Managerial firms' profitability, unions, and environmental taxes

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Abstract This article examines how determining an optimal environmental tax in a Cournot duopoly with unionised labour markets and managerial firms departing from the strict profit-maximisation. It is shown that firm-specific monopoly unions that set wages 1) reduce both the environmental tax and environmental damage and 2) counterintuitively, increase firms' profitability when the abatement technology is not too "efficient", and the public evaluation of environmental quality is sufficiently high. Within this framework, the work also develops the endogenous game played by firms that must choose between sales delegation (SD) and profit-maximisation . Results show that the SD contract always emerges as the unique, deadlock sub-game perfect Nash equilibrium, thereby solving the (prisoner's) dilemma emerging in the related existing literature assuming a competitive labour market.

Keywords Environmental taxes; Industrial pollution; Monopoly union; Managerial delegation; Cournot duopoly

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1. Introduction

The analysis of optimal environmental taxation has recently received in-depth attention in the economic literature, including the competitive context (e.g., Pigouvian taxes) and, more recently, with recognition that markets are often imperfectly competitive, as Requate (2006) surveys. The existence of both trade unions and managerial firms often exemplifies a context of imperfect competition describing the actual functioning of several industries in modern economies. The main aim of the present article is to extend the literature on managerial incentives (framed in strategic competitive context) and trade unions by introducing environmental policy and environmental concern (pollution externalities) as new factors in a market in which firms adopt an abatement technology and the government levies a welfare-maximising emission tax to incentivise firms to undertake emission-reduction actions.

A clear example of a polluting industry under the spectrum of the imposition of environmental taxes, in which large managerial companies operate vis-a-vis unionised workforce, is the metal industry in several European countries. This industry is characterised by the presence of a limited number of actors, i.e., subsidiaries of large multinationals such as ArcelorMittal, Voestalpine, Noersk-Hydro, GMK Noril'skiy Nikel' PAO, and Aurubis (Statista, 2020), whose country managers conduct local operations dealing also with trade unions, whose activities, particularly wage-setting, are more and more taking place at the decentralised level (see e.g., Buccella, 2018).

A Cournot duopoly model is built to describe a context as the above-mentioned one in which the government chooses the environmental tax to incentivise firms to undertake emission-reduction actions. These firms depart from the profit-maximisation behaviour as the labour market is unionised and ownership and control are separate, i.e., managers choose both output and abatement.

To analyse how unionisation under managerial delegation affects the government's choice of the environmental tax, the environmental damage, and firms' profitability, we propose a non-cooperative four-stage game with the following timing. In the first stage, a welfare-maximising government sets the environmental tax by anticipating the choices of (*i*) the managers' incentive contract by the owners, (*ii*) the wage by trade unions, and (*iii*) the amount of output and pollution abatement by the managers. At the second stage, owners simultaneously choose an incentive contract before their managers choose the quantity in the output market and the amount of pollution abatement (as well as before the wages are set by trade unions). At the third stage, unions fix the wages by anticipating the managers' choice of output and pollution abatement. Finally, at the fourth stage, managers compete *à la* Cournot in the product market by simultaneously choosing the quantity in the output market and the amount of pollution abatement.

The equilibrium outcomes of the model are ultimately expressed in terms of two key parameters "tuning", namely, the firms' cost of pollution abatement and the government's (societal) evaluation of the environmental damage. Then, it explores the role of trade unions in affecting these outcomes. The article then investigates the relationship between profitability and the presence of unions – which the common wisdom assumes to be always negative[1] – by considering a context in which an environmental policy exists, driven by a green-oriented government behaviour and managerial delegation.

Results show that 1) both the environmental tax and environmental damage monotonically reduce when the labour market is unionised compared to the competitive case, and 2) trade unions may counter-intuitively enhance firms' profitability, provided a sufficiently high cost of pollution abatement by firms and a sufficiently high evaluation of the environmental damage by the government. Definitively, challenging the common wisdom, firms polluting the environment might prefer higher unionised wages.

The article shows that the qualitative results of the basic model are robust in a context in which an industry-wide union setting a uniform wage is present, extending the analysis of this configuration to the case of an oligopoly with n firms, and to a conjectural variation model in a duopoly with decentralized unions. The key messages delivered by those extensions are that: 1) the more competitive the product market is, the higher the pollution and environmental damage generated; 2) increasing competition in the product markets leads the government to set increasing environmental taxes; 3) the more competitive the product market is, the higher the likelihood that profits under unionization are larger than those under competitive labour markets; and 4) the social welfare under non-unionization is higher than that in the presence of unions: larger production levels offset the damage of environmental degradation.

In contrast to the traditional managerial literature assuming a competitive labour market, the Nash equilibrium outcome of the managerial decision game with trade unions and negative environmental externalities is Pareto efficient (anti-prisoner's dilemma or deadlock). This is because the delegation contract works as a strategic device aimed at disincentivising the union's power in setting wages, thereby allowing the owners to offer a negative bonus to their own managers, which hinges upon a reduction in both production and the demand for labour. This eventually causes an increase in the market price and the market power of firms, which determines an increase in profits.

The remainder of the article is organised as follows. Section 2 presents the literature review. Section 3 introduces the model with firm-specific unions. Section 4 describes the model and the equilibrium outcomes with competitive labour markets. Section 5 analyses the effects of

[1] In fact, a well-established result of the literature is that the presence of unions reduces profits irrespective of the type of market structure (e.g., Naylor, 2003).

unionisation on environmental taxes and firms' profitability. Section 6 presents an endogenous delegation game (sales delegation versus profit maximisation) with negative environmental externalities and trade unions. Section 7 briefly summarizes the results of some model's extensions. Conclusions and the future research agenda are drawn in Section 8. The online appendix provides some analytical details.

2. Literature review

Concerning managerial firms, since the seminal works by Berle and Means (1932) and Baumol (1958), it is widely recognised, especially in large companies, that ownership and control are separate, and managers may be driven by other motives than pure profit-maximization. Moreover, in addition to anecdotal evidence, empirical data reveals that most of the operating firms in several oligopolistic industries are managerial entities (see e.g., Aggarwal and Samwick, 1999; Kedia, 2006). The strategic use of managerial incentives has recently generated remarkable interest in economics and management science. Assuming a separation between ownership and control, Vickers (1985) Fershtman and Judd (1987), and Sklivas (1987) (hereafter VFJS) argue that owners may provide incentives to managers which move them from pure profit-maximising behaviour for strategic purposes under a Cournot (or Bertrand) mode of competition. For example, in a two-stage quantity setting game, it is well established that, to induce a firm to capture a larger market share, owners incentivise their managers to act more aggressively than the strict profit-maximising behaviour would suggest. In other words, the separation between ownership and management allows owners to use managerial incentives as a strategic device as a firm reliably commits itself to act as if manufacturing costs were lower than they are.

Regarding the work of trade unions on the market, Booth (1995, p. 95) argues that "[i]t appears to be an empirical regularity that imperfections in the labour market are correlated with imperfections in the product market". Indeed, an important feature about labour markets in the actual world is that they are often unionised, as the recent growing literature on unionised oligopolies widely recognises (e.g., Horn and Wolinsky, 1988; Dowrick, 1989; Naylor, 1999). Those contributions assume, in a two-stage game, that 1) wages are unilaterally set by monopoly unions or bargained between firms and unions,[2] and 2) for given wages, each firm chooses its optimal, profit-maximising output (or price).

