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Abstract

Few endogenous growth models have focused attention on the strong Porter hypothesis, that *stricter* environmental policies induce innovations, the benefits of which exceed the costs. A key assumption in this hypothesis is that policy strictness pushes firms to overcome some obstacles to profit maximization. We model this hypothesis by incorporating pollution and taxation in the Aghion and Griffith (2005) analysis of growth with satisficing managers. Our theoretical results predict the strong Porter hypothesis. Moreover, they suggest that the stringency of environmental policy should adjust to changes in the level of potential competition in the intermediate inputs sector.

Keywords: Strong Porter hypothesis, Environmental policy, Endogenous growth.

JEL Classification: D43, E03, O31, O41, O44

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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.¹ 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 this policy could never be profitable. Jaffe and Palmer (1997) called that argument the *strong Porter hypothesis*, which they distinguished from a *weak* version whereby "the additional innovation [comes] at an opportunity cost that exceeds its benefits". 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.

Several theoretical papers in endogenous growth theory have constructed models of the strong Porter hypothesis as a channel of transmission of environmental policy to growth. A few of them focus attention on the role that the assumption of profit maximization plays in the strong Porter hypothesis. E.g., 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 owners. As far as we are aware of this strand of the endogenous growth literature, its authors assume that firms pursue profit maximization in all sectors and markets.² 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 for intermediate firms' decisions regarding innovation.

¹ See Porter (1996).

² The microeconomic literature on Porter's hypotheses includes various behavioural models of the firm, including bounded rationality and profit maximization under market failure; see Ambec *et al.* (2013) for a survey.

Ambec and Barla (2007) suggest to use the Aghion, Dewatripon and Rey’s (1997) framework, although they are not clear about which behavioural model of the firm to use. We model the strong Porter hypothesis allowing for pollution and environmental taxation in the R&D-driven endogenous growth model of Aghion and Griffith (2005). Their model is a special case of the framework of Aghion, Dewatripont, and Rey (1997, 1999) with *satisficing managers*, who pursue other objectives than profit maximization.³ In the model of Aghion and Griffith (2005), owners cannot monitor innovation efforts and incur a high fixed cost of production which they internally finance. Under these assumptions, the firm may go bankrupt. Satisficing managers preserve their private benefit of control and keep their jobs by choosing a size of innovation just high enough to avoid bankruptcy. A stricter environmental policy in our model plays the same role as an increase in the level of potential competition in the Aghion and Griffith’s (2005) model without pollution: the survival constraint of intermediate firms is no longer met; managers, who fear to lose their job, respond by increasing the supply of intermediate inputs. Second, it reduces pollution and third, it enhances the profits of taxed firms in the final good market, thus verifying the strong Porter hypothesis.

Previous endogenous growth models on Porter’s 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

³ All these models also consider intermediate firms with managers who maximize profit. Having both kinds of firms in a single endogenous growth model with pollution would extend the current literature; see Section 4 below.

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 the model of Hart (2004), environmental regulation consists in favouring recent vintages too. His results also verify the narrow 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 Hart (2004, 2007), productivity growth is negatively affected in his 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 analyzes 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 *et al.*, who extend Xepapadeas and de Zeeuw (1999) to allow for nonlinear functional forms and technological change, do not find the strong Porter hypothesis either.

The rest of the paper is structured as follows. Section 2 introduces the model and the assumption of satisficing managers. Section 3 focuses on the effects of an increase in the environmental tax on pollution and the profits of firms in both the intermediate sector and the final good market. Section 4 concludes with 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 model is a special case of the Aghion, Dewa-

tripont, and Rey (1997) analysis of the relationship between competition vs. industrial policy and growth when managers' decisions regarding the size of innovation is to maximize private benefits instead of intermediate firms' profits. The average 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 a fringe of less cost-effective firms and against final good producers.

