Environmental Regulation and Vertical Structure: Prices vs. Quantities *

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Abstract

We examine some potential interactions between environmental regulation and the degree of vertical integration in a polluting industry. In our model, vertical integration increases productive efficiency because final goods producers -unless being vertically integrated- have to trade in a *input market* where there are charged a positive markup price. While polluting firms' strategic decisions have no effect on the emission tax rate, they might however influence the equilibrium price of permits. Therefore, increased output level due to higher degree of vertical integration might either cause more pollution under an emission tax or increase the permits unit price. We investigate the welfare implications of these results. Furthermore, we show that the upward pressure imposed by vertical integration on the permits price exacerbates strategic complementarity in vertical integration: private incentives to vertically integrate increases with the degree of vertical integration. This might lead to higher degree of vertical integration under permit regulation than under tax regulation.

Key Words: Environmental Policy, Vertical Oligopoly, Permits, Emission taxes

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1 Introduction

This paper contributes to the "taxes versus permits" literature by examining potential interactions between environmental regulation and the degree of vertical integration in a polluting industry. We consider a complete information setup where the production of an intermediate good serving as an essential input for final goods producers generates byproduct emissions of a pollutant subject to environmental regulation (taxes or permits). Final goods producers operate in separate oligopolistic markets and -unless they are vertically integrated- purchase the intermediate good in an imperfectly competitive input market.[1] The degree of vertical integration in the industry increases as more final goods producers vertically integrate into the production of the input.

Consider for example, the cement and the pulp industries. First, cement production generates intensive emissions of air pollutants such as nitrogen oxide (NO_x), sulfur dioxide (SO_2) or carbon dioxide (CO_2). In turn, ready-mixed concrete firms use cement in fixed proportion to produce a ton of concrete. While many cement firms also operate concrete businesses, most non-integrated concrete firms trade with cement distributors (supplied by cement producers). Pulp mills emit intensive amounts of CO_2 and discharge aqueous effluent with persistent organic pollutants. While the largest paper firms often produce their own pulp, most non-integrated firms purchase the needed input in imperfectly competitive pulp markets. In most OECD countries, both sectors are subject to existing or forthcoming incentives-based environmental regulation. For instance, both are included in the scope of the European Union emission trading scheme (EU-ETS) and the Western Climate Initiative (WCI) cap-and-trade program or subject to a carbon tax.[2]

By eliminating the double marginalization problem in the integrated final good markets, vertical integration increases the industry productive efficiency (and hence increases the industry output). Thus, when polluting firms' output and emissions are complement, the potential impact of vertical integration on environmental outcomes becomes evident taking into account that pollution is an essential input for those firms. Taxing emissions and auctioning off pollution permits are just two different ways of selling this input (so-called emission rights). A uniform emission tax firmly sets the unit price of emission rights, whereas a permits scheme sets their

[1] The input suppliers' markup causes a so-called double marginalization problem in the non-integrated final good markets.

[2] The WCI is a partnership between several U.S. States and Canadian Provinces to reduce regional GHG emissions to 15 percent below 2005 levels by 2020. To date, only California and four Canadian Provinces are implementing the cap-and-trade program covering emissions from electricity, electricity imports, industrial combustion at large sources, and industrial process emissions. The first compliance date is January 1, 2013. As of July 2012 British Columbia was not implementing the WCI cap-and-trade program, but levying a carbon tax of \$30/ton of CO_2.

quantity (i.e. the number of permits) and relies on market forces to determine their unit price. Put differently, supply of emissions rights is perfectly elastic under an emission tax regulation, and perfectly inelastic under a permits scheme.

This fundamental difference between taxes and permits has immediate consequences. While polluting firms' strategic decisions have no effect on the emission tax rate, they might influence the equilibrium permits price. Given these basic considerations, we thus seek to answer the following questions: How does the industry vertical structure affect the welfare cost of introducing an environmental tax or permits regulation? Conversely, might environmental regulation affect the vertical structure in a polluting industry? Is there equivalence between taxes and permits, or which instrument performs best?

We start by remarking that *given* the industry vertical structure, the welfare cost of introducing an emission tax equals that of introducing a permits regulation of equivalent stringency.[3] Then, we show that higher productive efficiency due to higher degree of vertical integration might increase the demand for emission rights, which would either cause more pollution under a tax regulation or increase the permits price. Thus, since with emissions taxes vertical integration increases the level of both aggregate output and aggregate emissions, the total effect of vertical integration on welfare depends on how social benefits of enhanced productive efficiency compare with the costs of increased environmental damage. The steeper is the slope of the marginal damage function the less vertical integration is likely to enhance welfare.

Turning to permits regulation, we show that under reasonable assumptions welfare is more likely to increase (resp. to decrease) with the degree of vertical integration the more concave (resp. convex) is the final good demand. This result highlights the potential efficiency of a permits regulation in allocating scarce resources. When the final good demand is strictly concave (but not too concave), a higher degree of vertical integration ensures a better utilization of the scarce emission rights (at a reasonable cost). Indeed, given that vertical integration in a particular market increases the input price faced by non-integrated final good producers, it also induces an output contraction in their respective markets. These spared permits then flow from those relatively inefficient producers towards a more efficient producer that value them more. The more concave is the final good demand, the higher is the output contraction resulting from a slight increase in the permits price. When the final good demand is convex, such increase in the permits price does not induce much output contraction by non-integrated producers. This

[3] This is the well-known *static* equivalence between taxes and permits in the complete information world in which we conduct our analysis (see e.g., Weitzman (1974)'s seminal paper or Requate (1993) for an analysis with local monopolies).

mitigates the benefit from vertical integration in a particular final good market, while magnifying its detrimental impact on all other final good markets.

