Hacienda Pública Española / Revista de Economía Pública, 196-(1/2011): 65-78

Production externality and productivity of labor*

JUAN CARLOS BÁRCENA-RUIZ**
University of the Basque Country

Recibido: Enero, 2010
Aceptado: Febrero, 2011

Abstract

In this paper we consider two imperfectly competitive industries, with the polluting emissions from one industry harming the productivity of labor in the other. The polluting industry has to pay an environmental tax chosen by the government. In this framework, we analyze how the different organizational structure adopted by workers affect the environmental tax set by the government, total pollution emissions from the polluting industry and the productivity of workers in the industry that suffers the externality. We obtain that this depends on the degree to which pollution emissions from the polluting industry affects the marginal product of labor in the other industry.

Keywords: Production externality, productivity of labor, environmental taxes, imperfect competition, unionized labor.

JEL classification: J51, D62

1. Introduction

One of the questions analyzed by the literature on the environment is the environmental policy implemented by governments when firms produce pollutant emissions. There are many studies that assume that environmental damage is exogenous for consumers and producers (see, for example, van der Ploeg and Zeeuw (1992), Ulph (1996), Requate (2006)). However, environmental damage is endogenous when pollution affects the marginal product of labor and lowers the competitiveness of environmentally sensitive industries. Thus, this

* I wish to thank two referees for helpful comments. Financial support from Departamento de Educación, Universidades e Investigación del Gobierno Vasco (IT-223-07) and Ministerio de Ciencia y Tecnología and FEDER (SEJ2006-05596, ECO2009-07939) is gratefully acknowledged.
** Departamento de Fundamentos del Análisis Económico I, Facultad de Ciencias Económicas y Empresariales, Universidad del País Vasco. Avenida Lehendakari Aguirre, 83; 48015 Bilbao, Spain. Phone: 34+94 601 38 29; Fax: 34+94 601 38 91; e-mail: juancarlos.barcena@ehu.es

paper seeks to analyze the choice of environmental policy (an environmental tax) by governments when the firms of one industry inflict a negative production externality on the firms of another. We assume that these industries are imperfectly competitive.

There are examples in which pollutant emissions generated by one firm negatively affect the production processes of other firms, thereby creating a detrimental externality in production. This is the case, for example when manufacturing industries pollute watersheds on which fisheries depend, or electricity generation contributes to acid rain, damaging forests required for lumber production. Another example is given by the noise generated by road traffic, rail traffic, industry and recreational activities. The European Environment Agency (2001) points out that in highly industrialized European countries more than 50 per cent of the population are exposed to noise levels from transport which are above the level at which people become seriously annoyed. Noise causes physiological stress, affects mental health and influences performance and productivity.

There are few papers analyzing the above question. They consider that pollutant emissions from one industry harm the marginal product of labor in another industry. In this regard, Copeland and Taylor (1999) show that pollution can provide a motive for trade by spatially separating incompatible industries. Benarroch and Thille (2001) analyze the effects of transboundary pollution on trade and welfare. Williams III (2002) presents a model of environmental regulation under which pollution can have a wide range of different effects, including not only direct effects on utility but also productivity effects in different industries and a range of health effects. However, although these papers assume that emissions from one industry harms the marginal product of labor in others they do not consider that firms abate emissions and they assume that firms pay labor its marginal product and, thus, there is no wage bargaining. Moreover, only Williams III (2002) considers environmental regulation; however, he assumes that the government sets a tax per unit of the pollutant good instead of a tax per unit of pollutant emissions[1].

We assume in this paper that there are two imperfectly competitive industries, with one firm in each industry. Firms produce goods that are independent in demand. Production in one industry confers a negative externality (pollution) on the marginal product of labor in the other. The government sets an environmental tax per unit of pollutant emitted by the polluting industry. The polluting industry has technology available for abating the pollutant. The only factor used in the production process, in both industries, is labor. We consider three different wage setting structures. First, wages are exogenously given; in this case, workers get the opportunity wage. Second, there is an independent union in each firm. And, finally, workers at the two firms are organized in a single union. Following the monopoly-union model in Booth (1995), when wages are not exogenously given unions set the wage and, once the wage is set by the unions, firms choose the employment level.

We find that unions set higher wages when workers are organized in a single union than when there is an independent union in each firm, and in both cases wages are higher than the reservation opportunity wage. It must be noted that this result is not due to the fact that work-

ers are stronger under centralized negotiations, but rather to the fact that a single union internalizes the damage caused by the polluting firm to the productivity of labor of the other firm[2].

