The strong Porter hypothesis in an endogenous growth model with satisficing managers

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1. Introduction

In his engaging 1990's paper "America's green strategy", Michael Porter provided case studies to support the argument that the stricter a country's environmental policy, the more its firms innovate in a profitable way to produce less polluting or more resource-efficient products; see Porter (1996). Porter and van der Linde (1995) present further firm-level evidence and put forward that the above argument holds true in a world where firms do not always make optimal choices, due, e.g., to organizational inertia and control problems. Otherwise, complying with a stricter environmental policy could never be profitable. Jaffe and Palmer (1997) called that argument the *strong Porter hypothesis*, which they distinguished from a *weak* hypothesis whereby "the additional innovation [comes] at an opportunity cost that exceeds its benefits" for firms. They also identified a *narrow* version, which makes no consideration about profits and favors direct regulation (e.g., standards and output ceilings) when pollution requires immediate action.

There have been several attempts in endogenous growth theory to model the strong Porter hypothesis as one channel of transmission of stricter environmental policy to growth. In relation to the present paper, a few of them focus attention on the role that the assumption of profit maximization plays in the strong Porter hypothesis. Jaffe, Newell, and Stavins (2002) suggest that replacing profit maximization with non-optimizing behaviour creates possible improvements in profits. Ricci (2007a), in contrast, recommends researchers "[not to drop] the assumption of rationality", that is, the profit maximization model, under informational constraints on the part of firms' owners. As far as we are aware of this strand of the endogenous growth literature, its authors subscribe to the latter approach by assuming that firms pursue profit maximization in all sectors and markets.[1] Ambec and Barla (2007) suggest to use the Aghion, Dewatripont and Rey's (1997) framework which includes intermediate firms in which managers' decisions about innovation are better considered as *satisficing* rather than profit-maximizing.

This paper contributes to the debate on the importance of assuming profit maximizing firms in models of the strong Porter hypothesis. We relax this assumption regarding the decisions of managers on the size of innovation. We use the R&D-driven endogenous growth framework of Aghion and Griffith (2005), which we extend to allow for pollution and environmental taxation. The tax is paid in the final good sector as in Nakada's (2004) endogenous growth model. We think this is consistent with Porter and van der Linde's (1995) suggestion that governments should "regulate as late in the production chain as practical, which will normally allow more flexibility for innovation there and in the upstream stages." (p.111).[2] Aghion and Griffith's (2005) model is a special case of the framework of Aghion, Dewatripont, and Rey (1997) with satisficing managers and non-drastic innovation, in which owners incur a high fixed cost of production/innovation which they internally finance. These authors provide micro foundations for satisficing behaviour in a vintage capital model with managers who discount future benefits and costs but without environmental regulation. Under these assumptions, intermediate firms may go bankrupt. Satisficing managers preserve their private benefit of control and keep

[1] The microeconomic literature on Porter hypotheses includes various behavioural models of the firm; see Ambec, Cohen, Elgie, and Lanoie (2013) for a survey on these models. Other market imperfections are also covered in Mohr and Saha (2008) and André (2015).

[2] Porter and van der Linde (1995) who have a preference for market-based regulation pose the question of where to impose environmental regulation in the chain of production. We think our model is consistent with the idea of "late in the production chain", though the downstream firm does not innovate in our model.

their jobs by choosing a size of innovation just high enough to avoid bankruptcy.

Previous endogenous growth models on Porter hypotheses include Nakada (2004) who allows for pollution and a resource constraint on R&D activities in a framework *à la* Aghion and Howitt (1992). He finds that the "general equilibrium effect" of an increase in the environmental tax rate offsets the "profitability effect" in the intermediate inputs sector. In the long-term, environmental taxation enhances growth and reduces the level of pollution. We calculated the long-term effect of an increase in the tax rate on downstream firms' profits in Nakada's (2004) model. This effect is positive, thus verifying the strong Porter hypothesis. Mohr (2002) finds results consistent with the narrow Porter hypothesis in a vintage capital framework with positive spillovers in production, new technologies which are more productive and cleaner than the old technologies and producers who have a cost to switch to these latter. At any period every firm can behave selfishly by letting the others bear the switching cost. Under certain conditions, a stricter environmental policy (a technology standard whereby all firms must switch to the new technology) alleviates pollution and increases output. There is a risk in Mohr's (2002) model, however, that a benevolent planner finds profitable to let pollution be higher as technology improves. In Hart's (2004) model, environmental regulation consists in favouring recent vintages too. His results also verify the narrow version of Porter hypothesis.