Finally, we investigate the impact of the regulatory instrument choice on private incentives for vertical integration. We show that the introduction of an emission tax does not affect the equilibrium vertical structure. The reason is that an emission tax reduces the private incentives for vertical integration regardless of the initial vertical structure. Therefore, if a couple of firms had no incentives to merge before the introduction of the emission tax regulation, they would have fewer incentives to do so after. In contrast, the upward pressure imposed by vertical integration on the permits price exacerbates strategic complementarity in vertical integration: inputs and final goods producers' incentives to vertically integrate increases with the degree of vertical integration. This might lead to higher degree of vertical integration under permit regulation than under tax regulation.

The remainder of the paper is organized as follows. The next section presents the model. Section 4 derives comparative some preliminaries statics results under tax and permits regulation. Sections 5 comparative statics results on welfare. Section 6 investigates the impact of regulation on the equilibrium market structure. Section 7 offers some concluding remarks. All proofs are relegated to the appendices.

2 A model of vertically related oligopolies in a polluting industry

We consider the following upstream-downstream setup.

The downstream segment. There are n final good markets indexed by i, $i = 1, 2, , n$ and characterized by the same demand downward-sloping curve $P(q)$ (with $P'(q) < 0$ for all $q > 0$). Each market i is monopolized by one final good producer Di transforming one unit of input into one unit of final good at a *constant* unit cost which is normalized at zero. We assume (merely for technical reasons) that $P(Q)$ is well-behaved in the sense that $P(\cdot)$ is twice continuously differentiable and satisfies the following assumption.[4]

Assumption 1 ***(A1)*** *$P''(q)q/P'(q) > -2$ for all $q > 0$.*

The upstream segment. There are m intermediate good producers $U1, U2, ..., Um$, producing an essential input for production of the final good. We refer to these producers as the input

[4]This assumption is common in oligopoly theory, see for instance Février and Linnemer (2004).

producers or the upstream firms. They compete à la Cournot in a so-called input market to supply non-integrated final good producers. All the input producers use the same production technology, generating byproduct emissions of a regulated pollutant. The production process generates one unit of pollution per unit of output. However, each firm can control its pollution emissions by undertaking costly *abatement* efforts. The production costs of a polluting firm producing $\bar{q}$ units of output while abating an amount $a = \bar{q} - e \leq$ of pollution and thus emitting $e = q - a$ ($e \leq \bar{q}$), are given by

$$C(\bar{q}, e) = c\bar{q} + \frac{\gamma}{2}(\bar{q} - e)^2$$

Given the firm's output level $\bar{q}$, the abatement level minimizing its production costs is $a = 0$. In other words, the firm minimizes its costs when it emits as much pollution as it generates (i.e. when $e = \bar{q}$). The parameter γ captures the firms' pollution abatement efficiency.

Such a quadratic specification for the cost function of polluting firms has commonly appeared in the environmental regulation literature.[5] However, since much of our analysis hinges on the desirable properties of $C(\bar{q}, e)$ it might be worth discussing briefly some important underlying assumptions. First, note that $C_{\bar{q}}(\bar{q}, \bar{q}) = c$. Thus, in the absence of abatement efforts (i.e. when $e = \bar{q}$) a firm's marginal cost is constant. The assumption of upstream constant marginal costs is common to most vertical oligopoly models. Second, but perhaps more importantly, the marginal cost of abatement is independent of the production level (i.e. $C_{\bar{q}e}(\bar{q}, e) = 0$). In other words, we are implicitly assuming that firms implement an end-of-pipe abatement technology to control their emissions (e.g., scrubbers, filters, waste treatment, *et cetera*). Moreover, consistent with empirical examples of end-of-pipe abatement technologies, throughout the paper we assume that γ is sufficiently high and the regulation is not as stringent as any polluting firm would find it profitable to abate all its pollution.

Assumption 2 *(A2) In equilibrium every input producer's emission level is strictly positive.*

Vertical structure. Changes in the industry vertical structure can occur only through vertical integration, that is, vertical mergers involving a pair of input and final good producers. Since we do not allow entry nor exit in either segment, the degree of vertical integration simply refers to the number of final good producers vertically integrated into the production of the input. Note that since the final good producers operate in separate markets, there is no scope for strategic foreclosure, nor scope for strategic input purchases by an integrated producer to raise rivals'

[5] See e.g., Montero (2002), Requate and Unold (2003), Weber and Neuhoff (2010) to name a few.

costs. Therefore, we assume that the integrated producers which provide input "in-house", can still supply the input market.

Environmental regulation. We consider the following alternative incentives-based environmental regulation. First, an emission tax regulation under which polluting firms must pay a pollution tax τ per unit of emissions. Second, an emission permits scheme where polluters must buy as many permits as the number of pollution units they emit. In both cases, we consider an ex ante "once and for all" regulation, in that the regulation stringency is set once and for all at the outset of the game. That is, the emission tax rate τ or the total supply of permits (i.e. the number of permits to be auctioned off) are set given the initial industry vertical structure and does not change afterwards.

Timing. The chronicle of events runs as follows. Given the environmental regulation, at the opening of the compliance period firms decide whether to vertically integrate, determining the industry vertical structure. Each input producer then chooses its supply to the input market and vertically integrated producers decide how much input to produce for its downstream market. This determines the demand for emissions rights and the input market price w. Next, the production of the final good takes place: given the input market price each final good producer chooses its output level. Finally, the compliance period closes and polluting firms pay their emission taxes or buy their pollution permits at the market clearing price.

3 Product market equilibrium with v integrated producers

Let us assume that v firms are vertically integrated ($v < m$), say firms $i = 1, 2, ..., v$ and let ϕ_v denote the equilibrium unit price of emission rights. That is, under a tax regulation ϕ_v is simply the emission unit tax, τ, whereas under a permits regulation, ϕ_v is equal to the rationally expected permits unit price (given that v firm are vertically integrated).

