Timing of environmental technological choice and trade unions' climate solidarity

Abstract

We consider a Cournot duopoly consisting of two geographically separated firms, each associated with a local environmental-friendly trade union that exhibits climate solidarity. In the basic model, firms choose abatement technologies prior to bargaining over wages and employment with the unions. We show that wage demanded is decreasing as the union's degree of climate solidarity increases, providing additional incentives for firms to adopt greener technology, hence improving the social welfare. In the alternative model, where trade unions decide the wages prior to the firms' abatement and employment decisions, the firms choose the dirtiest available technology implying that the union's climate solidarity has no effect on the firm's abatement decisions. These results suggest that establishing climate solidarity as a norm across trade unions can, depending on the timing of the environmental technological choice, become a powerful instrument in battling climate change, critically supplementing the as yet ineffective international policy framework.

Keywords: green trade unions, reciprocity, climate solidarity, emissions, environmental technology

JEL: D 43, L 13, J 50, Q 5

1. Introduction

The political challenges of the global coordination on climate change have been increasingly recognised, particularly after the former US administration announced its withdrawal from the Paris Agreement. Although the Biden administration has overturned this decision and US has re-joined the Paris Accords, it has become evident that climate change cannot be effectively addressed solely by governmental actions. The fight against environmental degradation and global warming requires the active participation of citizens in their capacity as consumers, investors, employees, etc. Such challenges point to the increasing research attentions on the complexity of the strategic interactions in socio-economic activities upon which the optimal policy could be designed to promote the self-reinforcing sociotechnical transitions. (Alkemade and de Coninck, 2021). In this context, there is a growing discussion on the strategic engagement of trade unions in issues such as environmental protection and climate change (*e.g.*, Felli, 2014; Stevis and Felli, 2015). As the environmental movement gains strength in the society, there is considerable pressure for climate solidarity (Rome 2003) among trade unions to deal with environmental problems (*e.g.*, Hampton, 2015; Brecher, 2018). Examples of labour organizations characterised by climate solidarity are the Trades Union Congress (TUC)[1] and the International Trade Unions Confederation. [2]

From the perspective of labour studies, the solidarity between trade unions is a strong area of interest. The cross-border cooperation of trade unions has been long studied in the literature (*e.g.*, Driffill and Van der Ploeg, 1993; Gordon and Turner, 2000). The transnational trade union solidarity actions and their effect on wages and employment has been extensively discussed both in the context of multinational firms' operations and in the context of labour equality issues across countries (*e.g.*, Gajewska, 2009; Greer and Hauptmeier, 2008 and 2012; Fougner and Kurtoğlu, 2011; Dufour Poirier and Hennebert, 2015). However, the climate solidarity of trade unions, an issue introduced in the literature by Hampton, (2015), and Brecher, (2018), has yet to be explored from an economic, technological, environmental and welfare perspective.

[1] https://www.tuc.org.uk/sites/default/files/extras/greener_deals.pdf
[2] https://www.ituc-csi.org/IMG/pdf/climat_EN_Final.pdf

The research question we aim to explore is how the trade unions' climate solidarity affects the firms' choices of abatement technologies.[3] We consider this research question to be important as technological innovation, either as a transition from more to less polluting production technologies or as improved abatement technologies, is a key factor for improving the environmental performance of firms and ensuring sustainability.[4] Furthermore, from a strategic behaviour perspective, we aim to answer the question how trade unions' climate solidarity could influence market outcome, emissions, and social welfare. The answers to these questions have interesting policy implications and they are especially relevant for designing environmental policies aiming at promoting investments in abatement technologies.

Our paper extends the work of Asproudis and Gil-Molto (2015) (A&GM hereafter) and Fanti and Buccella (2017) that embedded the environmental concerns of the local trade union into the wage bargaining process with a local firm and examine the impact of trade union greenness on the firms' abatement technology choices. They show that green trade unions can influence the firms' environmental technological choice and can encourage firms to adopt greener abatement technology. Our work differs on two dimensions. First, to fill up the gap of the overlooked climate solidarity, we assume that a trade union does not only care about the emissions generated by its paired-firm but it also internalizes, to some extent, damages from emissions generated by all other firms. We show that, under specific conditions, climate solidarity reinforces the positive impact of trade union greenness on the paired-firm's abatement choice driving all firms to adopt better abatement technologies. However, improvements in abatement technology are not always coupled by a reduction in emissions. Numerical analysis shows that, when the market size is relatively small, there is an inverse U-shaped relation between the level of abatement technology and total emissions. Second, our analysis uses two different timing frames with respect to the negotiations between a trade union and the respective firm.[5] Wage negotiations can take place before or

[3] The impact of trade unions on firms' technological choice and innovation has been explored by Dowrick and Spencer (1994), Tauman and Weiss (1987), Ulph and Ulph, (1988, 1989, 1994, 1998 and 2001).

[4] For example, Aldieri *et al.* (2020) and Long *et al.* (2020) show that environmental innovation is characterized by environmental knowledge spillovers that improve firms' technical efficiency, while Wang *et al.* (2021) show that environmental innovation has led to more sustainable utilization of water resources in China.

