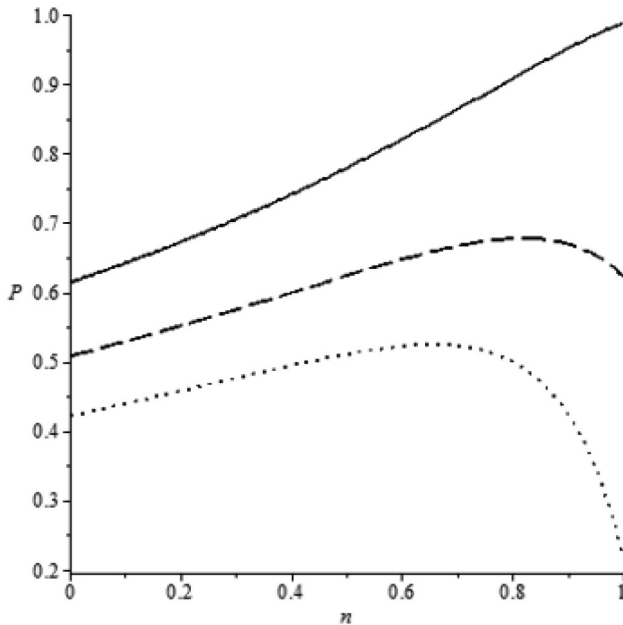


Fig. B.2. Total pollution, P , when the network effect (n) increases for three values of the union's environmental concerns (e), given $a=3$.

In Fig. B.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 $e=1.2$. Fig. B.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 (without network externalities) goods, while if the union is adequately “environmentalist” the total pollution may decrease (for high enough network effects) significantly below that produced by industries whose goods are without network externalities.

B.2. Graphical representations duopoly model

B.2.1 A graphical representation of the emission levels per firm, network vs standard industries

To see which industry (network vs standard) generates a higher degree of pollution, we construct the following per-firm emissions' differential from equation (22) (divided by two) in the main text and the corresponding value in Asproudis and Gil-Moltó (2015, last expression in p.174):

$$\Delta P^{N,S} = \left(\frac{4 \cdot z \cdot (2 - n + \gamma \cdot (1 - n)) \cdot (a - e) \cdot (8 \cdot z \cdot (2 - n + \gamma \cdot (1 - n))^2 - a \cdot e)}{(8 \cdot z \cdot (2 - n + \gamma \cdot (1 - n))^2 - e^2)^2} \right) - \left(\frac{3 \cdot z \cdot (a - e) \cdot (18 \cdot z - a \cdot e)}{(18 \cdot z - e^2)^2} \right)$$

Values of $\Delta P^{N,S} \geq 0$ indicate that network industries are more polluting than standard ones, while for values of $\Delta P^{N,S} < 0$ the reverse holds true. The threshold value of the network externality, $n^{TT}(a, e, \gamma)$, such that $\Delta P^{N,S} = 0$ is analytically complex.

As a consequence, to derive some conclusions, we run numerical simulations for precise parameter values and draw the corresponding figures (Fig. B.3). The two graphs on the top report $\Delta P^{N,S}$ for a relatively small market size ($a - e = 2$), while the two on the bottom depict $\Delta P^{N,S}$ for a relatively large market size ($a - e = 5$), in the presence of an inefficient ($z = 1$, left boxes) and efficient ($z = .25$, right boxes) abatement technology. As reported in the main text, the pictures reveal that, in the presence of an inefficient cleaning technology, the expansion of production levels due to the network externalities leads to high pollution because firms are not incentivized to abate emissions.

However, when the “green” technology is adequately efficient, in the presence of strong network effects, the indirect negative price effect due to output expansion on revenues is relevant, and firms are incentivized to invest more in cleaning technologies which now are economical. This leads both to the reduction of the firms’ operative costs and to abate emissions.

As a consequence, pollution can be lower than in standard industries, provided that, as highlighted, the network effects are adequately strong.