Non-integrated producers. Let us first consider the $n - v$ non-integrated final good producers. Given the input price w, each non-integrated downstream monopolist Di produces its profit-maximizing output

$$q(w) = \text{argmax}_q\, \pi(q|w) = [P(q) - w]q.$$

Given that one unit of the final good requires one unit of input, $q_i(w)$ also determines Di's input demand. Thus, aggregating over the $n - v$ non-integrated final good markets, the total demand in the input market is $\bar{Q}_v(w) = (n - v)q(w)$. Inverting this expression and using symmetry yield the inverse demand faced by the input producers

$$w_v(\bar{Q}) = P'(\frac{\bar{Q}}{n-v})\frac{\bar{Q}}{n-v} + P(\frac{\bar{Q}}{n-v}) \tag{1}$$

Next, consider the $m - v$ non-integrated input producers. We assume Cournot (quantity) competition in the input market like in Salinger (1988). Thus, taking as given the output of all the other input producers $\bar{Q}_{-i}$, each non-integrated input producer Ui solves the following problem

$$\max_{\bar{q},e}\{w_v(\bar{Q}_{-i} + \bar{q})\bar{q} - C(\bar{q}, e) - \phi e \quad s.t \quad e \leq \bar{q}\}$$

The (necessary and sufficient) first-order conditions for optimality are given by:

$$\begin{cases} w'_v(\bar{Q})\bar{q} + w_v(\bar{Q}) - c - \gamma(\bar{q} - e) = 0 \\ \gamma(\bar{q} - e) = \phi \end{cases} \tag{2}$$

which reduces to

$$w'_v(\bar{Q})\bar{q} + w_v(\bar{Q}) = c + \phi_v \tag{3}$$

Integrated producers. Each integrated input producer has to decide how much input to produce for its final good market and how much to supply in the input market. Taking as given the output of all the other input producers $\bar{Q}_{-i}$, each integrated producer $Ui - Di$ solves the following problem

$$\max_{q,\bar{q},e}\{P(q)q + w_v(\bar{Q}_{-i} + \bar{q})\bar{q} - C(q + \bar{q}, e) - \phi e \quad s.t \quad e \leq q + \bar{q}\}$$

The (necessary and sufficient) first-order conditions for optimality are given by:

$$\begin{cases} w_v'(\bar{Q})\bar{q} + w_v(\bar{Q}) - c - \gamma(q + \bar{q} - e) = 0 \\ P'(q)q + P(q) - c - \gamma(q + \bar{q} - e) = 0 \\ \gamma(q + \bar{q} - e) = \phi_v \end{cases} \tag{4}$$

which reduces to

$$\begin{cases} w_v'(\bar{Q})\bar{q} + w_v(\bar{Q}) = c + \phi_v \\ P'(q)q + P(q) = c + \phi_v \end{cases} \tag{5}$$

An integrated producer's profit-maximizing downstream level of output equalizes the marginal revenue from its final good market to its perceived marginal costs, encompassing the production unit cost, c, and the emission unit price associated to the last unit of output, ϕ_v. Besides, a glance at conditions (5) and (3) suggests that integrated and non-integrated input producers have identical incentives to supply non-integrated final good producers through the input market.[6] So let denote the (symmetric) individual quantities supplied in the input market by every input producers by $\bar{q}_v(\phi_v) = \bar{Q}_v(\phi_v)/m$ where $\bar{Q}_v(\phi_v)$ is solution in $\bar{Q}$ to the following equation

$$w_v'(\bar{Q})\frac{\bar{Q}}{m} + w_v(\bar{Q}) = c + \phi_v \tag{6}$$

Outputs and profits. For future reference we introduce the following notations.[7] Let $w(\phi_v)$ denote the equilibrium input price when there v vertically integrated producers. The optimal individual output level of integrated and non-integrated final good producers are respectively denoted $q(\phi_v)$ and $q(w(\phi_v)$. So, let $\pi(\phi_v) = [P(q(\phi_v)) - c - \phi]q(\phi_v)$ and $\pi(w(\phi_v)) = [P(q(w(\phi_v)) - w(\phi_v)]q(\phi_v)$ denote the corresponding final good market profits. The aggregate output level (i.e. the total production of input) is $Q_v(\phi)_v = vq(\phi_v) + (n - v)q(w(\phi_v))$.

A non-integrated input producer's optimal profit, $\bar{\pi}_v(w(\phi_v))$, is simply given by

$$\bar{\pi}_v(w(\phi_v)) = [w(\phi_v) - c - \phi_v]\bar{q}_v(\phi_v) + \frac{\phi^2}{2\gamma} \tag{7}$$

In turn, an integrated firm's total profit, $\bar{\pi}_v(\phi)$, is given by the sum of its downstream profit

[6]This confirms that in our setting of separate final good markets, one can safely not be concerned with foreclosure effects of vertical integration that might arise in the presence of downstream interactions. See e.g., Salinger (1988), Inderst and Valetti (2008) among others.

[7]Being understood that, here, the variable parameter of interest is ϕ_v, throughout we omit the dependence on c of all the equilibrium functions. Moreover, we indicate by a subscript v only the equilibrium functions that depend directly on v.

$\pi_v(\phi)$ and its wholesale profit equal to that of an non-integrated input producer, $\bar{\pi}_v(w(\phi_v))$. That is,

$$\bar{\pi}_v(\phi) = \pi(\phi_v) + \bar{\pi}_v(w(\phi_v)) \tag{8}$$

Emissions. When v firms are vertically integrated, at price ϕ_v, the total demand for emission rights corresponding to the aggregate emissions level is given by

$$E_v(\phi_v) = vq(\phi_v) + (n-v)q(w(\phi_v)) - m\frac{\phi_v}{\gamma} \tag{9}$$

The first two terms amount to the total input production: $q(\phi_v)$ transformed in-house by each of the v integrated producers and $(n-v)q(w(\phi_v))$ supplied through the input market to the $n-v$ non-integrated final good producers. The last term is the total pollution abatement realized by the input producers.