[5] The timing of technological choice is important and well explored in the economic literature from different aspects including for example the timing of environmental policy and the relation with environmental change, the firms' decision on timing of technological innovation etc. (see for example Dekimbe *et al*. (2000), Requate, (2005), Bibas *et al*. (2015), Kobos *et al*. (2018)).

after firms choose their abatement technology. The exact timing of the negotiations is determined by the type of abatement technology firms consider of installing and the length of the collective agreements.[6] If, for example, the abatement technologies considered have a long gestation period while collective agreements' length is short, it is logical to assume that wage negotiations precede the firm's choice of abatement technology. On the other hand, short gestation periods of abatement projects combined with relatively long-lived collective agreements infer that firms' abatement choices precede the wage negotiations. We argue that, depending on the timing of the negotiations, climate solidarity and trade unions greenness may have no effect on the choice of abatement technology.

In this framework we propose a theoretical model of two geographically distinct firm-union pairs where, as an expression of climate solidarity between the trade unions, each union cares about the emissions generated by its paired-firm but it also internalizes the emissions generated by the other firm. This could be the case of a home and a foreign firm-union pair where, each firm pollutes at a local level and each trade union cares for the level of the environmental damage in both countries (*i.e.*, transnational climate solidarity). On the other hand, the environmental solidarity can be embedded in firm's adoption of green technology via other mechanisms such as internal cultural recognition and technology spiller overs, as in Long *et al.* (2017) and Luo *et al.* (2020), or via directly stringent regulations Aldieri *et al.* (2020).

Following the established literature, we adopt the Monopoly Union model which is part of the Right-to-Manage approach to describe the wage bargain process within each firm-union pair.[7] Each firm is solely responsible for choosing an appropriate abatement technology. Firms may invest in abatement technologies for three main reasons: to comply with minimum environmental standards (Montero, 2002), to gain a competitive advantage (Asproudis and Filippiadis, 2021), or because of an external influence by green trade unions. We focus on the latter case.

We distinguish between two different time frames. In the basic model (BM) we follow the approach of Asproudis and Gil Molto (2015) and Fanti and Buccella (2017) where firms choose their abatement technology prior to bargaining with their respective union: In

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[6]According to Du Caju et al. (2009) "*the average length of collective agreements varies between one and three years in Europe and stands at one year in Japan*".

[7] See for example Oswald (1982), Petrakis and Vlassis (2004), Nickell and Andrews (1983), Espinosa and Rhee (1989), Booth (1995), Lopez and Naylor (2004), and Mukherjee (2008).

the first stage, firms decide their respective abatement technologies; in the second stage, trade unions decide wages; in the third stage the firms decide their production level. This can be the case where the choice of abatement technology requires changes in the production method. For example, to reduce the greenhouse gas emissions and improve the workers welfare, a power-producing plant can choose among different modes of generating electricity. We show that in the basic model the wages are decreasing in the degree of climate solidarity. This provides to the local firm sufficient cost-competitive incentives to adopt greener abatement technology and results in higher output, employment, and social welfare. The firm's optimal abatement technology under the BM scenario is greener compared to the case without climate solidarity. These results suggest that promoting climate solidarity, so as to eventually develop a norm across trade unions, can contribute significantly to battle global environmental problems without the need of policy intervention. Such a development is particularly important given the observed, even after the COP26, sluggishness in developing the necessary international policy framework to address the urgent environmental issues.

In the alternative model (AM) we assume that the trade unions decide wages prior to the firms' decision on abatement technology: In the first stage, the trade unions decide wages; in the second and third stage, firms decide the abatement technology and the production level, respectively. This can be the case where the choice of abatement technology does not require changes in the production method. For example, a refinery installs finer filters in the pipe (*i.e.*, less substantial green technology adoption). We show that, in this case, the firms' choices of abatement technology are not influenced by the wage-employment bargaining. Therefore, in such cases, trade unions, despite exhibiting climate solidarity, cannot affect firms' technological choice through the negotiation process.

Intuitively, the BM scenario reflects the firm's ability to commit to an abatement level, whereas under the AM scenario there cannot be such commitment. Consequently, in BM, technology is a truly strategic variable (*i.e.*, firms recognise it as a vehicle to influence the unions' choices of wages), whereas AM is equivalent to a model where technology is exogenous. Comparing the different timing frames, we show that, in both scenarios, wages decrease and production increases with the intensity of trade union climate solidarity. However, the effect of trade union climate solidarity on wages and output is stronger in the BM scenario. Moreover, in the BM scenario the abatement technology improves with the intensity of trade union climate solidarity while in the AM the firms will choose the dirtiest available technology irrespectively of the intensity of climate solidarity. Lower environmental damages and greater production in the BM compared to the AM are sufficient to ensure that in the BM the social welfare is greater than in the AM. Therefore, as the intensity of unions' environmental solidarity increases, environmental regulation must be stricter in industries where firms invest in abatement technology before wage negotiations take place.

2. Trade Unions and Environmental Protection. A brief presentation.

Historically, trade unions are an important part of the environmental movement that started in 1960s.[8] An increasing number of studies highlight trade unions' interest in environment protection and their collaboration with environmental groups.[9] Furthermore, trade unions participate in International Environmental Conferences and meetings actively supporting mitigation of international environmental problems.[10] Detailed analysis of green unionism's early development, is provided in Silverman (2006)'s literature review.