[2] This article concentrates on the monopoly union case. In the literature on unionized oligopolies, the monopoly union model is widely adopted (e.g., amongst others, Brekke 2004; Lommerud et al. 2005). Lommerud et al. (2005) note that, "As pointed out by, e.g., Dowrick (1989), this can be viewed as a limiting case of the wage-bargaining union, where the union has all the bargaining strength" (p. 723). This also means, by continuity, that the outcomes of the monopoly union model also apply to a "right-to-manage" model, according to which the wage is bargained by firm and union if the

However, the industrial economics literature has generally investigated either managerial delegation issues or unionised oligopolies separately. Only a few works have jointly analysed the interaction between trade unions and managerial delegation (e.g., Szymanski, 1994; Bughin, 1995; Fanti and Meccheri, 2013; Meccheri and Fanti, 2014), and the literature on environmental issues has generally followed the well-established route by separately extending either managerial delegation or unionised labour markets to include several environmental features.

Regarding the former point (managerial delegation), Bárcena-Ruiz (2002) studies the effects of firms' delegation to managers of the pollution abatement's choice on both the environmental tax and damage by assuming a competitive labour market and homogeneous products. Later, Pal (2012) extends the model of Bárcena-Ruiz (2002) to include product differentiation and alternative modes of product market competition, showing, under quantity (resp. price) competition, that the possibility for the emission tax rate to be positive and lower for highly differentiated products is higher (resp. lower) in the case of delegation than under profit maximisation.

About the latter point (unionised labour markets), Bárcena-Ruiz (2011) and Bárcena-Ruiz and Garzon (2003, 2009) consider different organizational structures of workers setting wages on the environmental taxes and standards, the preferences of governments, and the location of polluting firms in the context of profit-maximising firms (i.e., without managers).

None of these works, however, consider the link amongst environmental policy, trade unions, managerial incentives, and *firms' profitability*, which is completely disregarded to the best of our knowledge. The present article aims to fill this gap in the industrial organisation literature. As the literature on environmental issues does not consider the interplay between trade unions and managerial delegation, and neither the literature on unionised oligopoly nor the literature on managerial incentive contracts considers a modelling framework with polluting technology and environmental taxation (used by the government as a device to incentivise firms' emission-reduction actions), this study aims to close this gap by analysing the relationship amongst environmental policy, the strategic use of managerial incentives, and the labour market. On the one hand, the present article directly augments Fanti and Meccheri (2013) and Meccheri and Fanti (2014), who study the interaction between trade unions and managerial delegation and derive some results on how managerial delegation and different alternative unionisation structures affect sales, profits, consumer surplus, and social welfare. Specifically, the former article concentrates on the effects on unionisation structures differing in the degree of wage centralisation on managerial incentive contracts and product market outcomes. The latter, in contrast, studies the interaction between managerial delegations (sales and relative profits) and an industry-wide union that chooses

union's bargaining power is sufficiently high. Those considerations are valid both in the case of decentralized and industry-wide wage-setting structures.

the wage in the labour market. Compared to those works, the present article introduces environmental concerns (pollution externalities) and (welfare maximising) emission taxes in a modelling setting with sales delegation and trade unions. On the other hand, it also follows the recent work of Buccella et al. (2021), who concentrate on environmental issues and managers' abatement decisions in a Cournot game in which the choice between either "green" delegation (GD) or sales delegation (SD) contracts and profit maximisation is endogenous, in which the GD contract is based on emissions instead of sales. Compared to that work, the present article introduces the trade unions' behaviour as a new factor in the context in which the managerial contract is standardly based on sales volume and in which firms adopt a cleaning technology.

3. The model with trade unions

We consider a Cournot duopoly for homogenous products with a normalised linear inverse demand

$$p = 1 - Q, \tag{1}$$

where p denotes the price and Q the sum of the output levels, q_1 and q_2, of the two firms.[3]

As usual in the unionised oligopoly literature, we assume that both firms produce through a production function characterised by constant (marginal) returns to labour:

$$q_i = L_i, \tag{2}$$

where L_i represents the labour force employed by firm i.[4] We assume there are many available workers in the market to satisfy the firms' labour demand (no corner solutions). The i-th firm faces an average and marginal wage cost $w_i \geq 0$ for every unit of output produced, where w_i is the wage per unit of labour. Therefore, the firm i's wage cost function is linear and described by:

$$C_i(q_i) = w_i L_i = w_i q_i. \tag{3}$$

There is an amount of pollutant associated with the production of the goods and each unit produced causes one unit of pollution. To abate this pollutant, firms can use a given technology available on the market. If firm i chooses output level q_i and pollution abatement level a_i, its pollutant emissions are $e_i = q_i - a_i > 0$, i.e., the existing technology does not allow to eliminate emissions entirely (Asproudis and Gil-Moltó, 2015). The total pollution abatement cost (*CA*) at firm *i* is $CA_i = (d/2)a_i^2$, where d is a positive parameter measuring the "efficiency" of the abatement

[3] Note that the standard inverse demand model $p' = \alpha - \beta Q'$ can be transformed into this normalised model using $p = p'/\alpha$ and $Q = (\beta/\alpha)Q'$.

[4] As noted by Petrakis and Vlassis (2000, p. 265), this assumption "is equivalent to a two-factor Leontief technology in which the amount of capital is fixed in the short run and is large enough not to induce zero marginal product of labor."

technology (i=1, 2). A higher (resp. lower) value of d implies, *ceteris paribus*, a less (resp. more) efficient abatement technology.

The government sets an environmental tax per unit of pollutant emitted, t. Thus, firms must consider the burden of such a tax. The profits of the *i*-th firm are as follows:

$$\pi_i = (1 - w_i - Q)q_i - t(q_i - a_i) - \frac{d}{2}a_i^2 . \tag{4}$$

To measure the environmental damage (ED) generated by the production process, we use a standard quadratic functional form, that is

$$ED = \frac{g}{2}\left(\sum_i (q_i - a_i)\right)^2 , \; g > 0 , \tag{5}$$

where the environmental damage is a convex function of total pollution, and the positive parameter g is the weight the government attaches to the environmental quality, representing the society's environmental awareness toward a clean environment (alternatively, against the damage generated by the industrial production). This can be also interpreted as willingness to pay to decrease one unit of the environmental damage. The total taxes collected by the government are

$$T = t\sum_i (q_i - a_i), \quad i = 1, 2 . \tag{6}$$

We assume that there are two decentralised, firm-specific (symmetric) unions which simultaneously fix wages for their workers. That is, the unions not only set wages, but also apply a closed shop policy, which implies an inter-union wage competition. The following utility function represents firm i's decentralised union's preferences,

$$V_i = \left(w_i - w^\circ\right)^\theta L_i , \tag{7}$$

which is an example of a Stone-Geary utility function common in the literature on trade-unions (i.e., Pencavel, 1984, 1985, 1991; Dowrick and Spencer, 1994). The parameter w° is the reservation or competitive wage, and θ is a union's preference parameter for wages. For simplicity, and to gain analytical tractability, we set $w^\circ = 0$ and $\theta = 1$, that is, unions aim to maximise the wage bill.[5]

We assume that the firms' owners hire managers to whom they delegate both output and abatement decisions. Each manager receives a fixed salary plus a bonus element, which is related to a weighted combination of firms' profits and sales. The manager's compensation, therefore, can be expressed as $R = A + Bu \geq 0$, where $A \geq 0$ is the fixed salary component in a manager's

[5] The presence of a positive reservation/competitive wage $w^\circ > 0$ is simply scaling down all thresholds values for factor $(1 - w^\circ)$, and all the equilibrium values for factor $(1 - w^\circ)^2$, maintaining completely unchanged the qualitative results of the model, provided that the standard condition $[1 - (w^\circ + t)] > 0$, i.e. the highest willingness to pay of consumer larger than the marginal costs which ensures positive output, is satisfied.

compensation, $B \geq 0$ is a constant, and *u* is the manager's utility. Without the loss of generality, we set the fixed salary component of executive compensation to zero throughout the work.