3.1 Welfare

Assume that the costs of environmental damage are function of the level aggregate emissions only and let $D(E)$ denote the environmental damage associated to the level of aggregate emissions E. Assume that $D'(E) > 0$ and $D'(E) \geq 0$. Total welfare is the sum of total consumer surplus, $CS_v(\phi) = (n-v)\left[\int_0^{q(w(\phi))} P(u)du - P(q(w(\phi)))q(w(\phi))\right] + v\left[\int_0^{q(\phi)} P(u)du - P(q(\phi))q(\phi)\right]$; total industry profit, $v\bar{\pi}_v(\phi) + (m-v)\bar{\pi}_v(w) + (n-v)\pi(w)$; emission rights sales revenue, $\phi E_v(\phi)$, and environmental damage $-D(E_v(\phi))$. Therefore, when v final good producers are vertically integrated ($v < m$), given that $E_v(\phi) = vq(\phi) + (n-v)q(w(\phi)) - m\phi/\gamma$ we write total welfare as a function of the pollution price, ϕ, as follows

$$W(\phi_v) = v\int_0^{q(\phi)} [P(u)-c]du + (n-v)\int_0^{q(w(\phi))} [P(u)-c]du - m\frac{\phi^2}{2\gamma} - D(E_v(\phi)) \tag{10}$$

Thus, total welfare is obtained by summing the social surplus derived from the consumption of the final good in each final good market (i.e. the two first terms), and netting out the total abatement costs $m\frac{\phi^2}{2\gamma}$ incurred by the input producers and the costs of environmental damage. For future reference, let us define the Pigouvian level of regulation stringency for both a tax and a permits regulation as follows.

Definition 1 *(Pigouvian regulations) For all $v \leq m$, define the Pigouvian emission tax levels $\tau_v \equiv D'(E_v(\tau_v))$. Analogously, let us define the Pigouvian emission caps $\bar{E}_v$ such that $E_v(\tau_v) = \bar{E}_v$.*

Welfare cost of regulation. Before turning to the marginal welfare effect of vertical integration, let us remark that given the industry vertical structure (with v vertically integrated producers), the welfare costs of introducing an environmental regulation (yielding a pollution unit price ϕ_v) amount to $W_v(\phi_v) - W_v(0)$. For instance, the welfare costs of introducing the Pigouvian emission tax $\tau_v = D'(E_v(\tau_v))$ would be $W_v(\tau_v) - W_v(0)$. Likewise the costs of introducing an emission cap $\bar{E} = E_v(\tau_v)$ would be $W_v(\phi_v) - W_v(0)$ where ϕ_v would have to satisfy $E_v(\phi_v) = \bar{E}$ and therefore $\phi_v = \tau_v$ (since $\bar{E} = E_v(\tau_v)$). This suggests the following remark.

Remark 1 *Given the industry vertical structure, the welfare cost of introducing an emission tax regulation equals that of introducing a permits regulation of equivalent stringency.*

Although the celebrated *static* equivalence between taxes and permits applies to our framework, we shall see below that even if all costs could be ascertained, both regulatory instruments might no longer be equivalent when market structure is endogenous. Before that, it is interesting to understand how the incidence of environmental regulation is affected by the industry vertical structure. For instance, we could ask how does the degree of vertical integration affect the welfare cost of Pigouvian regulations? That is, what is the sign of $W_{v+1}(\tau_{v+1}) - W_{v+1}(0) - [W_v((\tau_v) - W_v(0)]$? Is it constant? To answer, we proceed to a comparative static analysis to understand the marginal impact of vertical integration on the equilibrium outcomes.

4 Comparative Statics

The following lemma, which indicates how the equilibrium output levels vary with the emission rights price is key to our analysis.

Lemma 1 *(i) The equilibrium input price $w(\phi_v)$ increases with the pollution unit price ϕ_v. (ii) The individual output levels of integrated and non-integrated final good producers, $q(\phi_v)$ and $q(w(\phi_v))$, decrease with the pollution unit price ϕ_v.*

Proof. See appendix. ■

An increase in the pollution unit price rises the perceived cost of producing the input. As one could expect, this decreases the optimal individual output levels of both integrated and non-integrated final good producers. Besides, observe that the first-order condition (**??**) can be rewritten as

$$\frac{w_v(\bar{Q}) - c - \phi_v}{w_v(\bar{Q})} = \frac{1}{m\epsilon_w} \tag{11}$$

where $\epsilon_w = w_v(\bar{Q})/w'_v(\bar{Q})\bar{Q}$ denote the elasticity of the input derived demand (evaluated at the equilibrium quantity). But since all the final good markets are independent and have the same elasticity, the price elasticity of the input demand does not depend upon the number of vertically integrated producers. Indeed, although vertical integration in a particular final good market reduces the input producers' customer base (since integrated final good producers are no longer purchasing input in their market), it does not change the price elasticity of the input demand.[8]

4.1 Emission tax regulation

As equation (11) suggests, when the pollution price ϕ_v does not depend on the industry vertical structure (which is the case under an emission tax regulation), nor does the optimal input price.

Lemma 2 *Under an emission tax regulation, the degree of vertical integration does not affect the input price i.e.* $w(\phi_v) = w(\phi_{v+1}) \equiv w(\tau)$ *for all* $v \leq m$.

Proof. The optimal input price solution to problem (**??**) is invariant under a monotonic transformation of the objective function $\bar{\Pi}_v(w)$. So, $w(\phi_v)$ is also solution to $\max_w \bar{\Pi}_v(w)/(n-v) = (w - c - \tau)q(w)$. The latter objective function being independent of v, so must be $w(\phi_v)$. ■

An immediate implication of this lemma is that, under a tax regulation, the purchasing conditions of non-integrated final good producers are independent of the degree of vertical integration. We can therefore state the following lemma.