Ricci (2007b) extends the multi-period frameworks of Hart (2004, 2007) by taking into account flexibility in the technological choice of R&D firms. He analyzes the possibility that environmental taxation, instead of standards, crowds out old and dirty intermediates inputs. Unlike in Hart (2004, 2007), productivity growth is negatively affected in Ricci's (2007b) model. Among non-endogenous growth models taking up the strong Porter hypothesis without departing from the maximization model, there is Xepapadeas and de Zeeuw (1999) who analyze the effect of environmental policy on capital accumulation. These authors eventually predict the weak Porter hypothesis: although an emission tax increases average productivity by stimulating the retirement of older vintage capital, the profits of taxed firms decrease. Feichtinger, Hartl, Kort, and Veliov (2005), who extend Xepapadeas and de Zeeuw (1999) to allow for nonlinear functional forms and technological change, do not find the strong Porter hypothesis either in their model.

The rest of the paper is structured as follows. In section 2 we present our extension of the Aghion and Griffith's (2005) model to allow for pollution and environmental taxation. Section 3 focuses on the effects of an increase in the environmental tax on innovation, pollution, growth and downstream profit. Provided innovation is not drastic, a stricter environmental policy, i.e. a higher tax rate in our model, plays the same role as an increase in the level of potential competition in Aghion and Griffith's (2005) model: it makes the survival constraint of intermediate firms tighter; satisficing managers, who fear to loose their job, respond by increasing the quality of intermediate inputs, which reduces pollution. Furthermore, the higher tax rate increases downstream firm's profit, thus verifying the strong Porter hypothesis. We also examine the concomitant effect of an increase in the level of potential competition in the intermediate sector. Section 4 concludes with further results then suggestions about possible extensions of the model.

2. The model

We use the R&D-driven endogenous growth model of Aghion and Griffith (2005) with satisficing managers, which we extend to allow for pollution and environmental taxation of producers in the final good market. Their two-period discrete model is a simplified version of the Aghion, Dewatripont, and Rey (1997) analysis of the relationship between competition, industrial policy and growth for two types of intermediate firms: firms in which managers' decisions regarding the size of innovation is to maximize profits and firms in which managers maximize their private benefits net of innovation efforts. In this paper we consider only the second type of firms. The growth rate of the economy is an increasing function of the satisficing size of innovation, which itself is determined by intermediate firms exploiting their market power against final good producers and blocking entry of a less cost-effective fringe.

2.1 The competitive final good sector. One final *numéraire* good y_t is produced competitively in period t according to the constant returns to scale production function

$$y_t = \int_0^1 A_t(i)^{1-\alpha} x_t(i)^{\alpha} di, \quad 0 < \alpha < 1, \tag{1}$$

where the productivity parameter $A_t(i)$ also measures the quality of the flow of intermediate input i at time t, $x_t(i)$.

We follow Nakada (2004) who assumes that pollution arises from the use of the x's in production of y. An environmental technology index $z_t(i)$ relates the quantities of intermediate inputs to pollution. Unlike in Nakada (2004), however, $z_t(i)$ is endogenous; it is inversely proportional to $A_t(i)$, that is, $z_t(i) = 1/A_t(i)$.[3] The structural pollution equation in each intermediate market i is therefore

$$z_t(i)x_t(i) = \frac{x_t(i)}{A_t(i)} \equiv P_t(i). \tag{2}$$

Equation (2) is consistent with the argument of Nakada (2004) that the higher the index (the lower the quality of i), the higher the level of pollution per unit of intermediate input (Ricci, 2007a, p. 696 defines this ratio as pollution intensity).[4] Environmental policy takes the form of a unit tax identical across sectors, τ_t. The tax, which varies directly as $P_t(i)$, is paid by downstream firms to discourage pollution, as in Nakada (2004).[5] This assumption is different, e.g., from that of Hart (2004) who applies the unit tax to output. Let the price of the ith intermediate input be $p_t(i)$. The representative downstream firm's profit $\pi_t(y)$ is:

$$y_t - \int_0^1 p_t(i)x_t(i)di - \int_0^1 \tau_t P_t(i)di. \tag{3}$$

For each intermediate input i, downstream firms maximize (3), given the technology in (1), up to the point where marginal productivity $\alpha(x_t(i)/A_t(i))^{\alpha-1}$ equals tax-inclusive marginal cost $p_t(i) + \tau_t(i)/A_t(i)$, which leads to the following inverse demand,

$$p_t(i) = \alpha(x_t(i)/A_t(i))^{\alpha-1} - \frac{\tau_t}{A_t(i)}. \tag{4}$$

We see that the unit tax on pollution shifts downward the demand schedule for the intermediate good. We now turn to incumbent firms' decisions in the intermediate sector.

[3] In section 4 we consider the less restrictive assumption of imperfect negative correlation between z and A ($z_t(i) = 1/A_t(i)^{\beta}$).

[4] Notice in equation (2) that there are no spillovers between sectors.