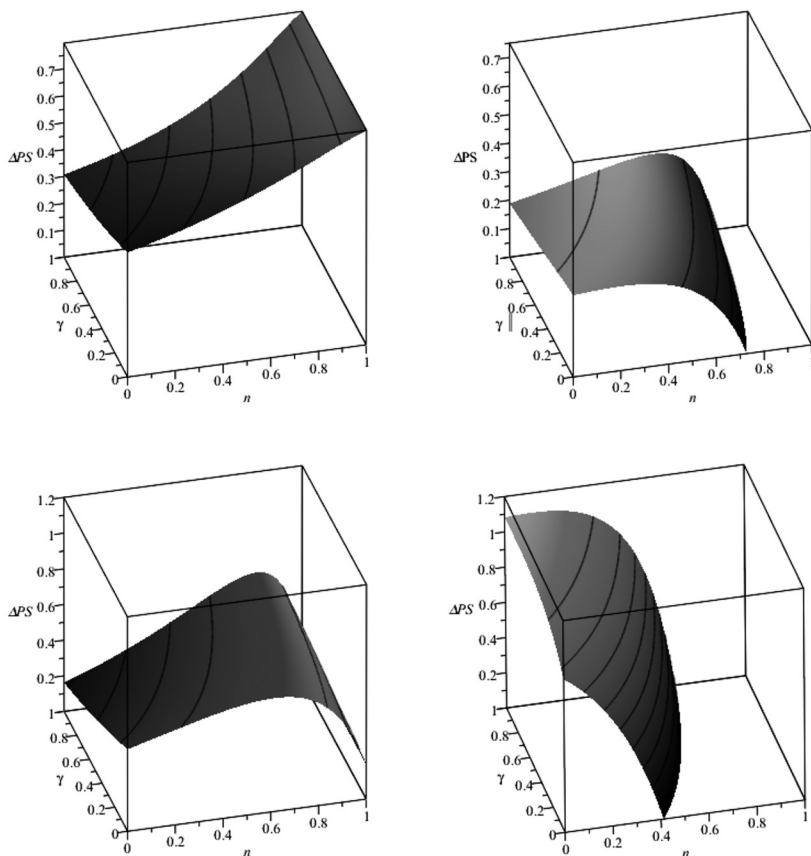


Fig. B.3: Plots of the function $\Delta P^{N,S}$ in the (n, γ) -space. Parameter set: $(a - e = 2)$ upper boxes; $(a - e = 5)$ lower boxes; $z=1$, left boxes, $z=.25$ right boxes.

B.2.2 A graphical representation of Results 4

Both parts i) and ii) of Result 4 in the main text can also 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. B.4 A) duopoly and B) monopoly, for a set of parameters such that $\Delta ERA > 0$, and - as regards the part ii) - Fig. B.5 A) $\gamma=1$ and B) $\gamma=0.05$.

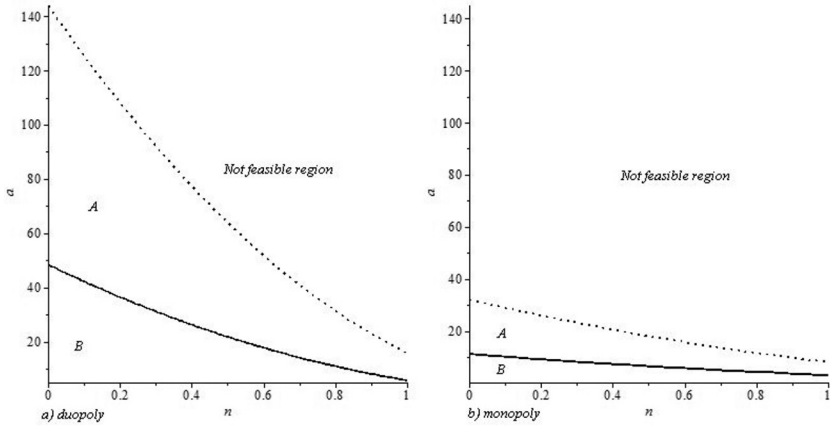


Fig. B.4: Plots of the regions with opposite effects of the network externalities on total pollution, in the plane (n,a) . Parameter set: $z=1, e=0.5, \gamma=1$. The curves represent: i) a^{*D} (solid line) and $a^{\circ D}$ (dotted line) in a) duopoly; ii) a^{*D} (solid line) and $a^{\circ D}$ (dotted 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 $\frac{\partial P}{\partial n} > 0$.