Lemma 3 *Under an emission tax regulation, vertical integration (i) increases both the level of aggregate output and the level of aggregate emissions, (ii) increases profits and consumer surplus in the integrated final good markets, (iii) reduces non-integrated input producers' profits. (iv) Vertical integration in a final good market does not affect profits and consumer surplus in the other final good markets.*

Proof. See appendix. ■

4.2 Permits regulation

Things are different under a permits regulation since the emission unit price ϕ_v, that is, the permits unit price is no longer exogenous to the degree of vertical integration.

[8] To see this note that the elasticity of the input derived demand can be rewritten as follows: $\epsilon_w = -\frac{P(w)}{(n-v)q(w)} \frac{(n-v)q'(w)}{P'(w)} \frac{w(\bar{Q})}{P(w)} \frac{P'(w)}{w'(\bar{Q})}$ where $P(w) = P(q(w))$ and $P'(w) = q'(w)P'(q(w))$. See e.g., Inderst and Valetti (2008).

Lemma 4 *The equilibrium permits unit price increases with the degree of vertical integration i.e.* $\phi_{v+1} > \phi_v$ *for all* $v < m$.

Proof. By virtue of assertion (i) in Lemma 3, for given ϕ, we have $E_{v+1}(\phi) > E_v(\phi)$ for all $v < m$. Hence, showing that $E_v'(\phi) < 0$ would prove the result since, the supply of permits being fixed, we must have $\phi_{v+1} > \phi_v$ for $E_{v+1}(\phi_{v+1}) = E_v(\phi_v)$ to hold. But $E_v'(\phi) = vq'(\phi_v) + w_v'(\phi)(n-v)q'(w(\phi_v)) - m\gamma < 0$ since by Lemma (1) we have $q'(\phi_v) < 0$, $q'(w(\phi_v)) < 0$ and $w_v'(\phi) > 0$. ■

In fact, vertical integration in a particular final good market puts an upward pressure on the demand for permits. However, the permits supply being fixed, this necessarily increases clearing price. Such a price increasing effect of vertical integration yields the following implications.

Lemma 5 *Under a permits regulation, (i) vertical integration increases the level of aggregate output and does not affect aggregate emissions (as long as the emission cap is binding); (ii) reduces non-integrated input producers' profits. (iii) A vertical integration in a final good market increases profits and consumer surplus in that market, but reduces profits and consumer surplus in all the other final good markets.*

Proof. See appendix. ■

By its very nature a binding emission cap prevents the level of aggregate emissions from changing with the industry vertical structure. More interestingly, assertion (i) indicates that the productive efficiency gain stemming from vertical integration outweighs the increase of production costs due to the permits unit price increase. (ii) That non-integrated input producers suffer from one of their former costumer' vertical integration is rather intuitive. Vertical integration not only reduces their customer base, but it also raises their production costs (through the increase of permits unit price). Since in each market consumer surplus is positively correlated with the output level, the result in assertion (iii) derives from the first assertion and lemma 1 and 4. Following vertical integration in a given market, all the producers see their production costs increase and thus all reduce their individual output levels, except the marginal vertically integrated final good producer (experiencing the productive efficiency gain) which expands its output level.

5 Welfare analysis

We now turn to the welfare effect of vertical integration given the existing environmental (tax or permits) regulation.

5.1 Emission tax regulation

To begin with, we analyze the marginal welfare effect of vertical integration under an emission tax regulation when there are v vertically integrated final good producers. Throughout, we shall maintain the assumption that *given* the prevailing emission tax level, producing the final good is profitable.

Assumption 3 $lim_{q->0+}P(q) - c > \tau$.

This assumption also ensures that in equilibrium every firm produces a positive quantity.

We then proceed by writing $\Delta W_{v+1}(\tau) \equiv W_{v+1}(\tau) - W_v(\tau)$ to get (see appendix):

$$\Delta W_{v+1}(\tau) = \int_{q(w(\tau)}^{q(\tau)} g(u)du - v \int_{q(\tau)}^{q(\tau)} g(u)du - (n-v) \int_{q(w(\tau))}^{q(w(\tau)} g(u)du + [D(E_v(\tau)) - D(E_{v+1}(\tau))] \tag{12}$$

where we posed $g(u) = P(u) - c$.[9] The marginal welfare effect of vertical integration can thus be decomposed into four terms. The first and only positive term is the gross benefit from eliminating the double marginalization problem in the marginal vertically integrated final good market. The second and third terms represent respectively the reduction in gross surplus in all other integrated and non-integrated final good markets due to the marginal vertical integration. Both are equal to zero since, as we have seen, under a tax regulation, vertical integration in a particular final good market does not affect the outcomes in the other final good markets. The last term is negative and corresponds to the increase in the costs of environmental damage resulting from the additional emissions due to the marginal vertical integration. Equation (20) can therefore be rewritten as

$$\Delta W_{v+1}(\tau) = \int_{q(w(\tau))}^{q(\tau)} g(u)du - [D(E_{v+1}(\tau)) - D(E_v(\tau))] \tag{13}$$

The sign of the marginal welfare effect of vertical integration depends on the slope, $D'(E)$, of the environmental damage function. To see this, notice that $D(E_{v+1}(\tau)) - D(E_v(\tau)) = \int_{q(w(\tau))}^{q(\tau)} D'(E_v(\tau) - q(w(\tau)) + u)du$. Suppose for instance that $D(E)$ is linear with $d = D'(E)$.

[9] $\int_0^q g(u)du$ then denotes the social surplus associated to the consumption of q units of the final good (gross of the cost of environmental damage).