[5] The average tax per unit of input $\tau_t P_t(i)/x_t(i) = \tau_t z_t(i)$ also varies directly as pollution intensity.

2.2 The decisions of monopolistically competitive intermediate firms. Incumbents make two related decisions: the quantity of x to sell to final good producers (regardless the degree to which this amount will degrade the environment). And, its managers decide on the size of innovation γ, which we will define later. Incumbents produce x from y according to the identity technology at a marginal cost of 1. In each intermediate market i, a fringe could produce the same good at a higher marginal cost (of imitation) $\chi > 1$. Innovation is non-drastic ($\alpha^{-1} > \chi$).[6] Incumbents exert their market power by charging the limit price $p_t(i) = \chi$ so as to prevent the fringe from entering their market. Setting equation (4) equal to χ, the demand for intermediate input i is

$$x_t(i) = \alpha^{\frac{1}{1-\alpha}} \left(\chi + \tau_t/A_t(i)\right)^{\frac{1}{\alpha-1}} A_t(i). \tag{5}$$

Inserting equation (5) in (2), pollution is equal to:

$$P_t(i) = \alpha^{\frac{1}{1-\alpha}} \left(\chi + \tau_t/A_t(i)\right)^{\frac{1}{\alpha-1}}, \tag{6}$$

which decreases with environmental regulation stringency, holding $A_t(i)$ and all parameters constant ($\partial P_t(i)/\partial \tau_t < 0$).

Intermediate firms are self-financed. In addition to a unit marginal cost they incur a fixed cost of production $\kappa A_{t-1}(i)$ at the beginning of period t. Self-financing is not a crucial assumption; we could, for instance, follow Aghion and Griffith (2005) who add a debt repayment obligation to the model, dA_{t-1}. More important are the assumptions that κ is sufficiently large to allow for bankruptcy ($\kappa > \chi - 1$) and that managers live for one period. The value for profit net of the fixed cost of production in period t is $\pi_t(i) = (p_t(i) - 1)x_t(i) - \kappa A_{t-1}(i)$. Under the previous assumption that intermediate incumbents opt for limit pricing and using equation (5), $\pi_t(i)$ can be rewritten as:

$$\pi_t(i) = (\chi - 1)\alpha^{\frac{1}{1-\alpha}} \left(\chi + \tau_t/A_t(i)\right)^{\frac{1}{\alpha-1}} A_t(i) - \kappa A_{t-1}(i). \tag{7}$$

Assuming that productivity evolves according to the first-order deterministic process

$$A_t(i) = \gamma(i) A_{t-1}(i), \tag{8}$$

then inserting (8) in (7), one obtains:

$$\pi_t(i) = \left[(\chi - 1)\alpha^{\frac{1}{1-\alpha}} \left(\chi + \frac{\tau_t}{\gamma(i)A_{t-1}(i)}\right)^{\frac{1}{\alpha-1}} \gamma(i) - \kappa\right] A_{t-1}(i), \ \forall\ 0 \leq i \leq 1. \tag{9}$$

Unlike the Aghion and Griffith's (2005, p. 38) model, in which there is no pollution and thus no environmental regulation ($\tau_t \equiv 0$), intermediate profits $\pi_t(i)$ are nonlinear in $\gamma(i)\ \forall\ 0 \leq i \leq 1$; thus, finding a solution which corresponds to incumbents' decisions on the size of innovation is not as simple as in Aghion and Griffith's (2005) model where the $\gamma(i)$'s are equal across intermediate markets.[7]

[6] α^{-1} is the monopoly price incumbent intermediate firms would charge were innovation drastic and environmental regulation absent. We solved the case of drastic innovation which we discuss in the concluding section.

[7] γ has i as argument because the $A_{t-1}(i)$'s are allowed to vary across markets.

2.3 Satisficing managers and the size of innovation. Porter and van der Linde (1995) suggest organizational inertia and lack of control over managers among the possible constraints that intermediate firms' owners will have to shift to comply with environmental policy. Interestingly, the Aghion and Griffith's (2005) behavioural model of growth assumes intermediate firms subject to organizational slack, although slack is not modeled explicitly. We define *slack* as under-exploited managerial resources to increase innovation, in the sense that managers enjoy private benefits (net of innovation efforts) greater than the amount required to retain them within the firm. Managers, who fear to loose their job, are mainly concerned with preserving their net benefit of control in intermediate firms. The above definition of slack, which can be found in Nohria and Gulati (1996), has a quantitative counterpart as we shall see in the next paragraph.