Furthermore, trade unions not only participate in international environmental negotiations, but they are also organised to larger international unions to enhance their influence in these meetings.[11] Such behaviour, exhibited in practice by trade unions consistently over the years, clearly justifies our assumption regarding solidarity among trade unions on international environmental problems.

The rest of the paper is organised as follows: in section three we develop the basic and the alternative model. In section four, the results of the two models are compared. Finally, section five concludes.

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[8] For details on the environmental movement see Rome (2003).

[9] See, among others, Truax (1992), Gordon (1998), Dewey (1998), Obach (1999, 2002, 2004), Bonanno and Blome (2001), Silverman (2004, 2006), Mayer (2009), Snell and Fairbrother (2010).

[10] According to Silverman (2004) "*trade union organizations like the International Confederation of Free Trade Unions, the International Trade Secretariats (Global Union Federations) and the European Trade Union Confederation, participated in a variety of international conferences and institutions such as the 1972 Stockholm Conference on the Environment, the 1992 Rio Earth Summit and the 2002 Johannesburg World Summit on Sustainable Development*".

[11] An example is trade unions' participation in climate negotiations under the United Nations Framework Convention on Climate Change. "*Trade union participation in the UNFCCC process is coordinated by the ITUC which claims to represent 200 million members in 163 countries and represents workers in multilateral institutions such as the United Nations (UN) and the International Labour Organization (ILO).*" (Thomas, 2021).

3. The model

Following A&GM we consider two geographically separated unionized firms indicated by $i, j = 1{,}2$ with $i \neq j$, producing a homogeneous product that is sold in a single market. Competition between the two firms which are at the same level on the supply chain is in quantities (à la Cournot). The inverse demand function is $p = a - q_i - q_j$, where $a > 0$ is the market size parameter, and q_i, q_j are the firms' outputs. Production exhibits constant returns to scale and it is described by $q_i = L_i$, where L_i represents the number of workers employed by firm i. The production process generates emissions, y_i, according to $y_i = k_i q_i$, where k_i is an abatement technology[12] allowing the reduction of the emissions rate per unit of output from 1 to $k_i \in (0,1]$ at a cost $\gamma(1 - k_i)^2$, where $\gamma > 0$ is a scale parameter.[13] This cost represents diminishing returns to investment in abatement technology.[14] The closer to one the value of technology k_i is, the lower the adoption cost and the more polluting the technology will be. Therefore, a firm's total cost, consisting of labour and abatement technology cost, is given by $C_i = w_i L_i + \gamma(1 - k_i)^2$, where w_i denotes the wage of firm i. The corresponding profits are $\pi_i = (a - q_i - q_j)q_i - w_i q_i - \gamma(1 - k_i)^2$. It should be noted that in the absence of any anti-pollution regulatory framework it will be optimal for the firms not to adopt any abatement technology and *race to the bottom.* It is only the trade unions environmental awareness that can motivate the firms, through the wage bargaining process, to invest in abatement technologies.

Each trade union cares about environmental quality at both locations. Therefore, trade union i's perceived damage from pollution is denoted by $(DF_i + zDF_j) = (ey_i + zey_j)$, where $z \in [0,1]$ represents the degree of climate solidarity of trade union i, and $e > 0$ is a scale parameter.[15] Furthermore, a trade union cares about the well-being of its members. This is expressed by the over-the-outside-option aggregate earnings from being employed by the

12 In this set up, a firm does not engage in an R&D activity to create a new environmentally friendly technology, but it rather adopts one from a spectrum of abatement technologies that are already available in the market. Therefore, there is no eco-innovation process and potential spill over effects to be considered in our model.

13 Hence, contrary to Puller (2006), an emissions reduction can be driven both by an improvement in abatement technology and a reduction in output.

14 This type of the technology could include the filters for the reduction of CO_2 or 'scrubbers' for the reduction of SO_2 emissions. For more details see Chao and Wilson (1993). The quadratic cost function for technology adoption captures the Kuznets Curve framework usually adopted in the empirical models such as Dauda *et al.* (2021).

15 Our model restrictions also require that $a > e$.

respective firm. If w_0 denotes the reservation wage these earnings are denoted by $(w_i - w_0)L_i$. In summary, the utility of trade union i can be expressed by $U_i = (w_i - w_0)L_i - (DF_i + zDF_j)$. For simplicity, for the remainder of this paper we have set the reservation wage equal to zero. After some substitutions and slight modifications, the trade union's utility is expressed by $U_i = L_i[w_i - (ek_i + zek_j)] - ze(L_j - L_i)k_j$.[16] The first term on the right-hand side shows that the trade unions utility increases with improvements in abatement technologies adopted by either of the two firms. The second term on the right-hand side expresses the competition effect showing the utility of trade union i's is decreasing in the difference between outputs of firms j and i.

Adopting the Monopoly Union model, we assume that the trade unions decide the wages while the firms decide the number of workers to be employed.

3.1 The Basic Model (BM)

In the basic model (BM) firms choose their abatement technology prior to bargaining with their respective union: In the first stage, firms decide abatement technologies; in the second stage, trade unions decide wages; in the third stage the firms decide their production level.