In this case we would have $\Delta W_{v+1}(\tau) = \int_{q(w(\tau))}^{q(\tau)}[g(u) - d]du$ for all $v < m$. The marginal welfare effect of vertical integration would thus have a constant sign: either vertical integration would always increase welfare (if $\int_{q(w(\tau))}^{q(\tau)}[g(u) - d]du > 0$) or always reduce welfare (otherwise). With constant marginal damage, either the productive efficiency gain from vertical integration outweighs the extra social costs of additional emissions or it does not. In the latter case, regardless of the industry vertical structure, vertical integration reduces welfare despite increasing producers and consumer surplus. In contrast, when the damage function is convex, the marginal welfare effect of vertical integration depends on the degree of vertical integration. It might be that for low degrees of vertical integration, welfare increases with further vertical integration, and that at some point a higher degree of vertical integration implies a lower total welfare. We summarize these results in the following proposition.

Proposition 1 *Let $\tau_v \equiv D'(E_v(\tau_v))$, $v \leq m$ and suppose Assumption 1 holds. Under emission tax regulation, welfare always increases with the degree of vertical integration if $\int_{q(w(\tau))}^{q(\tau)}[g(u) - \tau_m]du > 0$. Otherwise, let $\bar{v} = \min\{v : \int_{q(w(\tau))}^{q(\tau)}[g(u) - \tau_v]du < 0\}$, then welfare increases with the degree of vertical integration as long as $v < \bar{v}$ and decreases afterwards.*

Proof. See appendix. ■

Under emission tax regulation, vertical integration increases productive efficiency in the integrated final good market without affecting productive efficiency in the other markets. However, this enhanced productive efficiency comes at the cost of a higher environmental damage caused by the increase of the aggregate emission level. The steeper is the slope of the marginal damage function, the less a vertical integration is likely to enhance welfare.

5.2 Permits regulation

Let us now turn to the marginal welfare effect of vertical integration under a permits regulation, when there are v vertically integrated final good producers. Now, the level of aggregate emissions is exogenously capped by the total (and fixed) supply of permits, say $\bar{E}$. Here, we assume that the emission cap $\bar{E}$ is such that producing the final good is profitable regardless of the industry vertical structure. This is guaranteed by a limit condition analogous to that of Assumption 3.

Assumption 4 *$lim_{q->0+}P(q) - c > \phi_m$.*

Since according to lemma 4, ϕ_m (i.e. the permits auction clearing price when there are m vertically integrated producers) is the highest possible permits unit price, Assumption 4 also ensures that in equilibrium every firm produces a positive quantity. We therefore write

$$W_v(\sigma) = v\int_0^{q(\phi_v)}[P(u)-c]du + (n-v)\int_0^{q(w(\phi_v))}[P(u)-c]du - m\frac{\phi^2}{2\gamma} - D(\bar{E})$$

Then, recalling that $g(u) = P(u) - c$ we obtain after some simple manipulations

$$\Delta W_{v+1}(\phi) = \int_{q(w(\phi_{v+1}))}^{q(\phi_{v+1})} g(u)du - v\int_{q(\phi_{v+1})}^{q(\phi_v)} g(u)du - (n-v)\int_{q(w(\phi_{v+1}))}^{q(w(\phi_v))} g(u)du - \frac{m}{2\gamma}(\sigma_{v+1}^2 - \sigma_v^2) \tag{14}$$

Just like in the case of a tax regulation, the marginal impact of vertical integration can be decomposed into four terms. The first and only positive term is again the gross benefit from eliminating the double marginalization problem in the marginal vertically integrated producer's final good market. The second and third terms represent respectively the reduction in gross surplus in all the other integrated and non-integrated final good markets due to the marginal vertical integration. Both are negative now, since as we have seen, a vertical integration in a particular final good market increases the permits unit price and therefore induces an output contraction in all the other final good markets. The last term is also negative and corresponds to the increase in abatement costs due to the marginal vertical integration.

Moreover, the permits market clearing condition $Q_v(\phi_v) - m\phi_v/\gamma \equiv \bar{E}$ implies that $\Delta Q_{v+1}(\phi) \equiv Q_{v+1}(\phi_{v+1}) - Q_v(\phi_v) = m(\phi_{v+1} - \phi_v)/\gamma$. That is,

$$\int_{q(w(\phi_{v+1}))}^{q(\phi_{v+1})} du - v\int_{q(\phi_{v+1})}^{q(\phi_v)} du - (n-v)\int_{q(w(\phi_{v+1}))}^{q(w(\phi_v))} du = \frac{m}{\gamma}(\phi_{v+1} - \phi_v) > 0 \tag{15}$$

Therefore, posing $g(u, \bar{\phi}_{v+1}) = g(u) - (\phi_{v+1} + \phi_v)/2$, we can more simply write equation (14) as

$$\Delta W_{v+1}(\sigma) = \int_{q(w(\phi_{v+1}))}^{q(\phi_{v+1})} g(u, \bar{\phi}_{v+1})du - v\int_{q(\phi_{v+1})}^{q(\phi_v)} g(u, \bar{\phi}_{v+1})du - (n-v)\int_{q(w(\phi_{v+1}))}^{q(w(\phi_v))} g(u, \bar{\phi}_{v+1})du \tag{16}$$

which suggests that the sign of the marginal welfare effect of vertical integration depends on whether the increase in social surplus in the marginal vertically integrated final good producer's market (the first term of the RHS of equation (16)) outweighs the adverse effects of increased production costs in all the other final good markets (the last two terms). This in turn depends on the curvature of final good demand function.