We now describe the decision of managers on the size of innovation. The private benefit a manager gets from controlling the intermediate firm is B. And, $B - \gamma$ is this benefit net of innovation efforts. This difference is a simple version of managers' objective functions in Aghion, Dewatripont, and Rey (1999). B is not included in the model of Aghion and Griffith (2005) who consider a solution γ that results from equating equation (9) to 0.[8] We model the decision problem of satisficing managers regarding innovation by solving the classical programming problem $\max_{\gamma}\{B - \gamma : \pi \geq 0\}$, the solution of which, γ^{ND} ('ND' stands for 'non-drastic' innovation) is shown on Figure 1 below. It lies on the thick profit curve π (see the first part of Proposition 1 in Appendix A). If managers choose a size $\gamma < \gamma^{ND}$, then their net benefit of control increases but the firm goes bankrupt ($\pi < 0$). Whereas, if $\gamma > \gamma^{ND}$, owners' profit increases at the expense of managers. The difference $B - \gamma^{ND}$ may be defined as a measure of organizational slack in our model. If there were no organizational slack and managers had an outside option which yields a net benefit of zero, then B would be the maximum innovation effort and $[(\chi-1)\alpha^{\frac{1}{1-\alpha}}(\chi + \tau_t/BA_{t-1}(i))^{\frac{1}{\alpha-1}} B - \kappa] \equiv \bar{\pi}$ would be the maximum profit firm i's owners could obtain.

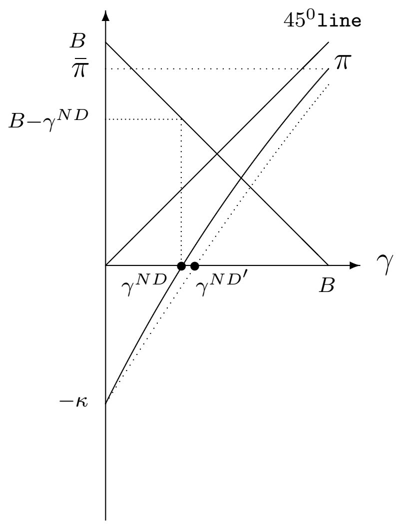

Figure 1. Satisficing size of innovation before the tax increase (γ^{ND}) and after ($\gamma^{ND'}$).

[8] Actually, Aghion and Griffith (2005) assume B is sufficiently large that it can be ignored and managers' program can be written as a minimization of $\gamma : \pi = 0$. Since there is no environmental regulation in their model they obtain the simple solution $\frac{\kappa}{(\chi-1)\left(\frac{\chi}{\alpha}\right)^{\frac{1}{\alpha-1}}}$, which is identical across markets.

3. Effect of a stricter environmental policy

Predicting the strong Porter hypothesis in our model requires first finding that the increase in τ_t, that is, a stricter environmental policy, reduces pollution ($\partial P_t/\partial \tau_t < 0$) and enhances innovation ($\partial \gamma^{ND}/\partial \tau_t > 0$; $\gamma^{ND'} > \gamma^{ND}$ in Figure 1). These results are shown as Proposition 2 and in the second part of Proposition 1 in Appendix A. In Proposition 3 we check that there is growth in the model and that the higher the tax rate, the higher the growth rate ($(y_t - y_{t-1})/y_{t-1} > 0$). The model should verify a fourth result: environmental policy benefits firms. This result only needs to be verified for the final market ($\partial \pi_t(y)/\partial \tau_t > 0$); the equilibrium value for profits in intermediate firms with satisficing managers indeed equals 0 (see subsection 2.3). Proposition 4 below shows this result.

Poposition 4. *A higher environmental tax rate increases downstream firms' profit.*

Proof. Using equations (2), (4) and the assumption $p_t(i) = \chi$, downstream profit can be rewritten as:

$$\pi_t(y) = \int_0^1 \left(\frac{1-\alpha}{\alpha}\right)(\chi + \tau_t/A_t(i))x_t(i)di. \tag{10}$$

Replacing $x_t(i)$ with the right hand side of (5), using (8) as well as the implicit profit equation, one obtains the following reduced downstream profit equation:

$$\pi_t(y) = \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\kappa}{\chi-1}\right)\int_0^1 \left(\chi + \frac{\tau_t}{\gamma^{ND}(\tau_t, i)A_{t-1}(i)}\right)A_{t-1}(i)di. \tag{11}$$

To prove proposition 4, we differentiate equation (11) with respect to τ_t at point $(\tau_t, \gamma^{ND}(\tau_t, i))$. But, $\frac{\partial}{\partial \tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right) > 0$ as shown in Proposition 2. Therefore, $\frac{\partial \pi_t(y)}{\partial \tau_t} = \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\kappa}{\chi-1}\right)\int \frac{\partial}{\partial \tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right)$ is positive. ||