In detail, following Jansen et al. (2009), if the firm *i*'s profits π_i are positive – otherwise there is no bonus – manager *i* receives a bonus *proportional* to $u_i = \pi_i + b_i q_i$, where owners *i* choose the weight b_i to maximize profits. The bonus can be either positive or negative[6]; owners can provide incentives or disincentives to the manager's choice of output (sales).[7]

The manager *i*'s utility function u_i can be rewritten as:

$$u_i = \pi_i + b_i q_i = (1 - w_i - Q + b_i) q_i - t(q_i - a_i) - \frac{d}{2} a_i^2 . \tag{8}$$

Hence, the equilibrium of the fourth stage of the game (that is, the simultaneous market as well as pollution abatement game) must satisfy:

$$\frac{\partial u_i}{\partial q_i} = 0 \Leftrightarrow 1 - w_i - 2q_i - q_j + b_i - t = 0, \quad \frac{\partial u_i}{\partial a_i} = 0 \Leftrightarrow -da_i + t = 0 , \tag{9}$$

for *i*, *j*=1,2 and $i \neq j$. From (9), one gets the firms' output reaction functions

$$q_i(q_j) = \frac{1 - w_i - q_j - t + b_i}{2}, \tag{10}$$

while both managers, provided that the endogenous production level is higher than the abatement level, choose the same level of pollution abatement, $a_i = \frac{t}{d}$.[8]

Solving the system of composed by the reaction function in (10) and its counterpart for firm *j*, the firm *i*'s equilibrium output for given w_i, w_j, b_i , b_j and *t* is

$$q_i(w_i, w_j, b_i, b_j, t) = \frac{1 + 2b_i - b_j - t - 2w_i + w_j}{3} \tag{11}$$

which implies that, to produce a non-negative amount of output, the environmental tax must satisfy the condition $t \leq 1 - 2(w_i - b_i) + (w_j - b_j)$.

At stage three, unions maximize their objective functions with respect to wages, taking managers' output decision (i.e., Eq. 11) into account. Substituting (11) into (7) and maximizing

[6] In the standard VFJS context, the manager's bonus at equilibrium is always positive to incentive managers to be more aggressive on output. However, as will be seen, in a unionised context, such a bonus may also be negative; that is, it is profitable for the owners to penalize managers with respect to output (see Fanti and Meccheri, 2013; Meccheri and Fanti, 2014).

[7] We also follow the standard assumption by managerial delegation theory that the fixed component (salary) of the manager's pay is chosen by the firm's owner such that the manager exactly gets his/her opportunity cost, which is normalized to zero.

[8] Note that this is the usual condition under which the firm abates pollution to the point at which marginal abatement cost equals the tax (see Ulph 1996; Bárcena-Ruiz, 2002), which holds also in this case irrespective of whether unions and managerial delegation are present.

with respect to w_i, we get the following sub-game perfect best-reply function in wages of the union-firm pair *i*:

$$w_i(w_j, b_i, b_j, t) = \frac{\left(1 + 2b_i - b_j - t + w_j\right)}{4}. \tag{12}$$

Solving the system of the wage reaction functions composed by (12) and its counterpart for *j*, we obtain the sub-game perfect equilibrium wage, for given weights on sales, b_i and b_j, and unit tax *t*

$$w_i(b_i, b_j, t) = \frac{\left[5(1-t) - 2b_j + 7b_i)\right]}{15} \tag{13}$$

which, to ensure positive wages, leads to the condition $t \leq 1 + \frac{7b_i - 2b_j}{5}$, less restrictive than the condition on non-negativity on output.

By substituting (13) in (11), we get output as a function of the weights on sales and unit tax only:

$$q_i(b_i, b_j, t) = \frac{2\left[5(1-t) - 2b_j + 7b_i\right]}{45}. \tag{14}$$

Finally, the substitution of both $w_i(b_i, b_j, t)$ (Eq. (13)) and $q_i(b_i, b_j, t)$ (Eq. (14)) in π_i (Eq. (4)) leads to profits as a function of the weights on sales and the unit tax:

$$\pi_i(b_i, b_j, t) = \frac{4d[31b_i + 4b_j - 10(1-t)][2b_j - 7b_i - 5(1-t)] + 2025t^2}{4050d}. \tag{15}$$

At the second stage, each owner *i* simultaneously chooses b_i, knowing the profits as a function of b_i, b_j, and t. Maximizing (15) and solving for b_i, one obtains the reaction function in the bonus space for the owner *i*:

$$b_i(b_j, t) = \frac{17\left[2b_j - 5(1-t)\right]}{434}, \tag{16}$$

which, in the symmetric equilibrium ($b_i = b_j = b^*$) yields

$$b^*(t) = -\frac{17(1-t)}{80}. \tag{17}$$

From (17), one notes that owners fix a negative bonus to disincentivize production. As Fanti and Meccheri (2013) explain, in a context without taxation, owners can use sales penalization in the managerial contract as a tool to recapture oligopoly rent shares that workers would gain through unionization, thus improving profitability. The reason for this result is that a positive bonus leads managers to act aggressively (output expansion); consequently, unions claim higher wages. Through sales penalization, owners can curb wage demands, leading to higher profits. However,

$\frac{db^*}{dt} > 0$: the environmental tax tends to soften the magnitude of the disincentive. The intuition behind this result is as follows. Because output is negatively related to the environmental taxation (see, for instance eqs. (10), (11) and (14)), owners tune the disincentive to the tax rate to avoid an excessive output contraction that would affect negatively revenues, and therefore profits.

Table 1. Equilibrium values as a function of the environmental tax, unionised labour markets

	wages	output	Union utility	Profits	Consumer surplus	Tax revenues	Environmental damage
Unionized labour market	$w_i^*(t) = \frac{21(1-t)}{80}$	$q_i^*(t) = \frac{7(1-t)}{40}$	$V_i^*(t) = \frac{147(1-t)^2}{3200}$	$\pi_i^*(t) = \frac{217(1-t)^2 d + 1600t^2}{3200d}$	$CS^*(t) = \frac{49(1-t)^2}{800}$	$T^*(t) = \frac{t[7d(1-t)-40t]}{20d}$	$ED^*(t) = \frac{g[40t-7d(1-t)]^2}{800d^2}$

Substituting (17) into (13), (14), and (15), we obtain the sub-game perfect equilibrium wages, output, and profit only as a function of *t*, all satisfying the condition $t \leq 1$. Then, the equilibrium union's utility, the consumer surplus ($CS^*(t) = \frac{(q_1^*(t) + q_2^*(t))^2}{2} = \frac{(2q^*(t))^2}{2}$), the tax revenue ($T(t) = 2t(q^*(t) - a^*(t))$), and the environmental damage ($ED(t) = \frac{g}{2}\left(\sum_i (q_i^*(t) - a_i^*(t))\right)^2$) are derived. Table 1 reports these results.