3.1.1 Stage three: Firms decide the production level

In the third stage, the firms decide their production levels. Assuming Cournot-type competition, the profit maximizing production levels, as it has been shown in A&GM, are

$$\hat{q}_i = L_i = \frac{a - 2w_i + w_j}{3} \tag{1}$$

Therefore, the profits are $\hat{\pi}_i = \hat{q}_i^2 - \gamma(1 - k_i)^2$.

Substituting the optimal quantity in the trade union's utility competition effect described earlier, yields $ze(w_i - w_j)k_j$. Thus, the relative production advantage of firm j to firm i is equal to the wage differential $(w_i - w_j)$. In other words, the trade unions are facing a trade-off between environmental protection and higher wage.

3.1.2 Stage two: Trade unions decide the wages

[16] $U_i = L_i\,[w_i - (w_o + ek_i)] - zeL_jk_j$ which we could rewrite to $L_i\,[w_i - (w_o + ek_i)] - ze(L_i - L_i + L_j)k_j = L_i\,[w_i - (w_o + ek_i)] - zeL_i\,k_j - ze(L_j - L_i)k_j = L_i\,[w_i - (w_o + ek_i + ze\,k_j)] - ze(L_j - L_i)k_j$.

On stage two, the trade unions simultaneously decide the wages. After the necessary substitutions and calculations, the utility maximization problem for each trade union becomes

$$\max_{w_i}\left\{U_i = \frac{1}{3}(w_i - ek_i)\big(a - 2w_i + w_j\big) - ek_j\big(a - 2w_j + w_i\big)z\right\} \tag{2}$$

Taking the first order conditions of the maximization problem above yields the reaction function of each trade union that is its own wage as a function of the other union's wage:

$$w_i^{rf} = \frac{1}{4}\big(a + 2ek_i + w_j - ek_jz\big) \tag{3}$$

We observe that $\partial w_i^{rf}/\partial w_j > 0$, implying that the wages are strategic complements. The intuition of the strategic complementarity between the trade unions has been explained in Petrakis and Vlassis (2004), if the union *j* sets higher wages, the level of the output of firm *j* will decrease but firm *i* will produce more. This induces union *i* to set higher wages to firm *i* when the rival firm deals with higher wages from the union *j*. Interestingly, since $\partial w_i^{rf}/\partial z < 0$, a trade union becomes less aggressive in the bargaining process with the degree of its climate solidarity. Intuitively, for any given wage chosen by trade union j, union i reduces its own wage to strengthen firm i's competition effect. This drives firm i's output higher and firm j's output and, *ceteris paribus*, emissions lower.

Solving simultaneously the reaction functions of the trade unions yields the equilibrium wages[17]

$$w_i = \frac{1}{15}\big(5a + e\big[k_i(8 - z) + 2k_j(1 - 2z)\big]\big) \tag{4}$$

Like in A&GM, $\partial w_i/\partial k_i > 0$, implying the wage chosen by union i decreases with improvements in abatement technology adopted by firm i. Moreover, we see that $\partial^2 w_i/\partial k_i \partial z = -e/15 < 0$. Thus, the more intense the climate solidarity is, the lower the trade union's incentive to penalize its respective firm for choosing dirtier technology.

However, contrary to A&GM the wages do not always increase with the rival firm's abatement technology: as $\partial w_i/\partial k_j = e(2 - 4z)/15$ it all depends on the level of the reciprocity. Hence, $\forall z \in [0, 1/2]$ a wage is increasing with the rival firm's abatement technology, while the opposite holds for $z \in [1/2, 1]$. Finally, as $\partial w_i/\partial z = -\frac{1}{15}e\big(k_i + 4k_j\big) < 0$, the wages are decreasing with the intensity of climate solidarity.

To compare our results with the results of A&GM where z=0, we can rewrite the wage as

[17] The SOC is negative and equal to -4/3.

$$w_i = \frac{1}{15}\left(5a + e\left[(8-z)\left(k_i + \frac{k_j}{4}\right) - k_j\left(\frac{7}{4}z\right)\right]\right)$$

The first part in the square brackets $e(8-z)(k_i + k_j/4)$ is always consistent with the predictions of A&GM, (*i.e.*, $\partial w_i/\partial k_i > 0$ and $\partial w_i/\partial k_j > 0$). The second part in the square brackets, $-k_j(7z/4)$, negatively contributes to the equilibrium wage (*i.e.*, $\partial w_i/\partial k_j < 0$) when $z > 0$. This effect increases in magnitude with z and k_j. This is consistent with the cost-competition effects as noted in Stage Three, which serves as sufficient incentive offered by trade unions to the firms for adopting better abatement technology in Stage One. Moreover, we can calculate the quantity competition effect by substituting the wage as expressed in equation (4) in equation (1). This yields the difference $q_j - q_i = e(\mathrm{k}_i - \mathrm{k_j})(2 + z)/5$. This implies that the relative production advantage of firm i to firm j is negatively linked to the improvements in abatement technology chosen in Stage One.

3.1.3 Stage one: Firms decide abatement technology

In the first stage, the firms choose the abatement technology. After substituting (4) in (1) we get

$$\bar{q}_i = \frac{1}{45}\left(10a + e\left[k_j(4+7z) - 2k_i(7+z)\right]\right) \tag{5}$$

Like in A&GM the production is increasing with improvements in own abatement technology ($\partial\bar{q}_i/\partial k_i < 0$) and decreasing in improvements of the rival's abatement technology ($\partial\bar{q}_i/\partial k_j > 0$).