Considered together, Propositions 1 to 4 verify the strong Porter hypothesis. From equation (3), a higher tax rate increases $\tau_t P_t(i)$, which has a direct negative effect on downstream profit. The downstream firm responds by reducing its demand for intermediate inputs, which implies both lower output and lower production costs. The lower demand also reduces the monopoly rent $(\chi - 1)x_t(i)$ of incumbent intermediate firms, in which managers react by increasing the size of innovation (Proposition 1). Thus, productivity increases. Overall, the marginal change in the production function part of the reduced profit equation is equal to $\frac{1}{\alpha}\left(\frac{\kappa}{\chi-1}\right)\int \frac{\partial}{\partial \tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right) > 0$. Concerning the effect on profit that operates through pollution, it is positive showing that a higher tax rate costs more to final good producers at equilibrium ($\left(\frac{\kappa}{\chi-1}\right)\int \frac{\partial}{\partial \tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right)$, is positive; see Proposition 2). This negative effect however is insufficient to overcome the direct positive effect of a higher tax rate on production. Combining these results, we find that the loss in downstream profit is more than offset by the general equilibrium effects.

Note that a stricter environmental policy does not impact costs of the competitive fringe. This assumption is consistent with our initial assumption that marginal production costs of incumbent intermediate firms is equal to unity and thus does not depend on τ_t either. Of course, one may consider $\chi(\tau_t)$ and examine the direction of the effect of a change in τ_t. There are three cases: (*a*) $\chi' < 0$, (*b*) $\chi' = 0$, (*c*) $\chi' > 0$. Case *b* is that we have considered so far. In cases a and c, the limit pricing strategy followed by incumbent intermediate firms is not affected because $p_t(i)$ remains equal to $\chi(\tau_t)$ regardless the functional form of the marginal cost $\chi(\cdot)$. In case a the equilibrium value of x increases because the lower χ has a negative effect on managers' unit rent $\chi - 1$ and on owners' profit $\pi_t(i)$ thus leading managers to increase innovation above γ^{ND}. Case c can be interpreted by using symmetric reasoning.

We conclude this section with some discussion about whether competition policy interferes with the win-win environmental policy. Let us assume a *decrease* in the cost of imitation χ, which can be interpreted as an increase in the level of potential competition (see Aghion and Griffith, 2005, p. 38).[9] This change in χ actually reinforces the positive effect of a stricter environmental policy on downstream firms' profit $(\partial^2\pi_t(y)/\partial(-\chi)\partial\tau_t > 0)$.[10] The main rationale for this is that a *lower* χ reduces the market power of intermediate incumbent firms, which benefits producers in the final good market $(\partial\pi_t(y)/\partial(-\chi) > 0)$. But, $\partial\pi_t(y)/\partial\tau_t > 0$ (Proposition 4). Thus, environmental policy and competition policy are complementary instruments in the sense that the former needs not be as strict as before potential competition increased. The effect on pollution should also be considered separately. Aggregated pollution increases as the cost of imitation decreases $(\partial P_t/\partial(-\chi) > 0)$. But, $\partial P_t/\partial\tau_t < 0$ as we showed in Proposition 2. Using tedious calculations shows that $\partial^2 P_t/\partial(-\chi)\partial\tau_t < 0$; thus, an increase in potential competition is not detrimental to the more stringent environmental policy.

4. Concluding discussion

This paper extends the Aghion and Griffith's (2005) model with satisficing managers to allow for pollution and environmental taxation. Our theoretical results predict the strong Porter hypothesis that a stricter environmental policy (a higher tax rate in our model) improves growth, the environment and induces profitable innovations. We also find that environmental policy and competition policy in the intermediate sector reinforce each other. To check for robustness of these results, we consider several changes to the model's assumptions: innovation is large enough to create a monopoly, vertical integration, different regulations and some opportunity cost in R&D when targeting cleaner innovations.[11]

Making the opposite assumption that innovation is drastic (the direction of the inequality $\alpha^{-1} > \chi$ changes to $\alpha^{-1} < \chi$), the strong Porter hypothesis no longer holds (proposition 4 is not verified). As shown in Appendix B, we need additional constraints on the parameter set to maintain incumbent prices $p_t(i)$ below χ, the marginal cost of the fringe. Under these assumptions, Propositions 1 to 3 are verified whereas Proposition 4 isn't so because downstream profit, $\frac{\kappa}{\alpha}\int_0^1 A_{t-1}(i)$, although higher than that when innovation is not drastic, does not depend on τ_t. Any extra rent from further innovation following the tax increase is fully appropriated by intermediate incumbents and none of it is transferred to owners whose satisficing managers increase innovation just enough so that intermediate economic profit is zero. This lack of effect on downstream profit is evidence of the weak Porter hypothesis. This result is also a consequence of the change in

9 The discussion below uses the result that $\partial\gamma^{ND}/\partial\chi < 0$ which we deduce from the implicit function theorem.