2.1 The final good market

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

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

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 the model developed by Nakada (2004), $z_t(i)$ is endogenous; it is inversely proportional to $A_t(i)$, that is, $z_t(i) \equiv 1/A_t(i)$. The structural pollution equation for each intermediate input i is

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

It is consistent with the argument of Nakada (2004) that the higher the index (the lower the quality), the higher the level of pollution per unit of intermediate input i .⁴

Environmental policy takes the form of a tax rate $\tau_t(i)$. The tax, which varies directly as $P_t(i)$, is paid by downstream firms to discourage pollution, as in Nakada (2004). This assumption is different, e.g., from that of Hart (2004) who applies the tax rate to output. Let the price of the i th intermediate input be $p_t(i)$. The representative downstream firm's

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

profit $\pi_t(y)$ is:

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

Downstream firms maximize (3), given the technology in (1), which leads to marginal productivity equals tax-inclusive marginal cost $p_t(i)+\tau_t(i)/A_t(i)$. Let the quality-adjusted environmental tax rate be $\phi_t \equiv \tau_t(i)/A_t(i)$; a similar assumption can be found in the endogenous growth model with pollution and labor as input of Verdier (1995), who adjusts the tax rate to wage; see also Nakada (2004). Unadjusted tax rate τ_t grows at the same rate as A_t , which implies that ϕ_t does not depend on the time period. Let $\phi \equiv \phi_t$. Combining these assumptions, profit maximization by downstream producers gives the following inverse demand for each intermediate input i , $p_t(i) = \alpha(x_t(i)/A_t(i))^{\alpha-1} - \phi$. We now turn to incumbent firms' decisions in the intermediate sector.

2.2 Intermediate firms' decisions

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, a decision on the size of innovation γ . They produce x from y according to a one-to-one technology at a marginal cost of unity. In each sector i , a fringe could produce the same good at a higher marginal cost (of imitation), $\chi > 1$. Note that the price of the incumbent intermediate firm would be $[1 + (1 - \alpha)\phi]\alpha^{-1}$, were the fringe to be ignored. This price is higher than α^{-1} that is the monopoly price in the model without pollution of Aghion and Griffith (2005). Innovation, however, is non-drastic ($\alpha^{-1} > \chi$). In each sector, the incumbent exerts its market power by charging the limit price $p_t(i) = \chi$ so as to prevent the fringe from entering. Under these assumptions, the demand for the intermediate input i is

$$x_t(i) = \left(\frac{\chi + \phi}{\alpha} \right)^{\frac{1}{\alpha-1}} A_t(i). \quad (4)$$

Let $\mu \equiv \left(\frac{\chi + \phi}{\alpha} \right)^{\frac{1}{\alpha-1}}$. Inserting equation (4) in equation (2), we obtain the following reduced pollution equation:

$$P_t(i) = \mu, \quad (5)$$

which is constant across intermediate inputs. μ is less than $(\chi/\alpha)^{\frac{1}{\alpha-1}}$, that is, pollution is lower under environmental policy. So is the demand for input i in equation (4) before innovation occurs, as expected.

Intermediate firms are self-financed and incur a fixed cost of production $\kappa A_{t-1}(i)$ per intermediate good i at the beginning of the period. To allow for bankruptcy Aghion and Griffith (2005) make the assumption that κ is sufficiently large ($\kappa > \chi - 1$). Managers live for one period and are only interested in the value for profit net of the fixed cost of production in that period, $\pi_t(i) = (\chi - 1)x_t(i) - \kappa A_{t-1}(i)$. Let $\delta \equiv (\chi - 1)\mu$. Using equation (4), $\pi_t(i)$ is rewritten as follows

$$\pi_t(i) = \delta A_t(i) - \kappa A_{t-1}(i). \quad (6)$$

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

$$A_t(i) = \gamma A_{t-1}(i), \quad (7)$$

then inserting (7) in (6), one obtains:

$$\pi_t(i) = (\delta\gamma - \kappa)A_{t-1}(i), \quad \forall 0 \leq i \leq 1. \quad (8)$$

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 firm's owners will have to shift to comply with environmental policy. Interestingly, the Aghion and Griffith (2005) behavioural model of growth assumes intermediate firms subject to organizational slack. We define *slack* as under-exploited managerial resources to increase innovation, in the sense that managers enjoy positive private benefits (net of innovation efforts) greater than the amount required to retain them within the firm.⁵ One rationale for those undue

⁵ See Nohia and Culati (1996).

benefits is that innovation efforts cannot be monitored by owners. And managers, who fear to lose their job, are mainly concerned with preserving their private benefit of control of intermediate firms. By Lemma 1 in the Appendix, $\mu < 1$, or equivalently $\delta < \chi - 1$. Besides, $\kappa > \chi - 1$ by definition. Combining these two statements implies $\pi_t(i) < \kappa(\gamma - 1)$. To avoid bankruptcy (and hence lose their job), managers should choose a size of innovation greater than 1. We now describe the decision of managers on the size of innovation. Then we will show the effect of a stricter environmental policy on that size.