Profit maximization is expressed as

$$\max_{k_i}\{\bar{\pi}_i = \bar{q}_i^2 - \gamma(1-k_i)^2\} \tag{6}$$

and solving simultaneously the resulting FOCs for $i = 1,2$ yields optimal technologies[18]

$$k_i^* = k_j^* = \frac{405\gamma - 4ae(7+z)}{405\gamma + 2e^2(z-2)(7+z)} \tag{7}$$

Substituting equation (6) in equations (4) and (5), yields optimal output, and wages:

$$q_i^* = q_j^* = \frac{45\gamma[2a + e(z-2)]}{405\gamma + 2e^2(z-2)(7+z)} \tag{8}$$

$$w_i^* = w_j^* = a - \frac{135\gamma[2a + e(z-2)]}{405\gamma + 2e^2(z-2)(7+z)} \tag{9}$$

[18] The SOC is negative for $\gamma > \frac{4e^2(7+z)^2}{2025}$. Therefore, hereafter we assume that this restriction applies.

Comparative statics analysis shows that, like in A&GM, the firms' abatement technology improves with the intensity of climate solidarity ($\partial k_i^*/\partial z < 0$). Intuitively, trade unions are accepting lower wages in exchange for greener production processes. This, in turn, provides to the local firm sufficient cost-competitive incentives to adopt greener abatement technology. Moreover, the firms' abatement technology improves with the market size ($\partial k_i^*/\partial a < 0$) and worsens with the cost of improvements in abatement technology ($\partial k_i^*/\partial\gamma > 0$).

Numerical analysis has been conducted to investigate additional dimensions of abatement technology's optimal choice. Parts (a), (b), and (c) of Table 1 show the optimal level of abatement technology (*i.e.*, k_i^*) for different sets of the model's parameter values, z, a, e, and γ.[19] As expected, the optimal abatement technology improves with climate solidarity intensity (*e.g.*, in any given column of the table, k_i^* decreases as we move down) and with the market size (*e.g.*, in any given row of any given part of the table, k_i^* decreases as we move to the right). Moreover, we observe the following:

(i) Optimal abatement technology improves at slower rate with the intensity of climate solidarity when the union's perceived damage from pollution is reduced. This is confirmed by comparing any given column of part (a) with the corresponding column of part (b) in the table.

(ii) Optimal abatement technology improves at slower rate with the intensity of climate solidarity when the cost of abatement increases. This is confirmed by comparing any given column of part (a) with the corresponding column of part (c) in the table.

	(a) $e = 1, \gamma = 0.5$			(b) $e = 0.8, \gamma = 0.5$			(c) $e = 1, \gamma = 1$		
	$a = 1$	$a = 3$	$a = 5$	$a = 1$	$a = 3$	$a = 5$	$a = 1$	$a = 3$	$a = 5$
$z = 0.1$	*0.99191*	*0.66830*	*0.34469*	*0.97056*	*0.72525*	*0.47994*	*0.99624*	*0.84599*	*0.69573*
$z = 0.5$	*0.95833*	*0.62500*	*0.29167*	*0.94896*	*0.69378*	*0.43860*	*0.98039*	*0.82353*	*0.66666*
$z = 0.9$	*0.92319*	*0.58179*	*0.24039*	*0.92603*	*0.66184*	*0.39765*	*0.96331*	*0.80027*	*0.63722*

Table 1: Optimal abatement technology, climate solidarity, and parameter values.

Moreover, wages decrease and output increases with the intensity of climate solidarity ($\partial w_i^*/\partial z < 0$, and $\partial q_i^*/\partial z > 0$), while output increases with market size ($\partial q_i^*/\partial a > 0$).

[19] All parameter values selected satisfy the necessary constraints. The robustness of the results presented in this table have been checked for a wide range of parameter values.

Such a positive sorting between the market size and intra-regional convergence of output and green production choice has also been observed empirically by Wang *et al.* (2019). Intuitively, as the climate solidarity of the trade unions intensifies, trade unions are willing to accept lower wages in exchange for improvements in abatement technologies by the firms. This trade-off is cost beneficial to the firms who can therefore hire more workers and expand production.

Result 1: In the Basic Model, the wages are decreasing, outputs and employment are increasing, and adopted abatement technology improves with the intensity of climate solidarity.

Individual firm's emission level is

$$y_i^* = \frac{45\gamma[2a+e(z-2)][405\gamma-4ae(7+z)]}{[405\gamma+2e^2(z-2)(7+z)]^2} \quad (10)$$

First, we observe that for relatively small market sizes emissions increase with the market size. However, there is a critical value, namely $a_{cv} = -\frac{1}{4}e(z-2) + \frac{405\gamma}{8e(7+z)}$, beyond which emissions start decreasing with market size. Part (a) of *Diagram 1*, demonstrates the inverted U-shape relationship between market size and emissions: in this contour plot the arrow line, drawn for a fixed value of climate solidarity (*z=0.4*), emissions level rise at first and then drop in the direction of the arrow. Moreover, optimal emissions do not change monotonically with the degree of climate solidarity. For any given level of the parameter values γ and e, emissions tend to increase with the intensity of climate solidarity when the market size is relatively small. However, this relationship is inverted for larger market sizes. Part (b) of *Diagram 1*, demonstrates this result: the arrow line on the left is drawn for small market size ($a = 2$) and emissions increase in the direction of the arrow showing a positive relationship between climate solidarity and emissions; the arrow line on the right is drawn for large market size ($a = 7.5$) and emissions decrease in the direction of the arrow showing a negative relationship between climate solidarity and emissions.