10 They are available upon request.

11 We thank the referees for having invited us to investigate these interesting situations. The former of these situations is well documented in the remaining of the paper. Proofs regarding the other situations are available upon request.

the behavior of managers who maximize profit in the inputs markets. Thus, complying with a more stringent environmental policy is not profitable when innovation is drastic so that incumbent's pricing is that of a pure monopoly. Considering vertically integrated firms provides another interesting insight regarding the effect that market structure has on our results. Assume that in each intermediate market, the vertically integrated firm maximizes the sum of downstream profit $A_t(i)^{1-\alpha}x_t(i)^\alpha - p_t(i)x_t(i) - \tau_t P_t(i)$ and intermediate incumbent's rent $(p_t(i)-1)x_t(i)$ in each market i; we consider the cost of production/innovation $\kappa A_{t-1}(i)$ later when deriving the satisficing size of innovation. We find that the size of the innovation is smaller than that under vertical separation, which can be seen using the first part of Proposition 1 applied to the new implicit function, say $h^{VI}(\tau_t,\gamma)$. It can be shown that $h^{VI}(\tau_t,\gamma) > h(\tau_t,\gamma)$, $\forall\gamma$, where $h(\tau_t,\gamma)$ which we defined in Appendix A is the implicit function under vertical separation. It is such that $h(\tau_t,\gamma^{ND}) = 0$, which implies that $h^{VI}(\tau_t,\gamma^{ND}) > 0$. But, h and h^{VI} are increasing in γ. Consequently, γ^{VI}, which solves the implicit equation $h^{VI}(\tau_t,\gamma) = 0$ is less than γ^{ND}. It is left for future research to examine the robustness of our results when we impose vertical integration. Overall, increasing the market power of firms seem to narrow the scope of the Porter hypothesis.

We also checked whether our results are valid for a different kind of regulation and when intermediate incumbents pay the tax. In these cases, the model is more tractable. First, considering a limit on the amount of pollution for each input ($P_t(i) \leq \bar{P}$) leads to two solutions according to whether $\bar{P}$ is greater or less than some threshold $\mu \equiv (\chi/\alpha)^{\frac{1}{\alpha-1}}$. When the constraint is binding ($P = \bar{P}$), we find solution $\bar{\gamma} = \frac{\kappa}{(\chi-1)\bar{P}}$, which is constant across markets. Besides, economic growth is equal to $\bar{\gamma}-1$, which is greater than 0 and increases with stricter regulation ($\bar{P}$ decreases). Proposition 4 is also verified. These results are slightly different if we consider a limit on the input-emission ratio ($z_t(i) \leq \bar{z}$; see, e.g., Verdier (1995)). All Propositions (except proposition 2) are verified in this case. Pollution is not affected by regulation stringency; it is just equal to μ. Second, if we modify the model by assuming that the government levies an environmental tax on intermediate goods producers, we again find that pollution is not affected by regulation. Thus, we do not find the strong Porter hypothesis in our model when intermediate firms pay the tax. To summarize, regulating the input-emission ratio or taxing intermediate firms lead to qualitatively similar results in that all propositions (except the second) are true. Regulators should favor a limit on the amount of pollution as policy instrument. We also examined the effect of assuming some opportunity cost in R&D when targeting cleaner innovations, say $z_t(i) \equiv \frac{1}{A_t(i)^\beta}$, with $\beta \in (0,1)$ ($\frac{\partial \bar{z}}{\partial A}\frac{A}{\bar{z}} = -\beta > -1$), our four propositions hold. They also hold if we consider that targeting more ambitious innovation implies an additional R&D cost, $c\gamma A_{t-1}(i)$, in the intermediate profit. One conclusion we draw from these results is that the scope of the strong Porter hypothesis is more sensitive to the choice of policy instrument available to the regulator and market configuration than to changes in the specification of the costs and the pollution equation.