To explore in detail how the presence of a union affects the choice of the managerial bonus (penalty) and the role played by the environmental tax, it can be useful to analyse the total derivatives of wages and output with respect to the tax rate in equilibrium, when $b_i = b_j = b^*$ and $w_i = w_j = w^*$. From (11) and (13), one obtains

$$\overset{(-)}{\frac{dw^*}{dt}} = \overbrace{\overset{(+)}{\frac{\partial w^*}{\partial b^*}}\overset{(+)}{\frac{db^*}{dt}}}^{+} + \overset{(-)}{\frac{\partial w^*}{\partial t}}; \quad \overset{(-)}{\frac{dq^*}{dt}} = \overbrace{\overset{(-)}{\frac{\partial q^*}{\partial w^*}}\left[\overbrace{\overset{(+)}{\frac{\partial w^*}{\partial b^*}}\overset{(+)}{\frac{db^*}{dt}} + \overset{(-)}{\frac{\partial w^*}{\partial t}}}^{(-)}\right]}^{(+)} + \overbrace{\overset{(+)}{\frac{\partial q^*}{\partial b^*}}\overset{(+)}{\frac{db^*}{dt}}}^{(+)} + \overset{(-)}{\frac{\partial q^*}{\partial t}}.$$

Let us first consider the effects of the environmental tax on the unions' wage-setting. On the one hand, the indirect channel has a positive impact. This is because a higher bonus tends to expand production, which increases the unions' labour demand and, therefore, wage claims; in addition, the environmental tax scales down the output penalty for managers. On the other hand, the direct effect is negative: the environmental tax increases the marginal costs for firms which, to reduce the overall costs of production, decrease their output, and therefore shrinks the unions' labour demand. The

direct effect of the environmental tax dominates the indirect one and, consequently, the overall effect on wages is negative: unions decrease their wage demand, as easily observed from Table 1.
Let us now consider the effects of the environmental tax on output. On the one hand, the indirect channels have a positive impact. First, the standard inverse relation in terms of comparative statics between wages and output applies; however, as seen, the overall impact of the tax on wages is negative, thus this channel leads to expand production. Second, production is directly linked to the managerial bonus, and the environmental tax softens the penalty. Therefore, this indirect channel stimulates production as well. On the other hand, the direct effect is negative: the standard effect of an increase in the marginal costs of production leading to a contraction in output appears. The direct effect of the environmental tax dominates the indirect one, and the overall effect on output is negative: firms decrease production, and unions face a lower labour demand, as observed in Table 1. Therefore, the above analysis helps identify a few elements that can improve firms' profitability: 1) a reduction in output decreases the tax base about the environmental tax, which has a positive impact on the firm's profitability; 2) the negative bonus impacts negatively both the unions' wages and labour demand, with a decreasing effect on the wage bill, adding a further element of cost reduction for firms; 3) output reduction works in the direction of increasing the market power of the firm; that is, the final price increases, with a positive (indirect) impact on firms' revenues and profits.

Given the obtained equilibrium values, we can now solve the first stage of the game. In this stage, the government chooses the tax t to maximize the social welfare at the equilibrium, $SW^*(t)$, which comprises the consumer's surplus, $CS^*(t)$, the firms' surplus, $PS^*(t)$ (i.e., the sum of firms' profits), the total taxes collected by government, $T^*(t)$, the rents obtained by the workers, $V(t)=V_1(t)+V_2(t)$, and the environmental damage caused by the production process, ED:

$$SW^*(t)=CS^*(t)+PS^*(t)+T^*(t)+V^*(t)-ED^*(t). \tag{18}$$

Note that the union rents are included in the definition of social welfare as usual in the literature (e.g., as that part of the producer surplus which is absorbed by the unions; see, for example, Brander and Spencer, 1988; Mezzetti and Dinopoulos, 1991; Zhao, 2001). Given the equilibrium values in Table 1, the social welfare is:

$$SW^*(t)=\frac{(1-t)7d^2(7g(t-1)+7t+33)-80dt(7g(t-1)+10t)-1600gt^2}{800d^2}. \tag{19}$$

The government fixes the following social welfare maximising environmental tax rate:

$$\frac{\partial SW^*(t)}{\partial t}=0\Rightarrow t^{OPT}=\frac{7d\left[d(7g-13)+40g\right]}{49d^2(1+g)+80d(7g+10)+1600g}. \tag{20}$$

Let us now compare the optimal environmental tax with the environmental marginal damage.[9] Differentiating with respect to the tax rate the expression of the environmental damage in Table 1 one obtains that the marginal environmental damage (*MED*) is $\frac{\partial ED^*(t)}{\partial t} = \frac{g[40t - 7d(1-t)](7d+40)}{400d^2}$. Solving $\frac{\partial ED^*(t)}{\partial t} = 0$ for t, one gets the Pigouvian tax rate $t^{MED} = \frac{7d}{7d+40}$, that is, the tax rate set to be exactly equivalent to the aggregate marginal social cost.

A direct comparison reveals that $t^{MED} > t^{OPT}$ in the overall relevant range of analysis (see the online Appendix). That is, the socially optimal environmental tax is lower than the Pigouvian tax, indicating that if the government consider the welfare of all the agents operating the economy, it does not fully charge firms for their polluting activities.

4. The model with competitive labour market

In this section, we consider a competitive labour market in which the reservation wage equals zero. Therefore, we have a *three-stage game*: 1) in the first stage, the government sets the environmental taxes anticipating the choices of the managers' incentive contract by the owners and the managers' decision on output and abatement levels; 2) at the second stage, owners simultaneously choose an incentive contract for their managers, anticipating the choices of output and abatement levels; 3) at the third stage, managers simultaneously choose output and abatement levels for the given incentive contracts. Therefore, π_i is now the following:

$$\pi_i = (1-Q)q_i - t(q_i - a_i) - \frac{d}{2}a_i^2 . \tag{21}$$

Making use of the same standard calculations as in the previous section, we obtain the following outcomes regarding output, level of pollution abatement, and profits as a function of the managers' bonuses and taxes:

$$q_i(b_i, b_j, t) = \frac{1 - t + 2b_i - b_j}{3}, \tag{22}$$

$$a_i = \frac{t}{d}, \tag{23}$$

and

$$\pi_i(b_i, b_j, t) = \frac{2(1 - t + 2b_i - b_j)(1 - t - b_i - b_j) + 9t^2}{18d}. \tag{24}$$

By maximising (21), the owner chooses the manager's bonus, which at equilibrium is

[9] This comparative analysis, useful in the literature of environmental economics to assess the policy intervention, can be found, among others, in Buchanan (1969), Barnett (1980), and Lee (1999).

$$b_i = b_j = b^{*C}(t) = \frac{(1-t)}{5}, \tag{25}$$

where the apex *C* denotes a "competitive labour market".

By using the expression in (25), one obtains the equilibrium values of output and consumer surplus as a function only of the unit tax, *t*, while profits and total revenue are functions of the unit tax and the technology abatement parameter, *d*. Finally, environmental damage and social welfare are functions of *t* and the evaluation of the damage by the government, *g*.

Table 2. Equilibrium values as a function of the environmental tax, competitive labour markets.

	wages	output	Union utility	Profits	Consumer surplus	Tax revenues	Environmental damage
Competitive labour market	$w_i^{*C} = 0$	$q_i^{*C}(t) = \frac{2(1-t)}{5}$	$V_i^{*C} = 0$	$\pi_i^{*C}(t) = \frac{4d(1-t)^2 + 25t^2}{50d}$	$CS^{*C}(t) = \frac{8(1-t)^2}{25}$	$T^{*C}(t) = \frac{2t[2d(1-t)-5t]}{5d}$	$ED^{*C}(t) = \frac{2g[5t-2d(1-t)]^2}{25d^2}$

After the usual calculations, we get the equilibrium output, profits, consumer surplus, tax revenue, and environmental damage, reported in Table 2.