When wages are exogenously given there are two types of distortion (see Barnett (1980), Kennedy (1994)): the distortion due to the damage caused by the pollutant emissions of the polluting firm, and the underproduction associated with the exercise of the market power of this firm. The environmental tax reduces the damage caused by the polluting firm but it also causes it to reduce its production further. Therefore, the government sets a tax below marginal damage to avoid an excessive reduction in the production level of the polluting firm. When the degree to which pollution emissions from the polluting firm harm the marginal product of labor in the other firm (damage to the marginal product of labor) is low enough, the latter outweighs the former and the government sets a tax of zero. By contrast, when the damage to the marginal product of labor is high enough, the government sets a positive tax.

When unions decide the wage, they set a wage above the reservation opportunity wage. Thus, for a given tax, the output of the firms is lower than when wages are exogenously given. As a result, the distortion due to the damage caused by pollutant emissions is weakened, and the distortion due to the underproduction associated with the exercise of the market power of the firms is stronger than when wages are exogenously given. This means that the government does not set a positive tax for a wider range of values of damage to the marginal product of labor than when the wages are exogenously given. Moreover, the tax set by the government is as least as high when wages are exogenously given as when the wage is set by unions.

When workers are organized in a single union, wages are higher than when there is an independent union in each firm. This means that when there is a single union the first type of distortion is weakened, and the second type is stronger than when there is an independent union in each firm. As a result, the government does not set a positive tax for a wider range of values of damage to the marginal product of labor than when there is an independent union in each firm. However, the tax set by the government is as least as high when there is an independent union in each firm as when there is a single union.

Total pollutant emissions are greater when workers are organized in independent unions than they are in a single union. As wages are higher when workers are organized in a single union production is lower. Moreover, the tax set by the government and thus the total pollution abatement level is as least as high when there is an independent union in each firm as when there is a single union. In this case, the higher output level has a stronger effect than the greater emission abatement level and thus pollutant emissions are greater when workers are organized in independent unions. As the marginal product of labor in the polluted firm depends on the total pollution emission level of the polluting firm, and the greater the total emissions of this firm the lower the marginal product of labor in the polluted firm, it is obtained that the marginal product of labor of the polluted firm is higher when workers are organized in a single union. However, total pollutant emissions and thus the marginal product

of labor of the polluted firm can be higher or lower when wages are exogenously given than when unions set the wage[3]. This result depends on the degree to which pollution emission from the polluting firm harms the marginal product of labor in the other firm.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 shows the results, and Section 4 draws conclusions.

2. The model

We consider a model with two industries, denoted by Y and X. There is one firm in each industry. The inverse demand function for product k is:

$$p_k = A - q_k,\ k = Y, X, \qquad [1]$$

where p_k is the price in force in industry k and q_k is the output level of firm k.

There is a pollutant associated with the production of good X and each unit of good X produced gives rise to one unit of pollution which reduces the marginal product of labor in firm Y. If firm X chooses output level q_X and pollution abatement level a_X, its total pollutant emissions are: $e_X = q_X - a_X$. Therefore, the emission level of firm X depends on its output and its abatement effort. Following David and Sinclair-Desgané (2005) we assume that the emission level is additively separable. For example, an investment in end-of-pipe abatement does not modify the production process and so does not affect the amount of pollution attributable to each unit produced. However, there is technology available for abating this pollutant. Following Ulph (1996) we assume that the total cost of pollution abatement cost for firm X is[4]: $CA_X = d(a_X)^2$. Parameter d is set equal to 1 without loss of generality.

The only factor used in the production process, in both industries, is labor. Firm k hires L_k workers with a uniform wage rate w_k. We consider three cases. First, there is no wage bargaining and workers get their reservation opportunity wage, w_k, which is the same in both industries; this can be interpreted as the wage earned in the competitive sector. Second, there is an independent union in each firm and the utility function of the union in firm k is: $U_k(w_k, L_k) = (w_k - w_r)L_k$, $k=X, Y$. Thirdly, there is a single union that sets the wages in the two firms whose objective function is: $U_X(w_X, L_X) + U_Y(w_Y, L_Y) = (w_X - w_r)L_X + (w_Y - w_r)L_Y$.[5] We consider the monopoly-union model to determine the wage set in each firm in the second and third cases (see Booth, 1995). This model assumes that the union chooses the wage while the firm chooses the employment level once the wage is set by the union. Therefore, the union has full bargaining power when setting the wage.