We now discuss possible extensions of the model in the direction of addressing less restrictively whether the assumption of profit maximizing firms is so crucial for the strong Porter hypothesis. A first extension would be to introduce profit maximizing firms in the intermediate sector. One approach to this would be to split the intermediate sector between a fraction m of inputs produced by profit maximizing managers/firms and the remaining inputs produced by satisficing managers. It is likely that a higher tax rate will adversely affect profit maximizing firms in the short-term. Allowing these firms the amount of the tax might solve the problem in the long-term. A second approach would be to divide the production of each intermediate input between the two types of firms and make some assumption regarding how they compete with each other, as in Aghion, Harris, Howitt, and Vickers (2001), and with the fringe. One could also embed environmental policy in the more sophisticated model of Aghion, Dewatripont, and Rey (1999) who consider an economy in which profit-maximizing firms and firms with satisficing managers – who minimize their effort by delaying adoption of more efficient innovations – co-exist. The general equilibrium analysis of their mixed economy, however, is questionable. Equilibrium growth rate in the mixed economy is an *ad hoc* linear and convex combination of growth rates of the two economies (with profit maximizing managers or satisficing managers). In an ongoing research, we split the intermediate sector between $m < 1$ profit-maximizing firms which monopolize intermediate markets from 0 to m, and $1 - m$ conservative firms owning the remaining markets. Thus, there is a one-to-one relationship between the number of firms of a given type and the number of intermediate markets they own. Another possible extension would consist in allowing for a more realistic agency problem with profit maximizing and managerial firms *à la* Scharfstein (1988). Quality A in non-profit maximizing firms would be affected by the realization of a non-observable random Bernoulli variable. Only managers would observe intermediate output, innovation and the value of the random shock. Intermediate firms' owners would require managers to satisfy a single profit target and condition managers' payment on output. This extension would have as advantage to preserve tractability of our model.

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Appendix

A Non-drastic innovation

PROPOSITION 1 *The size of innovation increases with the tax rate* ($\frac{\partial \gamma^{ND}}{\partial \tau_t} > 0$).

Proof. Denoting $\frac{1}{1-\alpha}$ by e then equating (9) to zero leads to the following implicit equation

$$\gamma - \frac{\kappa}{\chi - 1}\alpha^{-e}\left(\chi + \frac{\tau_t}{\gamma A_{t-1}(i)}\right)^e = 0. \tag{A.1}$$

First, we show that a solution $\gamma^{ND}(\tau_t)$ exists and differs across markets $i \in (0,1)$. Let us denote the function at the left and side of equation (A.1) as $h(\tau_t, \gamma)$. It is continuous an increasing in γ; $\lim_{\gamma \downarrow 0} h(\tau_t, \gamma) = -\infty$ and h is bounded above by B as γ tends to B with $\lim_{\gamma \uparrow B} h(\tau_t, \gamma) = B - \frac{\kappa}{\chi-1}\alpha^{-e}\left(\chi + \frac{\tau_t}{BA_{t-1}(i)}\right)^e < B - \kappa$. Furthermore, the partial derivative $\partial h(\tau_t, \gamma)/\partial \gamma > 1$. There exists a unique solution of (A.1). We remark that $\gamma^{ND} > 1$; indeed, $h(\tau_t, 1)$ is one minus the product of three terms, each being greater than 1. Therefore, $h(\tau_t, 1)$ is less than 0. But, h is increasing in γ, which suffices to prove that solution $\gamma^{ND} > 1$. Combining these results, h lies below the 45° line (see Figure 1 on page 5) and is concave. We can use the implicit function theorem at point $(\tau_t, \gamma^{ND}(\tau_t))$. We find $\partial h(\tau_t, \gamma)/\partial \gamma = 1 + e\tau_t/(\chi\gamma A_{t-1}(i) + \tau_t)$; thus, the direction of the effect of an increase in τ_t on γ is given by the sign of $-\partial h(\tau_t, \gamma)/\partial \tau_t = e\gamma/(\chi\gamma A_{t-1}(i) + \tau_t)$, which is positive. Therefore, the curve h shifts to the right; it is steeper at the new solution ($\gamma^{ND'}$ as indicated in Figure 1); consequently, γ increases as τ_t increases, which proves Proposition 1. ‖

PROPOSITION 2 *Pollution decreases as the environmental tax rate increases* ($\frac{\partial P_t}{\partial \tau_t} < 0$).

Proof. Using our definition for e, pollution in equation (6) can be written as $\alpha^e\left(\chi + \frac{\tau_t}{\gamma A_{t-1}(i)}\right)^{-e}$. Its derivative at point $(\tau_t, \gamma^{ND}(\tau_t))$ has the same sign as

$$-\frac{\partial}{\partial \tau_t}\left(\frac{\tau_t}{\gamma^{ND}}\right) = -\frac{1}{\gamma^{ND}}\left(1 - \frac{e\tau_t}{\chi\gamma^{ND}A_{t-1}(i) + \tau_t + e\tau_t}\right) < 0.$$

‖

PROPOSITION 3 *The growth rate of the economy* $(y_t - y_{t-1})/y_{t-1} \equiv g$ *is positive and increases with* τ_t.