Now, the social welfare function is:

$$SW^{*C}(t) = CS^{*C}(t) + PS^{*C}(t) + T^{*C}(t) - ED^{*C}(t). \tag{26}$$

whose expression, given the values in Table 2, reads as follows:

$$SW^{*C}(t) = \frac{4(1-t)d^2[2(1+g)t - 2g + 3] - 5dt[(8g+5)t - 8g] - 50gt^2}{25d^2}. \tag{27}$$

The government fixes the following social welfare-maximising environmental tax:

$$\frac{\partial SW^{*C}}{\partial t} = 0 \Rightarrow t^{OPTC} = \frac{2d\left[d(4g-1) + 10g\right]}{8d^2(1+g) + 5d(8g+5) + 50g}. \tag{28}$$

As described in the previous section, from the expression of the environmental damage in Table 2 one gets that the marginal environmental damage is $\frac{\partial ED^{*C}(t)}{\partial t} = \frac{4g[5t - 2d(1-t)](5+2d)}{25d^2}$. Solving $\frac{\partial ED^{*C}(t)}{\partial t} = 0$, it is obtain the Pigouvian tax rate, $t^{MEDC} = \frac{2d}{2d+5}$, with $t^{MEDC} > t^{OPTC}$ in the relevant range of analysis (see the online Appendix); also in this case, the socially optimal environmental tax falls short of the Pigouvian tax.

5. Effects of the labour unionization

In this section, we examine the impact of the unionization of labour market on environmental taxes and firms' profitability in a Cournot duopoly with managerial delegation and pollution abatement.

Lemma 1. *The pre-tax equilibrium levels of emissions are positive if and only if the tax rate is lower than the marginal environmental damage (Pigouvian tax), i.e.,* $e_i^*(t) = q_i^*(t) - a_i^*(t) > 0 \Rightarrow t < t^{MED}$ *, and* $e_i^{*C}(t) = q_i^{*C}(t) - a_i^{*C}(t) > 0 \Rightarrow t < t^{MEDC}$.

Proof: The result straightforwardly derives from the output expressions in Table 1 and Table 2 and considering the optimal abatement level in Eqs. (9) and (23).

The rationale for Lemma 1 is straightforward: an excessive tax, beyond the marginal environmental damage, would lead to an excess of the firms' abatement activities.

Lemma 2. *[1] The optimal environmental tax rate in both scenarios is positive*[10] *if and only if the government evaluation of environmental quality (g) is sufficiently high. In particular,* $t^{OPT} > 0$ *if and only if* $g > g^{\circ}(d) = \frac{13d}{7d+40}$ *in the trade unions scenario and* $t^{OPTC} > 0$ *if and only if* $g > g^{\circ C}(d) = \frac{d}{2(2d+5)}$ *in the competitive scenario, with* $g^{\circ C}(d) < g^{\circ}(d)$. *[2] The post-tax equilibrium amount of emissions is positive regardless of the size of the societal awareness toward the environmental quality. In particular,* $e_i^*(t^{OPT}) = q_i^*(t^{OPT}) - a_i^*(t^{OPT}) > 0$ *for any* $g > g^{\circ}(d)$ *in the trade unions scenario and* $e_i^{*C}(t^{OPTC}) = q_i^{*C}(t^{OPTC}) - a_i^{*C}(t^{OPTC}) > 0$ *for any* $g > g^{\circ C}(d)$ *in the competitive scenario.*

Proof: [1] Solving with respect to g the inequalities $t^{OPT} > 0$ (see Eq. (20)) and $t^{OPTC} > 0$ (see Eq. (28)), respectively, and by observing that $g^{\circ}(d) - g^{\circ C}(d) = \frac{45d(2+d)}{2(7d+40)(2d+5)} > 0$, the results hold.

[2] Computing the difference between output and abatement in each scenario and substituting out t^{OPT} in the case of trade unions and t^{OPTC} in the competitive case, the result follows.

The second result of Lemma 2 derives from the fact that the socially optimal tax rate in each scenario is smaller than the marginal environmental damage, as stated in Lemma 1. A direct consequence of Lemma 2 is that a positive tax rate is less likely to be imposed under unionisation.

Lemma 3. *Irrespective of the labour market structure, the optimal environmental tax rate is a monotonic increasing function of the policy parameter evaluating the environmental quality (g).*

[10] Note that, in the rest of the article, we limit ourselves to only non-negative tax rate. However, in principle, also negative tax (i.e., subsidy) can occur. In such a case, "the market distortion due to the underproduction generally associated with the exercise of the market power of firms is much stronger than the distortion due to the environmental damage caused by polluting emissions and, thus, there is a subsidy per unit of pollutant emitted" (Bárcena-Ruiz 2002, p. 306). Note that, in this work there is another distortion due to the imperfect competition in labour market, in addition to the two above.

Proof: The results easily follow from the expressions

$$\frac{\partial t^{OPT}}{\partial g} = \frac{140d^2(7d+66)(7z+40)}{\left[49d^2(1+g)+80d(7g+10)+1600g\right]^2} > 0$$

and

$$\frac{\partial t^{OPTC}}{\partial g} = \frac{40d^2(d+3)(2d+5)}{\left[8d^2(1+g)+5d(8g+5)+50g\right]^2} > 0$$

Intuitively, the higher the weight the government assigns to the environmental quality, the higher the environmental tax the government is willing to set, mostly to reduce emissions.

Lemma 4. *The equilibrium abatement levels in the cases of unionised and competitive labour markets are, respectively:*

$a^*(t^{OPT}) = \sum_{i=1}^{2} a_i^*(t^{OPT}) = \frac{7(7gd+40g-13d)}{49gd^2+560gd+49d^2+1600g+800d} > 0$ *for any* $g > g^{\circ}(d)$ *and*

$a^{*C}(t^{OPTC}) = \sum_{i=1}^{2} a_i^{*C}(t^{OPTC}) = \frac{2(4gd+10g-d)}{8gd^2+40gd+8d^2+50g+25d} > 0$ *for any* $g > g^{\circ C}(d)$

with $a < a^C$.

Proof: The result straightforwardly derives from the comparison of the two expressions above, that is, $a^*(t^{OPT}) - a^{*C}(t^{OPTC}) = \frac{-45(2g+d)(14gd^2+115gd+14d^2+200g+15d)}{(49gd^2+560gd+49d^2+1600g+800d)(8gd^2+40gd+8d^2+50g+25d)} < 0$.

The rationale for this result is immediate. As the output under a competitive labour market is larger than in the case of labour unionisations (because, overall, without labour unions, the marginal costs for firms are lower), therefore the abatement levels (which are directly linked to production) are higher. However, concerning the overall pollution, the next lemma holds.

Lemma 5. *The post-tax equilibrium polluting quantities (P) in the cases of unionised and competitive labour markets are, respectively:*

$P^*(t^{OPT}) = \sum_{i=1}^{2}(q_i^*(t^{OPT}) - a_i^*(t^{OPT})) = \frac{7d(7d+66)}{49gd^2+560gd+49d^2+1600g+800d} > 0$ *and*

$P^{*C}(t^{OPTC}) = \sum_{i=1}^{2}(q_i^{*C}(t^{OPTC}) - a_i^{*C}(t^{OPTC})) = \frac{8d(d+3)}{8gd^2+40gd+8d^2+50g+25d} > 0$

with $P^*(t^{OPT}) < P^{*C}(t^{OPTC})$.

Proof: The result straightforwardly derives from the comparison of the two expressions above, that $P^*(t^{OPT}) < P^{*C}(t^{OPTC}) =$ is, $\dfrac{-45d(59d+170)(d+2g)}{(49gd^2+560gd+49d^2+1600g+800d)(8gd^2+40gz+8d^2+50g+25d)} < 0$.

The intuition behind Lemma 5 is that, although the abatement levels per unit of output with competitive labour markets are higher than those in the presence of labour unions, the impact of the overall largest production due to the lower marginal costs is to increase pollution levels.