The technology for producing the good in industry X is: $q_X = L_X$. The pollutant emissions from firm X reduce the marginal product of labor in firm Y. The production technology in firm Y is linear in the amount of labor hired. However, the marginal product of labor in firm Y depends on the total polluting emissions of firm X:

$$q_Y = \frac{L_Y}{1+\beta e_x}, \qquad [2]$$

where parameter β represents the degree to which emissions from firm *X* harm the marginal product of labor (*MPL*) in firm *Y*. From [2], it is obtained that the marginal product of labor in firm *Y* is: $MPL = \frac{\partial q_Y}{\partial L_Y} = \frac{1}{1+\beta e_X}$ · Therefore, the marginal product of labor in firm *Y* strictly decreases with the pollutant emission level of industry *X* ($\partial MPL/\partial e_X<0$).[6] If $\beta=0$, $q_Y = L_Y$ and thus pollutant emissions do not harm firm *Y*. If $\beta>0$, the marginal product of labor in firm *Y* decreases with parameter β. We assume that $\beta<5/(6w_r) = \bar{\beta}$ to guarantee that the total emission level of firm *X*, e_X, is non negative when there is no wage bargaining. This assures a positive emission level in the other two cases.

The government sets an environmental tax, *t,* per unit of pollutant emitted by firm *X*. Given that firm *X* has to pay the tax and to abate emissions, its profit is given by:

$$\pi_X = (A - q_X)\, q_X - w_X L_X - t\,(q_X - a_X) - d\,(a_X)^2, \qquad [3]$$

where $L_X = q_X$. Firm *Y* does not pollute and, thus, it neither pays a tax nor abates pollutant emissions. Its profit is given by:

$$\pi_Y = (A - q_Y)\, q_Y - L_Y\, w_Y, \qquad [4]$$

where, from equation [2], $L_Y = q_Y(1+\beta(q_X - a_X))$.

The objective function of the government includes the producer surplus in industries *X* and *Y* (PS_X and PS_Y), the surplus obtained by consumers when acquiring goods *X* and *Y* (CS_X and CS_Y), the utility of the workers in industries *X* and *Y* (U_X and U_Y), and the total taxes collected by the government, *T*:

$$W = CS_X + CS_Y + PS_X + PS_Y + U_X + U_Y + T. \qquad [5]$$

Given that firm *X* pays a tax of *t* per unit of pollutant emitted, the total taxes collected by the government are: $T=te_X$. Moreover, as goods *X* and *Y* are independent in demand, the consumer and producer surplus in industry *k*, respectively, are: $CS_k=(q_k)^2/2$ *and* $PS_k=\pi_k$, $k=Y, X$. Union rents are included as that part of the producer surplus which is absorbed by the unions (see, for example, Brander and Spencer (1988), Ulph (1996), Bárcena-Ruiz and Garzón (2003)).

The timing of the game is the following. In the first stage, the government chooses the environmental tax that firm *X* has to pay. In the second stage, wages are set simultaneously by the unions (when the wage is not exogenously given). In the third stage, firms simultaneously choose the output (employment) and pollution abatement levels. The game is solved

by backward induction from the last stage of the game to obtain a subgame perfect Nash Equilibrium.

3. Results

In the third stage, firm X chooses the output (and thus, the employment) level, q_X, and the abatement level, a_X, that maximize its profit (equation [3]). Firm Y chooses the output level, q_Y, and the employment level, L_Y, that maximize its profit (equation [4]). Solving these problems it is obtained that:

$$q_X = L_X = \frac{1}{2}(A - t - w_X),\ q_Y = \frac{1}{4}(A(2 - w_Y\beta) - w_Y(2 - 2t\beta - w_X\beta)),$$
$$L_Y = \frac{1}{8}(2 + \beta(A - 2t - w_X))(A(2 - w_Y\beta) - w_Y(2 - 2t\beta - w_X\beta)), a_X = \frac{t}{2}. \quad [6]$$

Expression [6] shows that $a_X = t/2$, which is the usual condition that firm X abates emissions to the point where marginal abatement cost equals the tax (see Ulph (1996)).

3.1. There is no wage negotiation (N)

In this case, workers get their reservation opportunity wage, w_r, which is the same in both industries: $w_X = w_Y = w_r$. In the first stage of the game the government chooses the environmental tax, t, that maximizes social welfare (expression [5]). Solving this problem we obtain that the environmental tax, t^N, is positive if and only if $\beta > \beta^N$, where $\beta^N = (3-\sqrt{3})/(3w_r) < \overline{\beta}$. The expressions for t^N, e_X^N and MPL^N are relegated to Appendix A.