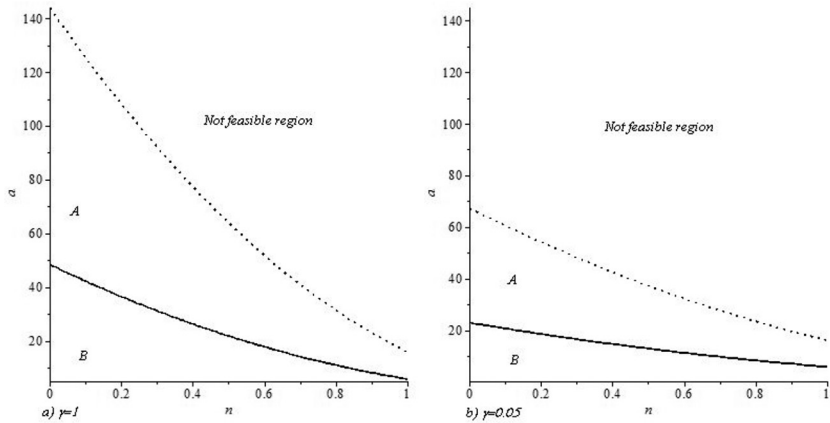


Fig. B.5: Plots under duopoly of the regions with opposite effects of the network externalities on total pollution in the plane (n,a) , for products perfect substitutes (left box: a) $\gamma=1$) and strongly differentiated (right box: b) $\gamma=0.05$). Parameter set: $z=1, e=0.5$. The curves represent a^{*D} (solid line) and $a^{\circ D}$ (dotted line). Legend: a) $\gamma=1$: A= region in which $\frac{\partial P^D}{\partial n} < 0$, B= region in which $\frac{\partial P^D}{\partial n} > 0$; b) $\gamma=0.05$: A= region in which $\frac{\partial P}{\partial n} < 0$, B= region in which $\frac{\partial P}{\partial n} > 0$.

Indeed, Fig. B.4 neatly shows that the feasibility and, more importantly, the parametric region where the relation “more network externality-less pollution” holds are larger under duopoly when the technology is not extremely efficient. As Fig. B.5 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.

B.3. 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 (3) in the main text (setting $w^\circ = 0$ for analytical simplicity) is modified as follows

$$(B.1) \quad V^S = (w - ek)^\theta q^{(1-\theta)},$$

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.¹³ 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.¹⁴ 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 (B.1), the maximization problem with respect to the wage level yields

$$(B.2) \quad w^S = a\theta + ek(1 - \theta),$$

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

¹³ Note that, when $\theta = 0.5$, this functional form represents the same union’s preferences given by (3). 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).

¹⁴ 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.

that, in the presence of a wage-oriented union, the firm is less incentivized to reduce such a damage. Substitution of (B.2) into the output expression in (5) in the main text gives production as a function of the cleaning technology

$$(B.3) \quad q^S(k) = \frac{(1-\theta)(a-ek)}{2-n}.$$

Substituting (B.2) and (B.3) into the monopolist profit function, subsequent maximisation with respect to the level of the cleaning technology leads to the optimal emission intensity

$$(B.4) \quad k^S = \frac{z(2-n)^2 - ae(1-\theta)^2}{z(2-n)^2 - e^2(1-\theta)^2}$$

Substituting (B.4) backwards, the final equilibrium output is

$$(B.5) \quad q^S = \frac{z(1-\theta)(2-n)(a-e)}{z(2-n)^2 - e^2(1-\theta)^2}$$

Analytical inspection of (B.4) and (B.5) reveals that

$$(B.6) \quad \begin{aligned} 1) \quad k^S > 0 &\Leftrightarrow a < a^{0S} = \frac{z(2-n)^2}{e(1-\theta)^2} \\ 2) \quad q^S > 0, \pi^S > 0 &\Leftrightarrow e^2 < \frac{2(2-n)^2}{(1-\theta)^2}, e < a < a^{0S}, \end{aligned}$$

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 B.1. 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 B.1 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 does not change the role of the network effect already evidenced by Lemma 1 in the main text). 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 result 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 (B.3) 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 in the main text), 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 (B.4) and (B.5) it is obtained that

$$(B.7) \quad P^S = k^S q^S = \frac{z(2-n)(1-\theta)(a-e) \left[z(2-n)^2 - ae(1-\theta)^2 \right]}{\left[z(2-n)^2 - e^2(1-\theta)^2 \right]^2}$$

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:

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

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. B.6 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 B.1 suggests, and as is clearly illustrated in Fig. B.6 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 B.6 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 union.