In summary, the only technical condition required to avoid a negative tax is $g > g^{\circ}$.

By substituting the optimal taxes – Eqs. (20) and (28) – in the profit expressions in Table 1, respectively, we obtain the equilibrium profits in both cases of unionised and competitive labour market as a function only of the parameters d and g:

$$\pi^*(t^{OPT}) = \frac{7\left[\begin{array}{l}1519d^4+28d^3(49g^2+35g+789)+4d^2(5439g^2+10080g+12400)+\\+320dg(357g+620)+198400g^2\end{array}\right]}{8\left[49d^2(1+g)+80d(7g+10)+1600g\right]^2}, \tag{29}$$

and

$$\pi^{*C}(t^{OPTC}) = \frac{2\left[4d^4+d^3(16g^2+8g+21)+d^2(96g^2+60g+25)+20dg(9g+5)+100g^2\right]}{\left[8d^2(1+g)+5d(8g+5)+50g\right]^2} \tag{30}$$

We can now summarise the main results. About the relationship between unionisation and taxes, we note the following:

Result 1. *The optimal environmental tax rate and the environmental damage in equilibrium are always lower under labour market unionisation than in the case of competitive labour market (i.e.,* $t^{OPT} < t^{OPTC}$ *and* $ED^*(t^{OPT}) < ED^{*C}(t^{OPTC})$*).*

Proof: The result straightforwardly derives by comparing Eqs. (20) and (28) for the tax rate, and with regard the environmental damage, by comparing the corresponding functions in Table 1 after substitution of (20) for the unionised labour market and (28) for the competitive labour market.

The rationale for this result is as follows. On the one hand, the environmental tax reduces the firms' output, which has an adverse effect on the overall social welfare; on the other hand, it enhances abatement, which leads to less pollution per unit of production. If firms' marginal costs of production are higher, the detrimental effect of taxation on welfare is higher, while the gain in terms

of environmental quality is lower (note that, in this model, abatement does not depend on the marginal cost of production). Therefore, in the case of higher marginal cost of production, the optimal tax rate will be lower. The environmental damage will also be lower in the case of higher marginal cost of production, as the cost effect will dominate the tax effect.

Now, we focus on the effects of labour market unionisation on the firms' profitability in a framework with environmental policy and managerial firms.

Result 2. *Profits under labour market unionisation can be higher than profits under a competitive labour market. This result is favoured by an inefficiency abatement technology ($d \uparrow$) and a large society's environmental awareness towards a clean environment ($g \uparrow$). Increasing (resp. reducing) the costs of pollution abatement, i.e., d increases (resp. d reduces), requires higher (resp. lower) levels of societal environmental sensitivity toward the environmental quality to let this relationship hold.*

Proof: See the online appendix.

Figure 1 represents a geometrical projection of Result 2. The solid black line defines, in the $(d, g)-$space, the locus of the points in which the profit differential $\Delta\pi \equiv \pi^{*}(t^{OPT}) - \pi^{*C}(t^{OPTC}) = 0$. For the firms, this can be thought of as an iso-profit or "indifference surface" between unionised and competitive labour markets cases.

Line $g = g^{\circ}(d)$ represents the threshold value for having a positive tax under the two market structures. Therefore, the portion of the (d, g) surface in which $g > g^{\circ}$ is the area of technical feasibility.

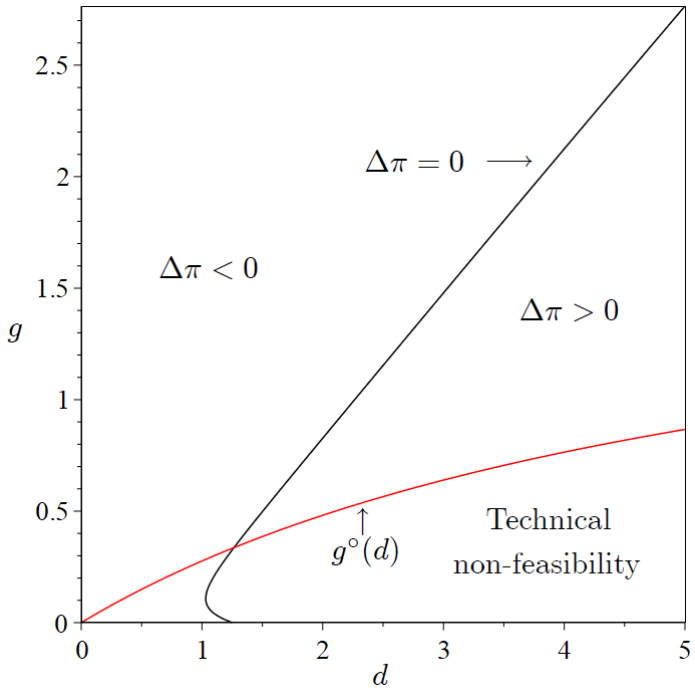

Figure 1. Profit differential ("indifference curve"), $\Delta\pi := \pi^*(t^{OPT}) - \pi^{*C}(t^{OPTC}) = 0$, in the $(d, g)-$space. The red solid line $g^\circ(d)$ separates the area of technical feasibility (non-negative taxation), above the red line, from the area of technical non-feasibility (negative taxation), below the red line. For all (d, g) combinations along the black solid line, the condition $\Delta\pi = 0$ holds. For all (d, g) combinations below (resp. above) the black solid line, profits in a unionised labour market are larger (resp. smaller) than profits when the labour market is competitive, i.e., $\Delta\pi > 0$ (resp. $\Delta\pi < 0$).

The parametric region below the curve $\Delta\pi = 0$ and above the threshold $g^\circ(d)$ is the one in which the presence of unions raises profits. That is, if *d* is not too low – i.e., the abatement technology is not too "efficient" – and *g* sufficiently high[11] – i.e., the environment is relatively important for the government – it emerges the unconventional result that firms benefit from the presence of unions.

In line with the common wisdom, if firms are profit-maximising (i.e., without managerial delegation), then profits are always higher if unions are absent.[12] Therefore, the presence of managerial delegation is a key ingredient for Result 2. In fact, as Fanti and Meccheri (2013) argue, the introduction of managerial delegation in the presence of unions increases profits. The rationale for the main message of Result 2 is as follows. Following the line of reasoning in Section 2, firms' owners, fixing a negative bonus in the managers' incentive contracts, "penalise" output (i.e., employment) to weaken the unions' wage claims; therefore, the wages the unions set are lower under managerial delegation. Moreover, the presence of an environmental tax has a direct negative effect on the demanded equilibrium wages. Furthermore, the presence of unions implies a lower taxation (see Result 1). In fact, it is easy to show that, if *d* is sufficiently high, then environmental taxes reduce profits. In particular, the tax-induced profit reduction is more intense in the absence of unions.[13] It follows that, for obtaining Result 2, a crucial role is played by the causal chain "presence of unions → reduced environmental taxes → increased profits". That is, if *d* is adequately high, the profit-reduction effect of the higher wage costs due to the unionisation is smaller than the relative profit-enhancing effect due to the lower environmental tax induced by the presence of unions.

Finally, let us consider the impact of unionization on the overall welfare. A direct analytical inspection leads to the next result.

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[11] Graphical inspection of Fig. 1 also reveals that, when $d < 1.2$, the relationship between the profit differential and the parameter g is of "hump"-type instead of monotonically increasing. However, in this parametric window, it holds that $g < g^\circ(d)$; that is, there would be environmental subsidies instead of taxes, a case that is treated in this work.

[12] The easy proof is not shown here for economy of space and is available on request.