The above results indicate the existence of a *rebound effect*: adapting greener technologies due to intensification of climate solidarity does not necessarily lead to emission reductions. Climate solidarity among trade unions affects emissions through two channels. First, there is a *direct abatement effect*, where, as climate solidarity intensifies, firms invest in greener technologies resulting in emissions reduction. Second, there is an *indirect output* *effect*, where production increases due to the lower wages accepted by the unions in exchange for the adaptation of greener technologies by the firms. Higher output is associated with higher emissions. Even when the abatement effect is stronger than the output effect, the latter weakens the power of green trade unions with respect to emissions reduction. Moreover, when the output effect surpasses the abatement effect a backfire effect is emerging, where emissions increase with the intensity of climate solidarity. However, the probability of a backfire effect decreases with the market size, implying that climate solidarity is more important in trade unions associated with firms operating in large markets.

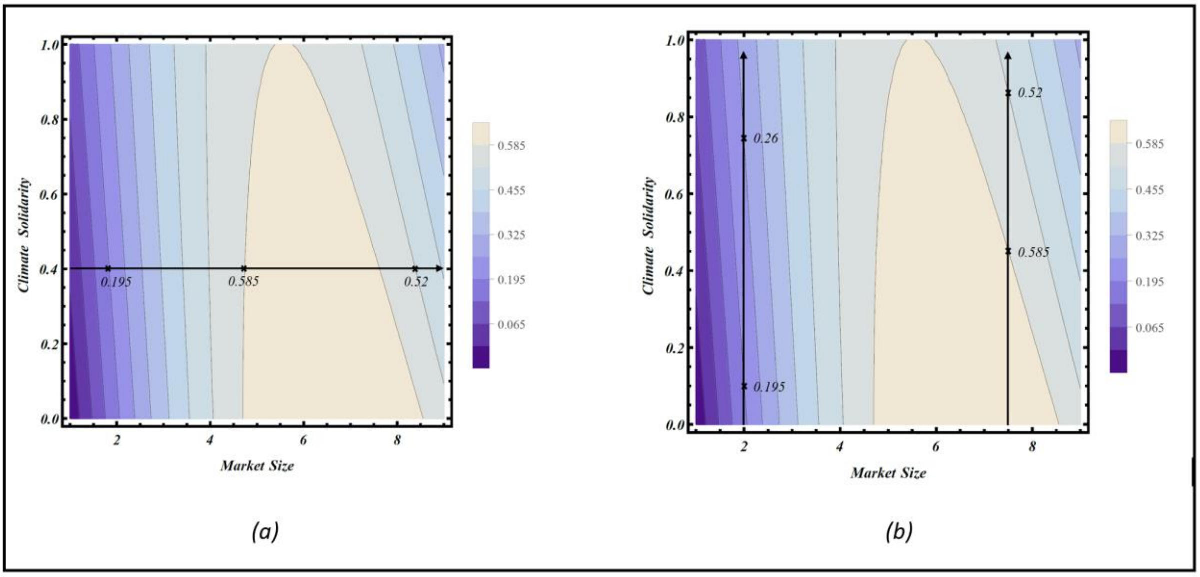

Diagram 1: Emissions, market size, and climate solidarity.[20]

Finally, we can calculate profits, trade union utility, and social welfare. The profits are

$$\pi_i^* = \frac{\gamma[2a+e(z-2)]^2[2025\gamma-4e^2(7+z)^2]}{[405\gamma+2e^2(z-2)(7+z)]^2} \tag{11}$$

Additionally, the damage function is $DF_i^* = ey_i^*$ and the Utility is

$$U_i^* = \frac{135\gamma[2a+e(z-2)][a(45\gamma+2e^2z(7+z)-45e\gamma(1+4z)]}{[405\gamma+2e^2(z-2)(7+z)]^2} \tag{12}$$

where for $0 < a < a^{cv}$ the utility is reducing in the market size and for $a > a^{cv}$ it is increasing in a with $a^{cv} = \frac{-2e^3(z-2)z(7+z)+45e\gamma(4+7z)}{180\gamma+8e^2z(7+z)}$. Finally, the SW[21] is

[20] In this diagram we have set the parameter values to $e = 1.2$ and $\gamma = 1$. The range of market size a in the diagram satisfies all necessary constraints.

[21] The formula of the SW = CS + PS + U_I^* + U_j^* + zDF_i^* + zDF_i^*

$$SW^* = \frac{2\gamma[2a + e(z-2)](a[14175\gamma + 2e^2 z(7+z)(41z-28)] - e(7+z)[2025\gamma + 4e^2(z-2)(7+z)])}{[405\gamma + 2e^2(z-2)(7+z)]^2}$$

(13)

Non-negativity of the above results requires that $a > (1/5)(e(7+z))$.