Given that firm X is an imperfectly competitive firm whose production reduces the marginal product of labor in firm Y, there are two types of distortion: the distortion due to the damage caused by pollutant emissions from firm X, and the underproduction associated with the exercise of the market power of the firms. The environmental tax reduces the damage caused by firm X but it also causes the firm to reduce its production further. Therefore, the government sets a tax, t^N, below marginal damage to avoid an excessive reduction in the production of firm X. When $\beta \leq \beta^N$ the degree to which polluting emissions from firm X harm the marginal product of labor in firm Y is low enough. As a result, the second type of distortion has a greater effect than the first one and the government does not set an environmental tax. By contrast, when $\beta > \beta^N$, the government sets a positive tax since the marginal damage caused by pollutant emissions from firm X is high enough.

3.2. There is an independent union in each firm (F)

In the second stage, union k chooses the wage, wk, that maximizes its utility function. Solving these problems it is obtained that:

$$w_X = w_r + \frac{1}{2}(A - w_r - t), w_Y = w_r + \frac{(A - w_r)(4 - w_r\beta) + 3tw_r\beta}{2(4 + \beta(A - w_r) - 3t\beta} \quad [7]$$

Given that firm X has to pay the tax, it is easy to see from equations [6] and [7] that its output and emission levels decrease with the tax ($dq_X / dt < 0$, $de_X / dt < 0$). As a result, the wage paid by firm X decreases with the tax ($dw_X / dt < 0$). Moreover, as the total level of polluting emissions of firm X decreases with the tax, the marginal product of labor in firm Y and the wage paid by this firm increase with the tax ($dMPL / dt > 0$, $dw_Y / dt > 0$).

In the first stage of the game, the government chooses the environmental tax t that maximizes social welfare (expression [5]). Solving this problem we obtain that the environmental tax, t^F, is positive if and only if $\beta > \beta^F$, where $\beta^F = 2(7-\sqrt{21})/(7w_r) < \overline{\beta}$. The reason for this result is the following: When $\beta \leq \beta^F$, the degree to which pollutant emissions from firm X harm the marginal product of labor in firm Y is low enough. As a result, the government does not set an environmental tax. By contrast, when $\beta > \beta^F$, the government sets a positive tax since the marginal damage caused by pollutant emissions from firm X is high enough. The expressions for t^F, e_X^F, MPL^F, w_Y^F and w_X^F are relegated to Appendix B.

3.3. Workers are organized in a single union (S)

In the second stage, the single union chooses wages, w_X and w_Y, that maximize the aggregated utility of the workers of the two firms. Solving this problem it is obtained that:

$$w_X = w_r + \frac{(2 + w_r\beta)((A - w_r)(4 - w_r\beta) - 2tw_r\beta)}{16 - w_r^2\beta^2},$$
$$w_Y = w_r + \frac{2(A - w_r)(4 - w_r\beta) - 6tw_r\beta}{(A\beta + 4)(4 - w_r\beta) + 12t\beta}. \quad [8]$$

As in the above section, we obtain that the output and emission levels of firm X decrease with the environmental tax ($dq_X / dt < 0$, $de_X / dt < 0$). As a result, the wage paid by firm X decreases with the tax while the wage paid by firm Y increases with the tax ($dw_X / dt < 0$, $dw_Y/dt > 0$).

In the first stage of the game, the government chooses the environmental tax t that maximizes social welfare (expression [5]). Solving this problem we obtain that the environmental tax, t^S, is positive if $\beta > \beta^S$, where $\beta^S = (\sqrt{73}-7)/(2w_r) < \overline{\beta}$. For the remaining values of parameter β, $t^S = 0$. The reason for this result is the following: When $\beta \leq \beta^S$, the government does not set an environmental tax since the degree to which pollutant emissions from firm X harm the marginal product of labor in firm Y is low enough. By contrast, when $\beta > \beta^S$, the government sets a positive tax. The expressions for t^S, e_X^S, MPL^S, w_Y^S and w_X^S are relegated to Appendix C.

3.4. Comparison of results

It is easy to see that $0<\beta^N<\beta^F<\beta^S<\overline{\beta}$. From the results obtained in the three cases considered we obtain the following.

Proposition 1. *When the pollutant emissions from firm X reduce the marginal product of labor in firm Y, in equilibrium:* $w_X^S > w_X^F > w_r$ *and* $w_Y^S > w_Y^F > w_r$.