Let B designate growth private benefit of control. If B is sufficiently large ($\delta B - \kappa \geq 0$),⁶ then we can model the decision problem of satisficing managers regarding innovation by solving the linear optimization program $\sup_{\gamma} \{B - \gamma : -\delta\gamma \leq -\kappa, \gamma \geq 0\}$, which has as solution κ/δ . Let γ^S be this solution. If managers choose a size $\gamma < \gamma^S$, then B , net of innovation effort γ , increases and the firm goes bankrupt. Whereas, if $\gamma > \gamma^S$, owners' profit increases, but at the expense of managers. It can be shown that any size of innovation $\tilde{\gamma}$, with $\gamma^S < \tilde{\gamma} \leq \bar{\gamma} \equiv B$, increases the sum of intermediate firms' profit and managers' net benefit. Innovation effort $\tilde{\gamma}$ actually benefits the whole economy but managers, since downstream profits increase with the size of innovation (Section 3 below). Growth benefit B is not included in the model of Aghion and Griffith (2005) who solve the dual problem of managers choosing the smallest size of innovation, such that $\pi_t(i) = 0$. The solution is the same as above, γ^S . For, if B is sufficiently large, then it can be ignored and manager's optimization problem can be written as a minimization program.

3 Effect of a stricter environmental policy

Predicting the strong Porter hypothesis requires first finding that the increase in ϕ , that is, a stricter environmental policy, reduces pollution ($\partial P_t / \partial \phi < 0$) and enhances innovation ($\partial \gamma^S / \partial \phi > 0$). These results are shown as Lemma 2 and Lemma 3 in the Appendix. Note that the response of economic growth g to an increase in ϕ is the same as the response

⁶ $\bar{\pi} \equiv \delta B - \kappa$ is the maximum profit the firm could obtain, would managers maximize profit.

of γ , since $g \equiv (y_t - y_{t-1})/y_{t-1} = \gamma - 1$, which can be shown readily. Besides, by Lemma 1, a condition for model consistency, $g > 0$, is verified, which confirms the necessary condition in the previous section that $\gamma > 1$. The model should verify a third result: environmental policy benefits firms, which only needs to be verified in the final market ($\partial\pi_t(y)/\partial\phi > 0$). The equilibrium value for profits in intermediate firms with satisficing managers indeed equals 0 (the no-bankruptcy constraint is binding). Proposition 1 below verifies this result.

Proposition 1. *A higher environmental tax rate increases downstream firms' profit.*

Proof. In equation (3) replace y_t with the production function (1), then replace $x_t(i)$, $P_t(i)$ and $A_t(i)$ with the right hand sides of (4), (5) and (7), respectively. One obtains, for downstream firms' profits:

$$\pi_t(y) = \left(\frac{1-\alpha}{\alpha}\right)(\chi + \phi)\mu\gamma, \quad (9)$$

with μ and γ which depend on ϕ . Replacing γ in (9) with the satisficing value γ^S , one obtains

$$\pi_t(y) = \kappa \left(\frac{1-\alpha}{\alpha}\right) \left(\frac{\chi + \phi}{\chi - 1}\right) \quad (10)$$

for the reduced profit equation, the derivative of which with respect to ϕ is positive. \parallel

From equation (3),⁷ a higher environmental tax rate increases $\tau_t(i)P_t(i)$, which has a direct negative effect on the profit of downstream firms. They respond by reducing their 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 further (see Lemma 3). Thus, productivity increases. Overall the marginal change in the production function part of the reduced profit equation is equal to $\frac{\kappa}{\chi-1} \frac{1}{\alpha} > 0$. Eventually, downstream firms pay a higher tax since pollution decreases (Lemma 2), but insufficiently to

⁷ From equation (8), $\pi_t(y)$ depends on the integral term $\int_0^1 A_{t-1}(i)di$, which itself does not depend on ϕ . We thus remove it from the profit equation.

overcome the higher tax cost; the net effect, $\kappa/(\chi - 1)$ is positive (at equilibrium a higher tax rate costs more to final good producers). Combining these results, we find that the loss in downstream firms' profit is more than offset by the general equilibrium effects (the effect on growth was discussed above).