3.2 The alternative model (AM)

In the alternative model (AM) we assume that the trade unions decide wages prior to the firms' decision on abatement technology: In the first stage, the trade unions decide wages; in the second and third stage, firms decide the abatement technology and the production level, respectively. The third stage results are identical between the two models, thus omitted here.

3.2.1 Stage two: firms decide the abatement technology

Provided the optimal choice of output and employment in the third stage, the profit maximization problem of firm i in the second stage is

$$\max_{k_i} \left\{ \hat{\pi}_i = \left(a - 2w_i + w_j\right)^2/9 - \gamma(1-k_i)^2 \right\}$$

Clearly, in the above problem the optimal choices of abatement are $k_i = k_j = 1$, implying that the trade unions cannot influence the firms' choice of technology when the decision on the wages is a relatively long-term commitment compared to the commitment of installing an abatement technology. From a regulatory perspective, environmental regulations must be stricter in industries characterized by long-term wage contracts and short-lived investments in abatement technology. In other words, the timing of the negotiations could be very important on the efficiency of chosen environmental policies.

Result 2: When the trade unions decide the wages prior to firms' decisions on abatement technology, the firms adopt the most polluting technology.

Finally, given the optimal choice of abatement in the second stage, profits are $\hat{\pi}_i = \left(a - 2w_i + w_j\right)^2/9$, emissions equal $\bar{y}_i = \left(a - 2w_i + w_j\right)/3$, and the perceived environmental damage is $DF_i = e\left(a - 2w_i + w_j\right)/3$.

3.2.2 Stage one: Trade unions set the level of the wages

Substituting the results of stages three and two in the utility function of trade union i, the utility maximization problem of the union becomes

$$\max_{w_i}\left\{U_i = \tfrac{1}{3}(w_i - e)\big(a - 2w_i + w_j\big) - e\big(a - 2w_j + w_i\big)z\right\}$$

Taking the first order conditions yield the reaction function $w_i^{rf} = \big(a + 2e + w_j - ez\big)/4$. Solving simultaneously the two reaction functions yields the optimal wages

$$w_i^* = [a - e(z-2)]/3 \qquad (14)$$

Hence, output and emissions are

$$q_i^* = y_i^* = [2a + e(z-2)]/9 \qquad (15)$$

So, environmental damage is $DF_i = e[2a + e(z-2)]/9$, price is $p_i^* = [5a + 2e(z-2)]/9$, and the profits are

$$\bar{\pi}_i^* = \bar{q}_i^{*^2} = [2a + e(z-2)]/81 \qquad (16)$$

Finally, the trade unions utility equals

$$U_i^* = [2a + e(z-2)][a - e(1+4z)]/27 \qquad (17)$$

and, as in the basic model, the Social Welfare is given by

$$SW^* = 2[2a + e(z-2)][7a - e(7+z)]/81 \qquad (18)$$

4 Comparisons

In this section we compare the results of the two models. The superscripts BM and AM are used to indicate the results of the basic and the alternative model, respectively. With respect to differences in the choice of abatement technology, output and employment, wages, and prices we state the following

Result 3: Let $z \in (0,1), a > e(7+z)/5$ *and* $\gamma > 4e^2(7+z)^2/2025$. *Then firms in the BM choose greener technology, produce more output, pay lower wages, and charge less compared to firms in the AM, i.e.,*

(a) $k^{BM} - k^{AM} < 0$

(b) $q^{BM} - q^{AM} > 0$

(c) $w^{BM} - w^{AM} < 0$

(d) $p^{BM} - p^{AM} < 0$

Intuitively, when a firm's abatement choice precedes the decision over wages and employment, environmental-friendly trade unions can give a leeway to the firms by accepting lower wages provided that the firms will abate more. Lower wages will lead to higher employment, hence higher output, and lower prices in the market. When a firm's abatement choice follows the decision over wages this trade-off (*i.e.*, lower wages in return for more abatement) is not available due to a commitment issue: given that wages have been determined in a previous stage, firms have no incentive to adopt costly abatement technologies. Trade unions knowing that, they will set a higher wage (leading to lower output and employment) compared to the case where there is no such a commitment issue.

Provided that both abatement and production are stronger in the BM than in the AM one cannot be sure about the difference in emissions between the two models: the former reduces emissions while the latter increases them. It is shown that the abatement effect overcomes the output effect on emissions if the market is sufficiently large. Therefore, with respect to differences in emissions we state the following

Result 4: Let $z \in (0,1), a > e(7+z)/5$ *and* $\gamma > 4e^2(7+z)^2/2025$. *Then firms in the BM pollute less compared to firms in the AM provided that the size of the market is sufficiently large, i.e.,*

$$y^{BM} - y^{AM} < 0 \;\; if\, a > \frac{e(z-2)(405\gamma + e^2(z-2)(7+z))}{405\gamma}.$$

Finally, with respect to differences in firms' profits, unions' utilities, and social welfare we state the following

Result 5: Let $z \in (0,1), a > e(7+z)/5$ *and* $\gamma > 4e^2(7+z)^2/2025$. *Then, compared to the AM, in the BM unions enjoy higher utility, firms earn higher profits, and the society achieves higher welfare, i.e.,*

(a) $U^{BM} - U^{AM} > 0$
(b) $\pi^{BM} - \pi^{AM} > 0$
(c) $SW^{BM} - SW^{AM} > 0$

Table 2 below summarizes the findings described in *Results 3-5*.