This proposition shows that wages are higher when there is a single union than when there is an independent union in each firm. Moreover, when labor is unionized wages are higher than the reservation opportunity wage, w_r. The reason for this result is the following: As goods are independent in demand, when firm *X* does not harm the productivity of labor in firm *Y* the wage set by unions is the same in both cases. However, if firm *X* harms firm *Y*, when there is a single union it internalizes the damage that firm *X* causes to the productivity of labor in firm *Y*. The marginal productivity of labor in firm *Y* increases with the wage paid by firm *X*. Then, the wage paid by firm *Y* increases with the wage paid by firm *X*. As a result, when there is a single union it sets higher wages in the two firms than when there is an independent union in each firm. It should be noted that the result shown in this proposition is not due to the fact that workers are stronger under centralized negotiations, but rather to the fact that the union internalizes the environmental damage caused by firm *X*.

From the results obtained in the three cases considered we also obtain the following.

Proposition 2. *When the polluting emissions from firm X reduce the marginal product of labor in firm Y, in equilibrium: (i) if* $\beta>\beta^S$, *then* $t^N>t^F>t^S>0$; *(ii) if* $\beta^S\geq\beta>\beta^F$, *then* $t^N>t^F>t^S=0$; *(iii) if* $\beta^F\geq\beta>\beta^N$, *then* $t^N>t^F=t^S=0$; *and (iv) if* $\beta^N\geq\beta$, *then* $t^N=t^F=t^S=0$.

This proposition shows that the range of values of parameter β for which the government does not protect firm *Y* (i.e., the environmental tax is zero) is wider when there is a single union and smallest when there is no wage bargaining ($\beta^S>\beta^F>\beta^N$). Moreover, the tax set by the government is as least as large when wages are exogenously given as when there is an independent union in each firm, and in this case the tax is as least as large as when there is a single union.

As seen in Subsection 3.1, when wages are exogenously given there are two types of distortion: the distortion due to the damage caused by pollutant emissions from firm *X*, and the underproduction associated with the exercise of the market power of the firms. The environmental tax reduces the damage caused by firm *X* but it also causes the firm to reduce its production further. When β is low enough ($\beta\leq\beta^N$), the second type of distortion has a greater effect than the first and the government sets a tax, t^N, of zero. By contrast, when $\beta>\beta^N$, the government sets a positive tax since β is high enough.

When there is an independent union in each firm, as seen in Proposition 1, unions set a wage above the reservation opportunity wage: $w_k^F > w_r$, $k=X, Y$. This implies that, for a given

tax, the output of the firms is lower than when wages are exogenously given. As a result, the distortion due to the damage caused by pollutant emissions from firm X is weakened, and the distortion due to the underproduction associated with the exercise of the market power of the firms is greater than when wages are exogenously given. This means that $\beta^F > \beta^N$ and, thus, the government does not set a positive tax for a wider range of values of β than when the wages are exogenously given. Moreover, the tax set by the government is as least as large when wages are exogenously given as when there is an independent union in each firm.

When there is a single union, as seen in Proposition 1, wages are higher than when there is an independent union in each firm ($w_k^S > w_k^F$, $k=X, Y$). This means that when there is a single union the first type of distortion is weakened, and the second type of distortion is stronger than when there is an independent union in each firm. As a result, $\beta^S > \beta^F$ and thus the government does not set a positive tax for a wider range of values of β than when there is an independent union in each firm. Moreover, the tax is as least as large when there is an independent union in each firm as when there is a single union.

It can be shown that $e^N > e^F$ if and only if $\beta < \beta^1$, and that $e^N > e^S$ if and only if $\beta < \beta^2$, where $\beta^1 = (27 - \sqrt{313})/(13\ w_r)$, $\beta^2 = 14/(19\ w_r)$, and $0 < \beta^N < \beta^F < \beta^1 < \beta^2 < \beta^S < \overline{\beta}$. Comparing total pollutant emission levels of firm X obtained in the different cases, we obtain the following result.

Proposition 3. *When the pollutant emissions from firm X reduce the marginal product of labor in firm Y, in equilibrium: (i) if $\beta^1 > \beta$, then $e^N > e^F > e^S$; (ii) if $\beta^2 > \beta \geq \beta^1$, then $e^F > e^N \geq e^S$; and (iii) if $\beta \geq \beta^2$, then $e^F > e^S \geq e^N$.*

To explain the result obtained in this proposition it must be noted that the total pollutant emission level of firm X is: $e_X = q_X - a_X = q_X - t/2$. Therefore, the total pollutant emission level depends on the output of the firms and on the environmental tax set by the government.