[13] From the profit expressions in Table 1, one gets $\frac{\partial\pi^*}{\partial t} = \frac{1600t - 217d(1-t)}{1600d}$, $\frac{\partial\pi^{*C}}{\partial t} = \frac{25t - 4d(1-t)}{25d}$ and $\left|\frac{\partial\pi^*}{\partial t}\right| < \left|\frac{\partial\pi^{*C}}{\partial t}\right|$.

Result 3. *Social welfare under unionisation is lower than under a competitive labour market (i.e.,* $SW^*(t^{OPT}) < SW^{*C}(t^{OPTC})$*).*

Proof: The result immediately derives from the comparison between Eqs. (19) after substituting (20) and (27) after substituting (28).

Therefore, despite a higher environmental damage, the standard result arises that social welfare with competitive labour markets is larger than with unionized labour markets. That is, even if the society has a large environmental awareness, the gains in terms of consumer surplus due to a larger production with competitive labour markets more than offset the associated overall environmental damage. This seems to suggest that, if the objective function of the social planner assigns equal weights to each welfare component, the government should introduce labor markets regulations tending to soften the wage setting power of unions and improve the overall welfare. Despite a higher degree of pollution, such a policy would benefit consumers the most; nonetheless, it can potentially harm profits and it will deteriorate workers' welfare. Those elements can have a high political cost; therefore, prior to the design and implementation of labor markets interventions, they should be considered carefully. [14]

6 . A managerial delegation game with pollution externalities and trade unions

This section provides insights about the firms' choice of being sales delegated or profit maximisers in an environment with negative pollution externalities when the government levies a welfare-maximising emission tax to incentivise firms to undertake emission-reduction actions. In this sense, it augments the endogenous game studied in Buccella et al. (2021) by introducing an imperfect labour market with decentralised or firm-specific monopoly unions that aim at setting the wage rate at a higher level than the market-clearing wage.

Therefore, the four-stage non-cooperative game studied in Section 3 is now augmented by an additional stage, the contract decision stage, in which the owners must choose to be sales delegated or profit maximisers in an environment with decentralised wage-setting monopoly unions and negative environmental externalities. We pinpoint that the results presented in this section assuming homogeneous products holds also under the assumption of horizontal differentiation.

[14] In an exercise, we have considered that managers receive from the owners a bonus proportional to emissions, that is, each manager's utility is $u_i = \pi_i + b_i(q_i - a_i)$ (Buccella et al., 2021), where owners select the positive or negative weight b_i to maximize profits. The qualitative results are all confirmed. From the quantitative point of view, both a higher degree pollution abatement cost (lower efficiency of the abatement technology) and environmental awareness of the society are needed for the emergence of a higher firms' profitability in the presence of unions.

6.1. The endogenous choice of managerial delegation

To avoid lengthening the article, the online appendix reports the main equilibrium outcomes of the game – computed by adopting the usual backward induction logic – in reference to the symmetric sub-games in which both firms are sales delegated (SD/SD) or profit maximisers (PM/PM) and the asymmetric sub-games in which one firm adopts the SD contract and the rival the

Table 3. Post-tax equilibrium profit (payoff matrix) of the endogenous game SD versus PM.

Firm 1 \ Firm 2	SD	PM
SD	$\pi_1^{*SD/SD}$, $\pi_2^{*SD/SD}$	$\pi_1^{*SD/PM}$, $\pi_2^{*SD/PM}$
PM	$\pi_1^{*PM/SD}$, $\pi_2^{*PM/SD}$	$\pi_1^{*PM/PM}$, $\pi_2^{*PM/PM}$

PM contract (SD/PM). The relevant post-tax payoff matrix, used by the owners to compare profits and choose to design the SD contract or the PM contract, can easily be computed by substituting out the optimal tax rate corresponding to each scenario in the entries of Table 3, reported in the online appendix together with the optimal environmental tax rate corresponding to each sub-game, that is $t^{OPT,SD/SD} > 0$ for any $g > g^{\circ SD/SD}(d) = g^{\circ}(d) = \frac{13d}{7d+40}$, $t^{OPT,PM/PM} > 0$ for any $g > g^{\circ PM/PM}(d) = \frac{5d}{2(2d+9)}$ ($g^{\circ PM/PM}(d) < g^{\circ SD/SD}(d)$), and $t^{OPT,SD/PM} = t^{OPT,PM/SD} > 0$ for any $g > g^{\circ SD/PM}(d) = g^{\circ PM/SD}(d) = \frac{130d}{87d+434}$ ($g^{\circ PM/PM}(d) < g^{\circ SD/PM}(d) < g^{\circ SD/SD}(d)$). Therefore, the relevant threshold useful to identify the feasible region (non-negative taxation) of the managerial decision game with trade unions and negative environmental externalities is $g > g^{\circ SD/SD}(d) = g^{\circ}(d)$. In addition, the post-tax net emissions emerging in each symmetric sub-game are positive for any relevant value of g. Regarding the asymmetric sub-games, the net emissions of the PM firm are always positive, and the net emissions of the SD firm are positive if and only if $g < g^{\circ\circ SD/PM}(d) = \frac{5d(609d+5300)}{17(87d+434)}$. This implies that the public evaluation of the environmental quality should not be too high to avoid levying an excessively high optimal tax rate in the asymmetric scenario, that is, a tax rate not compatible with the existing abatement technology. Definitively, for any d, the feasible region of the managerial decision game with trade unions and negative environmental externalities is bounded by the inequalities $g^{\circ SD/SD}(d) < g < g^{\circ\circ SD/PM}(d)$.

To satisfy the technical restrictions and have well-defined equilibria in pure strategies for every strategic profile (one for each player), the analysis is restricted to the feasibility constraints discussed above (which henceforth are assumed to be always satisfied). Then, to derive all possible

equilibria of the game, one must study the sign of the profit differentials that follow for $i, j = \{1, 2\}$ ($i \neq j$), that is

$$\Delta\pi_A = \pi_i^{*SD/PM} - \pi_i^{*PM/PM}, \tag{31}$$

$$\Delta\pi_B = \pi_i^{*PM/SD} - \pi_i^{*SD/SD}, \tag{32}$$

and

$$\Delta\pi_C = \pi_i^{*PM/PM} - \pi_i^{*SD/SD}. \tag{33}$$

Through some cumbersome calculations, Eqs. (31)-(33) reveal that the sign of the profit differentials is univocal for any $d > 0$ within the range $g^{\circ SD/SD}(d) < g < g^{\circ\circ SD/PM}(d)$. Then, the following result holds.

Result 4. (SD,SD) is the unique Pareto-efficient Nash equilibrium, and the managerial decision game with trade unions and negative environmental externalities is a deadlock for any $d > 0$, and $g^{\circ SD/SD}(d) < g < g^{\circ\circ SD/PM}(d)$.

Proof: As $\Delta\pi_A > 0$, $\Delta\pi_B < 0$ and $\Delta\pi_C < 0$ for any $d > 0$ and $g^{\circ SD/SD}(d) < g < g^{\circ\circ SD/PM}(d)$, the result follows.

The intuition behind the main result of this section (pareto efficiency of the Nash equilibrium (SD,SD)) is as follows. As already underlined in the previous section, in the presence of trade unions, the owners give their managers a negative bonus in the SD contract to disincentivise production for the sales-delegated firm. Therefore, given the production function, the demand for labour is also reduced, and this implies that the equilibrium wage rate bargained by the unions under SD will be lower than in the PM case. These forces work toward an increase in the market power of the firm (i.e., an increase in the price) in the product market and hence an increase in profits (again relative to the PM contract) (see Fanti and Buccella, 2017). This means that the delegation contract works as a strategic tool to disincentivise the union's power in setting wages.