Technology	$k^{BM} < k^{AM}$
Production	$q^{BM} > q^{AM}$
Wages	$w^{BM} < w^{AM}$
Utility	$U^{BM} > U^{AM}$
Price	$p^{BM} < p^{AM}$
Profits	$\Pi^{BM} > \Pi^{AM}$
Social Welfare	$SW^{BM} > SW^{AM}$
Emissions	$y^{BM} \leq or \geq y^{AM}$

Table 2: Comparisons between the BM and the AM results

5 Conclusions and Discussions

From policy perspective, the inter-governmental coordination on climate change issues has become increasingly difficult as it is often argued to limit the competitiveness of domestic firms and sometimes discourage local employment, whereas the social norm of being environmental considerate have been widely accepted across societies. Hence, any policy that facilitates the establishment of climate solidarity across trade unions would be a good step of progression and could help internalise the environmental issues within the industry competitions.

This paper studies how the trade unions' climate solidarity affects the firms' choices of abatement technologies. We consider a Cournot duopoly consisting of two geographically separated firms, each paired with a local trade union that exhibits climate solidarity, *i.e.*, the unions care about the environmental damage at both locations. Firms have access to a wide range of abatement technologies. We employ a Monopoly Union model where, in a sequential manner, the trade unions decide the wages and the firms decide the employment level. Allowing for the order of the sequence to change, we consider two distinct timing frames. First, in the basic model, firms choose abatement technologies prior to bargaining over wages and employment with the unions. Second, in the alternative model trade unions decide the wages prior to the firms' abatement and employment decisions.

In basic model we show that climate solidarity as a norm across trade unions provides additional incentives for firms to adopt greener technologies. Compared to a case without climate solidarity, the abatement technology chosen by the firms is greener when this norm prevails. Intuitively, this greener choice is incentivised by the subsequent lower wages offered by the trade union, hence giving firms more flexibility to increase their output level and become more competitive in the market. The more intense the climate solidarity is, the stronger this incentive will be. In addition, we show that larger market size (*i.e.*, increased degree of market integration) and lower technology adoption cost tend to strengthen the relative significance of labour cost over the cost of adopting abatement technologies. This implies that policies promoting market integrations and encouraging R&D activities on environmental technologies[22] would naturally strengthen the climate solidarity effect of trade unions on firms' abatement choices.

Moreover, it is worth noting that the adoption of greener technology may not necessarily lead to an overall reduction of emissions. The model shows that the firms' greener technological choice, *i.e.*, decreasing k_i, would be ultimately rewarded with higher level of production, *i.e.*, q_i increases. While the former lowers emissions by decreasing the pollution intensity of the production process (direct effect), the latter increases emissions through an increase in output (indirect effect). Our numerical exercises showed that there is an inverse U-shaped relation between the abatement technology choice and total emissions.[23] Specifically, for a relatively small market size (*i.e.*, low degree of market integration) greener technologies are more likely to be coupled with higher total emissions. This further highlights the importance of understanding the complex interactions between designed policies and the strategic considerations of economic agents.

Although the climate solidarity norm across trade unions may function as a parallel mechanism to promote the environmental accountability of local firms on their technology investment decision, especially when regulators are facing coordination challenges across the borders, it is important to note that the effectiveness relies on the industry and market structure that permits the incentive compatibility. In the alternative model, where trade unions set the wages prior to the firm's decisions on abatement technology and production, we show that the union's climate solidarity has no effect on the firm's abatement decisions.[24] The local firms will adopt the dirtiest technology available, and the total social welfare is reduced. In a practical sense, embedding climate solidarity extends the objectives of trade unions in the

22 It should be noted that such policies can also stimulate eco-innovation as, according to the empirical studies of Leitner (2018) and Cai and Li (2018), the main drivers of eco-innovation include, among others, investment in R&D and customer "green" demand.

23 A&GM (2015) derives a similar result for the case of green trade unions without climate solidarity.

24 A&GM (2015) and Fanti and Buccella (2017) did not account for this.

wage process. But for sectors with long-term rigid wage contract or weak power of the trade union, the decision of adopting abatement technology will simply matter as a cost-advantage in the market competition. In this scenario, the environmental regulations must be fully set in place.

In addition to the aforementioned empirical implications, this research can be extended in several dimensions. For instance, our model imposes no specific dynamics on the firms' technology process so that the cost implications of the trade union's climate solidarity are mostly leveraged upon the firm's adoption of an existing technology during the sequential decisions. This can be further extended in future studies by allowing competing firms/regions to conduct eco-innovations or sustainable technology transitions (*e.g.*, van der Vooren *et al*., 2013; van den Berge *et al.*, 2020) so that the solidarity channel could further influence the processes of R&D. Another dimension is to reposition the firms along the *industry supply chain (*e.g., Lin *et al.*, 2020) so that the solidarity channel would generate additional layers of impact on the eco-innovation investment and inter-industry knowledge spill-overs. Those extensions would enrich the prediction of the dynamics regarding the industry's abatement technology adoption and the associated levels of pollution and social welfare.

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