This proposition shows that the total pollutant emissions of firm X are greater when workers are organized in independent unions than in a single union ($e^F > e^S$). The explanation of this result is the following. Proposition 1 shows that the wages set by unions are higher in the first case ($w_X^S > w_X^F$), which means that production is lower in that case ($q_X^S < q_X^F$). Moreover, Proposition 2 shows that the tax is as least as high when there is an independent union in each firm as when there is a single union ($t^F \geq t^S$); this means that the total pollution abatement level of the firms is as least as great when there is an independent union in each firm as when there is a single union ($a_X^F > a_X^S$). In this case, the greater output level has a greater weight than the greater emission abatement and thus e^F is greater than e^S.[7]

This proposition also shows that the total pollutant emissions of firm X can be higher or lower when wages are exogenously given than when unions set the wage. The explanation of this result is the following. When β is low enough ($\beta^1 > \beta$), the environmental tax is low when the unions set the wage (in this case, $t^F = t^S = 0$ if $\beta^F > \beta$). Thus, output level has a greater effect than environmental taxes on the pollution abatement level. As a result, when β is low enough the total pollutant emission level is higher when wages are exogenously given than when the

unions set the wage. When β is high enough ($\beta \geq \beta^2$), the tax is high enough when the unions set the wage. Thus, the output level has less effect than environmental taxes on the pollution abatement level. As a result, when β is high enough the total pollutant emission level is lower when wages are exogenously given than when the unions set the wage. Finally, when β takes an intermediate value ($\beta^2 > \beta \geq \beta^1$) it is obtained that $e^F > e^N \geq e^S$. In this case, taxes have a greater effect than production when there is an independent union in each firm than when wages are exogenously given and thus $e^F > e^N$. By contrast, taxes have less effect than production when there is a single union than when wages are exogenously given, and thus $e^N \geq e^S$.

Next we compare the marginal product of labor in firm *Y* in the three cases considered. From Proposition 3 we obtain the following result.

Corollary 1. *When the pollutant emissions from firm X reduce the marginal product of labor in firm Y, in equilibrium: (i) if* $\beta^1 > \beta$, *then* $MPL^S > MPL^F > MPL^N$; *(ii) if* $\beta^2 > \beta \geq \beta^1$, *then* $MPL^S > MPL^N \geq MPL^F$; *and (iii) if* $\beta \geq \beta^2$, *then* $MPL^N > MPL^S \geq MPL^F$.

From expression [2] we have that the marginal product of labor in firm *Y* is: $MPL = 1/(1+\beta e_X)$. Therefore, it depends on the total pollutant emission level of firm *X*, e_X, and the higher the value of e_X, the lower the marginal product of labor in firm *Y*. Therefore, the result obtained in Corollary 1 is explained by the result obtained in Proposition 3.

4. Conclusion

One of the issues analyzed by the literature on the environment is the environmental policy implemented by governments when firms generate pollutant emissions. There are many studies that assume that environmental damage is exogenous for consumers and producers. However, pollution may affect the marginal product of labor, lowering the competitiveness of environmentally sensitive industries. In this case, pollutant emissions generated by one firm negatively affect the production processes of other firms, thereby creating a detrimental externality in production.

In this paper we analyze the choice of an environmental tax by the government when one industry inflicts a negative production externality on other industry. We consider that production in one industry confers a negative externality (pollution) on the marginal product of labor in the other. Firms are imperfectly competitive. The polluting industry has to pay an environmental tax chosen by the government. There are three different wage setting structures. First, wages are exogenously given. Second, there is an independent union in each firm. And, finally, the workers of the two firms are organized in a single union. In this framework, we analyze how the different organizational structures adopted by workers affect the environmental tax set by the government, total pollution emissions from the polluting industry and the productivity of workers in the industry that suffers the externality. We obtain that it depends on the degree to which pollution emissions from the polluting firm affect the marginal product of labor in the other firm.

One possible extension of this paper would be to consider more general functions. However, the resolution of the model becomes considerably more complicated. A conjecture on how the results may change is the following. The result obtained in Proposition 1 is due to the fact that a single union internalizes the damage caused by the polluting firm. In relation to Proposition 2, the output and emission levels of the firms and thus the tax set by the government in the different cases depend on the organizational form adopted by workers to set wages. Therefore, propositions 1 and 2 do not depend on the functional forms considered in the paper and these results should hold when more general functions are assumed. However, the result obtained in Proposition 3 (and Corollary 1) could change. As the total emission level of firm X affects the output level of firm Y, the total emission level of firm X could vary in a different way if an alternative function is assumed for the externality in production. Therefore, it is possible that some of the cases obtained in Proposition 3 (and Corollary 1) might not appear.