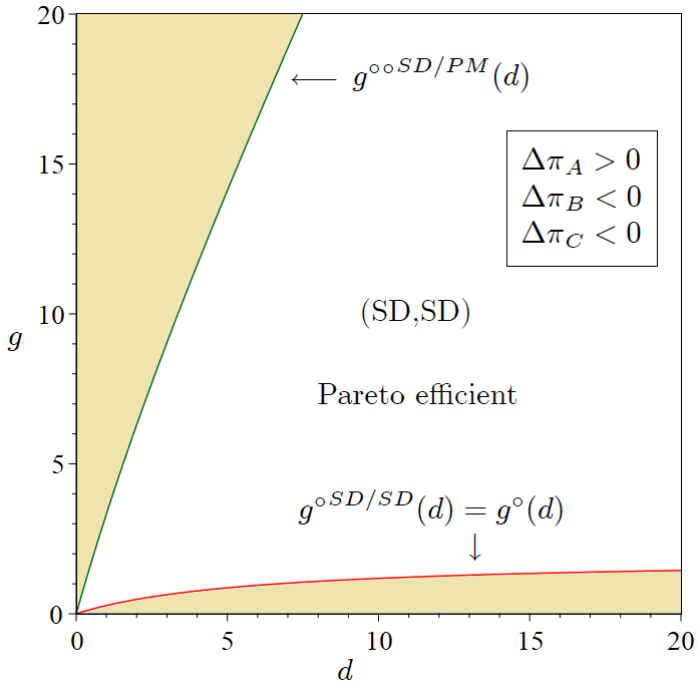

Figure 2. SD versus PM with trade unions and negative environmental externalities, Nash equilibria in the parameter space (d, g). Technical feasibility requires that $g > g^{\circ SD/SD}(d) = g^{\circ}(d)$ (as discussed so far) and $g < g^{\circ\circ SD/PM}(d)$, which is required to guarantee that emissions are positive for the SD firm in the asymmetric sub-game SD/PM. This constraint implies that the public environmental awareness should not be too high to avoid levying an (excessively high) environmental tax rate not compatible with the existing technology (negative emissions). The sand-coloured regions represent areas of technical non-feasibility. In the (white) feasible region, the signs of the profit differentials are $\Delta_A > 0$, $\Delta_B < 0$, and $\Delta_C < 0$ (the Nash equilibrium (SD,SD) is Pareto efficient) for any $g^{\circ SD/SD}(d) < g < g^{\circ\circ SD/PM}(d)$, and $d > 0$.

7 . Extensions

In this section, we briefly report the results of some extensions of the basic model, whose detailed analytical results can be found in the online appendix.

The first extension analysed considers n-firm oligopoly model with centralized wage setting, i.e., the presence of an industry-wide union fixing a uniform wage for all workers in the sector. The qualitative results of the model are confirmed also under this configuration. However, some remarkable facts arise, briefly discussed here.

First, in the presence of an industry-wide union, firms in oligopoly offer a positive bonus to their managers. Fanti and Meccheri (2013) provide the rationale for this result. A positive bonus makes managers more aggressive concerning output (and therefore employment), and as explained, this leads unions to raise wages. A penalty on quantities allows owners to curb unions' wage demands, hence leading to higher profits. However, in the presence of an industry-wide union, owners lose the advantage of 'tuning' the sales aggressiveness of their managers to lessen the union wage

demand: centralization internalizes inter-union competition, which causes a reduction in wage costs and an increase in profits via sales delegation to the manager.

Second, the optimal environmental tax with unionization is lower than that under a perfectly competitive labour market. For the precise case of $n = 2$, the optimal environmental tax is identical to the one with decentralized unions. The intuition behind this result is that higher wages set by the union lead the government not to impose a tax rate that would hinder production by increasing the firms' marginal costs. Given that pre- and post-tax output levels are identical, regardless of the unionization structure, firms under unionization have the same incentive to abate pollution. This result implies that, in a duopoly pollution, environmental damage and social welfare are unaffected by the unionization structure; the different wage setting has a simple redistributive effect of income among firms and workers.

Third, increasing competition in the product market generates higher pollution and environmental damage levels, leading the government to set higher environmental taxes. Moreover, a more competitive product market increases the parametric region in which firms' profitability under unionization is higher than that under competitive labour markets. Finally, the standard result that social welfare under non-unionization is higher than that with unions always apply; the positive effect of output expansion more than offsets the impact of environmental degradation.

The second extension considers a duopoly model with decentralized unions and conjectural variations. The rationale for this choice is that n-firm oligopoly model with decentralized wage setting is analytically complex to be treated. The conjectural variation model captures with one parameter a wide range of competition structures (from −1 for perfect competition to 1 for full collusion). Therefore, insights into the impact of product market competition with decentralized unions can be more easily derived. Also in this case, the qualitative results of the basic model are confirmed. The effects of increasing competition are qualitatively identical to those described in the extension discussed above. However, a result is worth noting. With decentralized unions, when the product market becomes adequately competitive (for instance, a value of the conjectural parameter of −.5 is already sufficient), the profits under unionization are always higher than those with competitive labour markets in the relevant range of the model. The rationale for this result is as follows. On the one hand, the direct effect of output expansion on revenues tends to increase profits. On the other hand, the indirect negative effect of output expansion lowers the price level. The presence of unions increases wages, reduces production, and, via the pass-through effect of costs, allows prices not to fall too drastically. Consequently, there is a less intense direct effect of output but an even less negative indirect effect on prices and revenues. The latter effect dominates the former, leading to increasing profits.

8 . Concluding remarks

This research investigated how governments can establish an optimal environmental tax in imperfect competitive industries. It analysed in detail a standard Cournot duopoly augmented to consider that in the actual world 1) labour markets are often unionised (studying the case of firm-specific monopoly unions that set wages); and 2) firms hire managers instructed to depart from the strict profit-maximising behaviour. The article specifically focused on the effects of unionisation on the environmental damage, environmental taxes, and firms' profitability. Results showed, on the one hand, that the trade union behaviour always reduces both environmental taxes and environmental damages; on the other hand, it might improve firms' profitability, provided that the abatement technology is not efficient, and the evaluation of the environment by the government is adequately high. The positive relationship between unionisation (i.e., higher wages) and profits challenges the common wisdom and is due to the presence of pollution and environmental policy.[15] The rationale for the fact that firms polluting the environment might prefer higher unionised wages is that unions induce the government to set lower environmental taxes, and this reduction of the tax burden means an increase in profits. This profit-enhancing effect could, under opportune levels of abatement costs and public environmental interest, overweigh the profit-reduction effect of the higher wage costs due to the unionisation.

Our results provide several testable implications: 1) in countries with managerial delegation practices, expensive (i.e., inefficient) abatement technologies, and sufficient care for the environment, unions would be more widespread and eagerly approved by firms, and 2) there should be higher environmental taxes in industries with competitive labour markets.

Further research is called to check the robustness of these results. A first issue is that the model implicitly assumes perfect information, but there is evidence of asymmetric information between polluters and regulators regarding production and abatement costs. Usually, the regulator does not know the type of abatement technology that the polluter has chosen to use, which thus remains private information. Those asymmetries offer a subject worth investigation. Moreover, our findings need to be tested in the presence of different 1) instruments of environmental policy (e.g., emission permits); 2) modes of competition with differentiated products (e.g., Bertrand and Cournot), 3) labour market institutions (e.g., bargaining arrangements), 4) the endogenous location of polluting firms (Markusen, 1997), and 5) partial cross-ownership (Bárcena-Ruiz and Campo, 2012).

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[15] We recall that also a context of managerial delegation is needed because it implies lower wages by itself.

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