Proof. To ease the exposition we remove the exponent 'ND'. From the zero-profit condition, $x_t(i) = \frac{K}{\chi-1}A_{t-1}(i)$ and $x_{t-1}(i) = \frac{K}{\chi-1}\frac{A_{t-1}(i)}{\gamma(\tau_t)}$. Using these results and denoting $\Gamma(\tau_t, i) \equiv \gamma(\tau_t)^{-\alpha}A_{t-1}(i)$ and $s(\tau_t, i) \equiv \frac{\Gamma(\tau_t, i)}{\int \Gamma(\tau_t, i)di}$, we can deduce $\frac{y_t}{y_{t-1}} = \int s(\tau_t, i)\gamma(\tau_t, i)di$, which is a convex combination of the γ's. But, $\gamma > 1$ (see the proof of Proposition 1). Thus, $\frac{y_t}{y_{t-1}}$, which is a convex combination of the γ's, all greater than 1, is greater than 1 and $g > 0$, which proves the first part of Proposition 3.

Using the Leibniz's rule, g_{τ_t} is equal to

$$\int s\left(\alpha\gamma\frac{\int(\gamma_{\tau_t}/\gamma)\Gamma}{\int \Gamma} + (1-\alpha)\gamma_{\tau_t}\right)di,$$

which is the integral of s times a convex combination of positive terms. It is positive, thus showing the second part of Proposition 3. $\|$

B Drastic innovation

Assuming innovation is drastic changes the direction of the inequality $\alpha^{-1} > \chi$ to $\alpha^{-1} < \chi$. We add two new assumptions, which are $\alpha^2 > 1/\chi$ and $\tau_t < \alpha A_{t-1}(i)\ \forall i$. These assumptions are sufficient conditions for $\alpha^{-1} < p_t^D(i) < \chi$. The first assumption implies that of a drastic innovation ($\alpha^2 > 1/\chi \Rightarrow \alpha^{-1} < \chi$). The second assumption sets an upper bound for the value of the tax rate. Assuming that in its intermediate input market i incumbent maximizes $(p_t(i) - 1)x_t(i)$ with respect to $x_t(i)$, where the final sector's inverse demand is given by equation (4), we obtain the following quantity $x_t^D(i) = \alpha^{\frac{2}{1-\alpha}}(1 + \tau_t/A_t(i))^{\frac{1}{\alpha-1}} A_t(i)$, where 'D' stands for drastic, and corresponding monopoly price $p_t^D(i) = \alpha^{-1} + \alpha^{-1}(1-\alpha)\tau_t/A_t(i)$.

The size of innovation γ^D is determined by satisficing managers, $\gamma^D : (p_t^D(i)-1)x_t^D(i) - \kappa A_{t-1}(i) = 0$ as in the case of non-drastic innovation with the difference that the economic rent per unit of x, $p^D - 1$ is endogenous. The implicit equation can be rewritten:

$$\gamma - e\kappa\alpha^{-(1+\alpha)e}\left(1 + \frac{\tau_t}{\gamma A_{t-1}(i)}\right)^{e\alpha} = 0, \tag{B.1}$$

where e was already defined. To prove Proposition 1, we follow the same reasoning as in Appendix A. We rewrite the function at the left hand side of (B.1) as $h^D(\tau_t, \gamma)$. It is increasing in γ. Using the assumptions $\alpha^{-1} < \chi$ and $\kappa > \chi - 1$ we can show that $\gamma^D > 1$. Then we find $\partial\gamma^D/\partial\tau_t = \frac{e\alpha\gamma^D}{\gamma^D A_{t-1}(i) + \tau_t + e\alpha\tau_t} > 0$, using the implicit function theorem. Regarding the effect of a more stringent policy on pollution, note first that

$$P_t^D(i) = x_t^D(i)/A_t^D(i) = \alpha^{2e}\left(\frac{1}{1 + \tau_t/\gamma^D A_{t-1}(i)}\right)^e. \tag{B.2}$$

Differentiating (B.2) with respect to τ_t leads to a decrease in pollution; the proof follows that of Proposition 2 in Appendix A. The derivative of $P_t^D(i)$ at point $(\tau_t, \gamma^D(\tau_t))$ has the same sign as

$$-\frac{\partial}{\partial\tau_t}\left(\frac{\tau_t}{\gamma^D}\right) = -\frac{1}{\gamma^D}\left(1 - \frac{e\alpha\tau_t}{\gamma^D A_{t-1}(i) + \tau_t + e\alpha\tau_t}\right) < 0.$$

Proposition 3 still holds. Its proof is simpler than that when innovation is non-drastic, for the ratio of outputs

$$\frac{y_t}{y_{t-1}} = \frac{\int_0^1 A_{t-1}(i)di}{\int_0^1 (\gamma^D(i))^{-1} A_{t-1}(i)di},$$

is greater than 1 and increases as τ_t increases. Proposition 4, however, is not verified because downstream profit, $\pi_t(y) = \frac{\kappa}{\alpha}\int_0^1 A_{t-1}(i)$, does not depend on τ_t. Considered together, these results verify the weak Porter hypothesis, which we define in the introduction of the paper.