Another possible extension of this work is to consider that the revenue from environmental taxes is used to reduce labor taxes, thus increasing employment. However, if the reduction in labor taxes increases production and emissions in the polluting firm, such a policy might undo to some extent the effect of the environmental tax. Thus, it may be of interest to analyze whether to reduce labor taxes in both industries or only in the polluted industry. Moreover, tax revenues from environmental tax can be used to cut other taxes. This could contribute new insights to the analysis of the double dividend hypothesis. This is left for future research.

Notes

1. There are other papers that relate environmental policy with wage bargaining for other environmental problems. For example, Bárcena-Ruiz and Garzón (2003) analyze how the choice of environmental standards is affected by the existence of wage bargaining when firms' location is endogenous. Bayındır-Upmann (2004) studies the conditions under which a revenue-neutral environmental tax reform may yield an improvement in environmental quality and an increase in aggregate employment (an employment double dividend).

2. If there is no externality the optimal tax is zero and thus the two industries are independent in demand. Thus, the wage paid is the same in both cases, both when workers are organized in a single union and when there is an independent union at each firm. The relationship between the two industries is due to the externality that reduces the marginal product of labor in one industry. If the bargaining power of the union depended on the size of its total membership, the result would depend also on the fact that workers are stronger under centralized bargaining. In that case there is an additional effect that raises wages when workers are organized in a single union which, in its turn, lowers the environmental tax. Therefore, the main results obtained in the paper hold. However, an additional effect arises in the model due to the fact that workers are stronger under centralized bargaining.

3. How emissions and the marginal productivity of labor in the affected industry compare for the different wage setting arrangements depends on the different functional forms adopted. If more general functions are considered, given that the total emission level of one firm affects the output level of the other firm, the total emission level of the first firm could vary in a different way if an alternative function is assumed for the externality in production. Therefore, it is possible that some of the cases obtained might not appear.

4. The abatement technology considered in the paper can be better understood if we consider an alternative interpretation of the assumptions of the model (see Katsoulakos and Xepapadeas (1996)). Firm *X* undertakes R&D to develop an environmentally-clean production technology that reduces total emissions. The total emis-

sions of this firm are $q_X - a_X$, where a_X is the "technological knowledge" of firm X. To achieve knowledge a_X, the firm has to incur R&D expenditure given by the quadratic function CA_X.

5. The assumptions made in the model are standard in the relevant literature (see, for example, Dobson (1994), Symeonidis (2010)).

6. Benarroche and Thille (2001) assume that $q_Y = (1-\beta q_X)L_Y$. Thus, the production of good X (and its associated pollutant emission) reduces the productivity of labor in industry Y via a pollution externality. Similarly, Williams III (2002) assumes that the externality generated in the consumption or production of good X causes a negative externality that affects the health of the population causing labor to spend time sick. The time spent sick decreases with environmental quality.

7. This result could change if more general functions are considered. As the total emission level of firm X affects the output level of firm Y, the total emission level of firm X could vary in a different way if an alternative function is assumed for the externality in production. Therefore, it is possible that some of the cases obtained in Proposition 3 might not appear.

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Resumen

Suponemos en este trabajo dos industrias imperfectamente competitivas y que las emisiones contaminantes de una industria dañan la productividad del trabajo en la otra. La industria contaminante tiene que pagar un impuesto medioambiental fijado por el gobierno. En este marco, analizamos cómo se ve afectado el impuesto fijado por el gobierno, las emisiones totales de la industria contaminante y la productividad de los trabajadores de la industria que sufre el externalidad por la estructura organizativa adoptada por trabajadores. El resultado depende del grado en que las emisiones de la industria contaminante afectan al producto marginal del trabajo en la otra industria.

Palabras clave: externalidad en la producción, productividad del trabajo, impuestos medioambientales, competencia imperfecta, trabajo sindicado.