Proposition 2 *Assuming that $lim_{q->0+}g(q) > \phi_m$, welfare is more likely to increase (resp. to decrease) with the degree of vertical integration the more concave (resp. convex) is the final good* *demand.*

Proof. See appendix. ■

This proposition highlights the potential efficiency of permits regulation in allocating scarce resources. Note that here the sign of the marginal welfare effect of vertical integration does not depend on the slope of the environmental damage function, but on the curvature of the demand function. When the final good demand is strictly concave (but not too concave), a higher degree of vertical integration ensures a better utilization of the scarce emission rights (at a reasonable cost). Indeed, given that vertical integration in a particular market increases the input price faced by all the final good producers, it also induces them to raise their prices, reducing the demand in their respective markets. With a concave demand, the higher is the price the greater, the extent to which a slight price increase will reduce the demand for the good. This means that more permits flows from the relatively inefficient non-integrated final good producers towards the relatively more efficient marginal vertically integrated producer. Since each permit generates a higher surplus in an integrated markets, this will tend to increase welfare. When the final good demand is convex, such an increase in the permits price does not induce much output contraction by non-integrated producers relatively to their integrated counterparts. This mitigates the benefit from the marginal vertical integration, while magnifying its detrimental impact on all other final good markets.

6 Endogenous vertical structure

6.1 Private Incentives for Vertical Integration

Let us now turn to the private incentives for vertical integration in these settings. To that purpose, let us define our measure of a pair of non-integrated producers' incentives to merge when there are v ($v < m$) vertically integrated firms as follows

$$I_v(\phi) = \bar{\pi}_{v+1}(\phi) - [\bar{\pi}_v(w(\phi)) + \pi_v(w(\phi))] \tag{17}$$

Let us first consider the case of emission tax regulation.

$$\begin{aligned} I_v(\tau) &= \bar{\pi}_{v+1}(\tau) - [\bar{\pi}_v(w(\tau)) + \pi_v(w(\tau))] \\ &= \pi(\tau) - [\pi(w(\tau)) + (w - c - \tau)q(w(\tau))] > 0 \end{aligned} \tag{18}$$

The last inequality in (18) is guaranteed by the well-known fact that the profit of an integrated monopolist exceeds the joint profit of the non-integrated "monopoly chain". Moreover, observe that $I_v(\tau)$ is independent of v. This suggests that the private incentives for vertical integration do not depend on the degree of vertical integration. Therefore, borrowing McLaren (2000)'s vocabulary, we shall say that there is "no strategic complementarity in vertical integration" under an emission tax regulation.

Given that, as we have seen, vertical integration is always a profitable strategy, the equilibrium vertical structure should then feature m vertically integrated final good producers unless something prevents the vertical mergers wave to ever start. So, let us assume that there is a cost F to vertical integration. It is jointly profitable for an intermediate good producer and a final producer to merge if their post-merger joint profit exceeds the sum of their pre-merger individual profit, that is, if $I_v(0) \geq F$. Thus, if the industry was found is a separate vertical structure ($v = 0$) before the introduction of the emission tax, it must be that the cost F was exceeding the benefits from vertical integration i.e. $I_v(0) < F$. The question then, is whether introducing the emission tax would displace the threshold $\underline{F} = I_v(0)$ above which the cost of vertical integration would prevent vertical integration to take place. Formally, this would be the case if and only if $I_v(\tau) > I_v(0)$. We thus have the following.

Proposition 3 *Under an emission tax regulation, the private incentives for vertical integration do not depend on the degree of vertical integration. Moreover, if the final good demand is linear, introducing the emission tax does not affect the equilibrium vertical structure.*

Let us now turn to the private incentives for vertical integration under a permits regulation. Note that now the measure of firm private incentives for vertical integration must account for the induced changes in the equilibrium permits unit price.

$$\begin{aligned} I_v(\phi_v) &= \bar{\pi}_{v+1}(\phi_{v+1}) - [\bar{\pi}_v(w(\phi_v)) + \pi(w(\phi_v))] \\ &= \pi(\phi_{v+1}) - \pi(w(\phi_v)) + \frac{\phi_{v+1}^2 - \phi_v^2}{2\gamma} - \frac{\alpha q^2(w(\phi_{v+1}))}{mq'(w(\phi_{v+1}))} - \frac{\alpha(n-v)}{m}\left[\frac{q^2(w(\phi_{v+1}))}{q'(w(\phi_{v+1}))} - \frac{q^2(w(\phi_{v+1}))}{q'(w(\phi_v))}\right] \end{aligned}$$

The private benefits from a vertical merger now depend on the curvature of the demand function.

Proposition 4 *Under an emission permits regulation, the private incentives for vertical integration depends on the degree of vertical integration. Moreover, if the final good demand convex or not too concave, introducing the permits regulation reinforce strategic complementarity in vertical integration and might affect the equilibrium vertical structure.*

Proof. See Appendix ■

7 Conclusion

We have investigated some potential interactions between environmental regulation and the degree of vertical integration in a polluting industry. In our model, vertical integration increases productive efficiency because final good producers -unless being vertically integrated- have to trade in a *input market* where there are charged a positive mark-up price. When more production entails more pollution, there is a trade-off between productive efficiency and environmental efficiency. While polluting firms' strategic decisions have no effect on the emission tax rate, they might however influence the equilibrium price of permits. Therefore, increased output level due to higher degree of vertical integration might cause more pollution under an emission tax regulation or, alternatively, increase the permits unit price. We have shown that introducing a permits regulation might exacerbates the strategic complementarity in vertical integration and therefore lead to higher endogenous degree of vertical integration than under emission tax regulation. These results are particularly important since vertical oligopoly in commonplace in industry subject to many existing of forthcoming regulation.