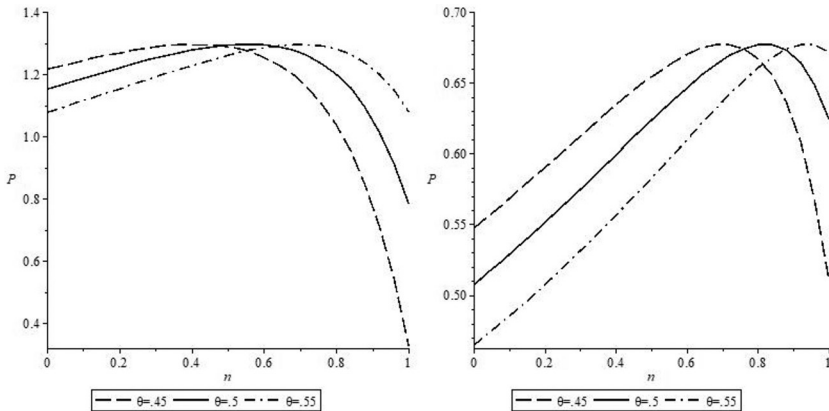


Fig. B.6. Total pollution, P^S , when the network effect (n) increases for three values of the wage orientation parameter (θ), far a given technology level ($z = 1$). Left box: $a=6, e=0.5$; Right box: $a=3, e=0.8$.

For example, in Fig. B.6, 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.

B.4. 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,

making use of (5) and (6) in the main text, it is obtained that the union utility, the profits and the consumer surplus (defined as $CS = \frac{(1-n)q^2}{2}$) are, respectively

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

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

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

where the upper script G stands for ‘‘Government’’. The positivity condition for (B.8) is ensured by the following inequalities:

$$(B.9) \quad \begin{aligned} 1) \quad e^2 &< \frac{4z(14-6n)(2-n)^2}{(7-3n)^2} \\ 2) \quad k^G > 0 &\Leftrightarrow a < a^{0G} = \frac{8z(2-n)^2}{e(7-3n)}. \end{aligned}$$

A straight forward observation of a^{0G} and a^0 in (10) in the main text (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 (B.8) into the expression for quantity leads to

$$(B.10) \quad q^G = \frac{4z(2-n)(a-e)}{8n^2z + (3e^2 - 32z)n - 7e^2 + 32z}$$

Having assumed that $a > e$, and recalling (B.9), 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 B.2: 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 larger 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:

$$(B.11) \quad P^G = k^G q^G = \frac{4z(2-n)(a-e)[8n^2z + (3ae - 32z)n - 7ae + 32z]}{[8n^2z + (3e^2 - 32z)n - 7e^2 + 32z]^2}.$$

Therefore, from (B.11), it is obtained that

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

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 Fig. B.7 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 Fig. B.7, 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.

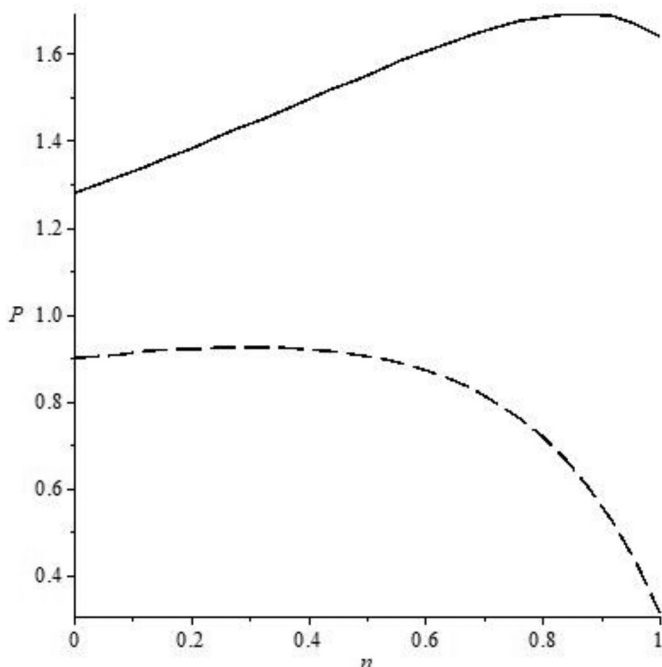


Fig. B.7. Levels of total pollution, P^G and P , when the network effect (n) increases, for given $a=6$, $e=0.3$, $z=1$. Legend: solid line, technology level chosen by the firm; dashed line, technology level chosen by the Government.

Fig. B.7 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.

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

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