Clasificación JEL: J51, D62

Appendix A. No wage negotiation (*N*)

The tax set by the government is $t^N = \frac{(A-w_r)(2+3w_r\beta(w_r\beta-2)}{6(w_r^2\beta^2-1)}$, being positive if and only if $\beta > \beta^N$, where $\beta^N = (3-\sqrt{3})/(3w_r) < \overline{\beta}$. Then, if $\beta \leq \beta^N$: $t^N = a_X^N = 0$, $q_X^N = e_X^N = (A-w_r)/2$ and $MPL^N = \frac{2}{2+(A-w_r)\beta}$. If $\beta > \beta^N$: $t^N > 0$, $a_X^N = t^N/2$, $q_X = \frac{(A-w_r)(8-3w_r\beta(2-w_r\beta))}{12(11-w_r^2\beta^2)}$, $e_X^N = \frac{(A-w_r)(5-6w_r\beta)}{6(1-w_r^2\beta^2)}$ and $MPL^N = \frac{6(1-w_r^2\beta^2)}{6-5w_r\beta+A\beta(5-6w_r\beta)}$.

Appendix B. An independent union in each firm (*F*)

The tax set by the government is $t^F = \frac{(A-w_r)(16+7w_r\beta(w_r\beta-4))}{3(7w_r^2\beta^2-16)}$, being positive if and only if $\beta > \beta^F$, where $\beta^F = 2(7-\sqrt{21})/(7w_r) < \overline{\beta}$. Then, if $\beta \le \beta^F$: $t^F = a_X^F = 0$, $q_X^F = e_X^F = (A-w_r)/4$, $MPL^F = \frac{4}{4+(A-w_r)\beta}$, $w_Y^F = w_r + \frac{(A-w_r)(4-w_r\beta)}{2(4+A\beta-w_r\beta)}$ and $w_X^F = w_r + \frac{A-w_r}{2}$. If $\beta > \beta^F$: $t^F > 0$, $a_X^F = t^F/2$, $q_X^F = \frac{(A-w_r)(32-7w_r\beta(2-w_r\beta))}{6(16-7w_r^2\beta^2)}$, $MPL^F = \frac{16-7w_r^2\beta^2}{8(2-w_r\beta)+A\beta(8-7w_r\beta)}$, $e_X^F = \frac{(A-w_r)(8-7w_r\beta)}{16-7w_r^2\beta^2}$, $w_Y^F = w_r + \frac{4(A-w_r)(2-w_r\beta)}{A\beta(8-7w_r\beta)+8(2-w_r\beta)}$ and $w_X^F = w_r + \frac{(A-w_r)(32-14w_r\beta+7w_r^2\beta^2)}{48-21w_r^2\beta^2}$.

Appendix C. Single union (*S*)

The tax set by the government is $t^S = \frac{2(A-w_r)(4-w_r\beta)^2(w_r\beta(7+w_r\beta)-6)}{576-300w_r^2\beta^2+3w_r^4\beta^4}$, being positive if and only if $\beta > \beta^S$, where $\beta^S = (\sqrt{73}-7)/(2w_r) < \overline{\beta}$. Then, if $\beta \le \beta^S$: $t^S = a_X^S = 0$, $q_X^S = e_X^S = \frac{A-w_r}{4+r\beta}$, $MPL^S = \frac{4+w_r\beta}{4+A\beta}$, $w_Y^S = w_r + \frac{(A-w_r)(2+w_r\beta)}{4+w_r\beta}$ and $w_Y^S = w_r + \frac{2(A-w_r)}{4+A\beta}$. If $\beta > \beta^S$: $t^S > 0$, $a_X^S = (t^S)/2$, $e_X^F = \frac{(A-w_r)(96-92w_r\beta+4w_r^2\beta^2+w_r^3\beta^3)}{192-100w_r^2\beta^2+w_r^4\beta^4}$, $q_X^S = \frac{(A-w_r)(192-2w_r\beta(58+17w_r\beta)+w_r^3\beta^3(2+w_r\beta))}{576-300w_r^2\beta^2+3w_r^4\beta^4}$, $MPL^S = \frac{192-100w_r^2\beta^2+w_r^4\beta^4}{4(24(2-w_r\beta)-w_r^2\beta^2(2+w_r\beta))+A\beta(4(24-23w_r\beta)+w_r^2\beta^2(4+w_r\beta))}$, $w_X^S = w_r + (A-w_r)(2+w_r\beta)(192-140w_r\beta-w_r^3\beta^3)/(576-300w_r^2\beta^2+3w_r^4\beta^4)$ and $w_Y^S = w_r + \frac{2(A-w_r)(48-24w_r\beta-2w_r^2\beta^2-w_r^3\beta^3)}{4(48-24w_r\beta-2w_r^2\beta^2-w_r^3\beta^3)+A\beta(96-92w_r\beta+4w_r^2\beta^2+w_r^3\beta^3)}$.