8 Appendices

Proof. Let $h(\phi)$ be a positive and continuously differentiable function of ϕ with $h'(\phi) > 0$. Then let us define the function $q(h(\phi))$ solution in q to the following equation

$$P'(q)q + P(q) = h(\phi) \tag{19}$$

We first show that $q'(\phi_v) > 0$. Note that the first-order condition for profit-maximization is given by $P'(q_v(\phi))q_v(\phi) + P(q_v(\phi)) = c + \phi$. Totally differentiating this equation w.r.t. ϕ yields

$$q'(\phi_v) = \frac{1}{2P'(q_v(\phi)) + P''(q_v(\phi))q_v(\phi)} < 0$$

Next, totally differentiating condition (**??**) w.r.t. ϕ yields

$$w_v'(\phi) = \frac{q_v'(w(\phi_v))}{q_v''(w(\phi_v))(w(\phi) - c - \phi) + q_v'(w(\phi_v))} = \frac{[q']^2}{2[q']^2 - q''q}$$

It remains to show that $-\frac{q''q}{[q']^2} = qP''(q)/P'(q) > -2$ by assumption ■

Proof. (i) We first show that, given the emission tax rate τ, $E_{v+1}(\tau) > E_v(\tau)$ for all $v < m$, by writing $\Delta E_v(\tau) = E_{v+1}(\tau) - E_v(\tau)$ to get:

$$\begin{aligned}\Delta E_v(\tau) &= (v+1)q_{v+1}(\tau) + (n-v-1)q_{v+1}(w(\tau)) - m\frac{\tau}{\gamma} - [vq_v(\tau) + (n-v)q_v(w(\tau)) - m\frac{\tau}{\gamma}] \\ &= v[\underbrace{q_{v+1}(\tau) - q_v(\tau)}_{=0}] + (n-v)[\underbrace{q_{v+1}(w(\tau)) - q_v(w(\tau))}_{=0}] + q_{v+1}(\tau) - q_{v+1}(w(\tau)) \\ &= -\int_{\tau}^{w(\tau)} q_{v+1}(w)dw > 0\end{aligned}$$

where the last inequality follows from the fact that $q'_{v+1}(w) < 0$ and $w(\tau) > \tau$. Then, it follows that $Q_{v+1}(\tau) = E_{v+1}(\tau) - m\tau/\gamma > E_v(\tau) - m\tau/\gamma = Q_v(\tau)$. (ii) Noting that $w_v(\tau) > \tau$, the first assertion follows from $\pi'_v(w) < 0$ and $q'_v(w) < 0$. (iii) $\bar{\pi}_{v+1}(w_{v+1}(\tau)) - \bar{\pi}_v(w_v(\tau)) = -(w_{v+1}(\tau) - c - \tau)q_{v+1}(w_{v+1}(\tau))/m < 0$. (iv) Since the input price, $w_v(\tau)$, is independent of v, so are the monopoly profit $\pi_v(w_v(\tau))$ and consumer surplus in every non-integrated final good market. ■

Proof. (i) By its very nature a binding permits regulation caps the aggregate level of emissions. Suppose that there are v vertically integrated producer and let $Q_v(\phi_v) = vq(\phi_v) + n - v)q(w(\phi_v))$ and $\bar{E}$ respectively denote the industry aggregate output level and the total supply of permits. Then the permits market clearing condition implies that $Q_v(\phi_v) \equiv \bar{E} + m\phi_v/\gamma$. Therefore, the aggregate level of output increases with the degree of vertical integration since, for all $v < m$, $\Delta Q_{v+1}(\sigma) = Q_{v+1}(\phi_{v+1}) - Q_v(\phi_v) = m(\phi_{v+1} - \phi_v)/\gamma > 0$. (ii) Using (**??**), we show that for all $v < m$, $\bar{\pi}_{v+1}(w(\phi_{v+1})) < \bar{\pi}_v(w(\phi_v))$, by writing $\Delta\bar{\pi}_{v+1}(w) \equiv \bar{\pi}_{v+1}(w(\phi_{v+1})) - \bar{\pi}_v(w(\phi_v))$ and omitting redundant indices, to get

$$\begin{aligned}\Delta\bar{\pi}_{v+1}(w) &= \frac{\alpha}{m}\left[(n-v-1)q(w(\phi_{v+1})) - (n-v)q(w(\phi_v))\right] \\ &= \frac{\alpha}{m}\left[(n-v)(q(w(\phi_{v+1})) - q(w(\phi_v))) - q(w(\phi_{v+1}))\right] \\ &= \frac{\alpha}{m}\left[(n-v)\int_{w(\phi_v)}^{w(\phi_{v+1})} q'(w)dw - q(w(\phi_{v+1}))\right] < 0\end{aligned}$$

where the last inequality follows from claim 1 and lemma 4) which imply that $\int_{w(\phi_v)}^{w(\phi_{v+1})} q'(w)dw < 0$. (iii) Given that $q(\phi_v) - q(\phi_{v+1}) = \int_{\phi_v}^{\phi_{v+1}} q'(\phi)d\phi < 0$ (since Lemma 4) and that $q(w(\phi_v)) -$

$q(w(\phi_{v+1})) < 0$ (see the proof of assertion (i)). Hence, vertical integration reduces consumer surplus in all final good markets except in market $v+1$ since $q(\phi_{v+1}) > q(w(\phi_v))$ must hold to have $\Delta Q_{v+1}(\sigma) > 0$. (iii)

■

$$\begin{aligned}\Delta W_{v+1}(\tau) &= \int_{q(w(\tau))}^{q(\tau)} [P(u) - c - \tau]du + \tau[q(\tau) - q(w(\tau))] + D(E_v(\tau)) - D(E_{v+1}(\tau)) \\ &= \int_{q(w(\tau))}^{q(\tau)} [P(u) - c]du - \int_{E_v(\tau)}^{E_{v+1}(\tau)} D'(E)dE \\ &= \int_{q(w(\tau))}^{q(\tau)} [P(u) - c - D'(E_v(\tau) + u)]du\end{aligned} \tag{20}$$

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