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).⁸ This change in χ actually reinforces the positive effect of a stricter environmental policy on downstream profits ($\partial^2\pi_t(y)/\partial\chi\partial\phi > 0$). 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, $\partial\pi_t(y)/\partial\phi > 0$ (Proposition 1). 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 is less trivial. Aggregated pollution increases as the cost of imitation decreases ($\partial P_t/\partial\chi < 0$). But, $\partial P_t/\partial\phi = \partial P_t/\partial\chi$, since χ and ϕ enter symmetrically in $P_t = \mu$, which is convex and continuous everywhere for $\phi \in (0, 1)$ and $1 + \delta < \chi < \kappa + 1$. The gradient in the direction of the unit vector $\frac{1}{\sqrt{2}}(-1, 1)$ equals 0 (pollution remains constant when $d\phi = -d\chi$); thus, a stricter environmental policy may not reduce pollution. A benevolent planner whose first objective is to reduce pollution should adjust the stringency of environmental policy to the infinitesimal change in potential competition in the intermediate inputs sector, that is $d\phi > -d\chi$.

4 Concluding remarks

This paper extends the Aghion and Griffith's (2005) model with satisficing managers to allow for taxation of pollution. Our theoretical results predict the strong Porter hypothesis that a stricter environmental policy (a higher tax rate in our model) induces

⁸ We can also measure the effect of more competition by varying α , as in Aghion, Dewatripont, and Rey (1997). Our production function, however, is different than theirs so that α is not just a measure of the substitutability between inputs in our model.

innovations, the benefits of which exceed the costs. We also find that environmental policy and competition policy in the intermediate sector may reinforce each other. The stringency of competition policy should, however, adjust to that of potential competition to avoid increasing pollution. We now discuss two 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 is 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). One could also embed environmental policy in the more sophisticated model of Aghion, Dewatripont, and Rey (1999) with satisficing managers who minimize their effort by delaying adoption of more efficient innovations. 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).

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 manager's payment on output. This extension would have as advantage to preserve tractability of our model.

Appendix

We prove several lemmata.

LEMMA 1 *The growth rate of the economy is positive ($g \equiv (y_t - y_{t-1})/y_{t-1} > 0$).*

Proof. From equations (1), (4), (7), one obtains as growth rate of the economy

$$g = \gamma^S - 1,$$

where the equilibrium size of innovation γ^S is equal to κ/δ and δ denotes $(\chi - 1)\mu$ (see Section 2). We remark that Lemma 1 can be proved by establishing that $\gamma^S > 1$.

First, assumptions $\kappa > \chi - 1$ in Section 2 implies $\kappa/\delta > (\chi - 1)/\delta$. Second, assumptions $\alpha \in (0, 1)$, $\phi \geq 0$ and $\chi > 1$ (see Section 2) imply $1/(\alpha - 1) < -1$ and $(\chi + \phi)/\alpha > 1$. Thus, we obtain $\mu \equiv [(\chi + \phi)/\alpha]^{\frac{1}{\alpha-1}} < 1$. Therefore, $(\chi - 1)/\delta = 1/\mu$ is greater than 1, so is γ^S . ||

LEMMA 2 *Pollution decreases as the environmental tax rate increases ($\partial P_t/\partial \phi < 0$).*

Proof. Notice in equation (5) that pollution in sector i does not depend on the time period; it is equal to μ . Aggregated pollution $\int_0^1 P_t(i) di$, which we denoted by P_t , is also equal to μ . Differentiating P_t with respect to ϕ , one obtains $\frac{\partial \mu}{\partial \phi} = \left(\frac{1}{\alpha-1}\right) \left(\frac{1}{\alpha}\right) \mu^{2-\alpha} < 0 \forall \alpha \in (0, 1)$. ||

LEMMA 3 *The size of innovation increases with the environmental tax rate ($\frac{\partial \gamma^S}{\partial \phi} > 0$).*

Proof. Differentiating γ^S with respect to ϕ , gives $-\frac{\kappa}{\delta^2} \frac{\partial \delta}{\partial \phi}$. But $\frac{\partial \delta}{\partial \phi} = (\chi - 1) \frac{\partial \mu}{\partial \phi}$, which from Lemma 2 is less than zero. Thus $\frac{\partial \gamma^S}{\partial \phi} > 0$. ||

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