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Does Entrepreneurial Behaviour Matter for the Strong Porter Hypothesis?*

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Abstract

The traditional economic argument states that compliance with environmental policy diverts resources from innovation. In his engaging paper, Porter (1991) argues counterintuitively that more stringent environmental policies induce innovations the benefits of which exceed the costs. We build a Schumpeterian endogenous growth model that takes account of both arguments by including satisficing and profit-maximizing managers. Our theoretical results enable us to determine the validity condition of the strong Porter hypothesis which is consistent with empirical results.

Keywords: Endogenous growth, Environmental Porter hypothesis, Environmental policy, Entrepreneurial Behaviours.

JEL Classification: D40, H23, L21, 033, 044, Q58

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1 Introduction

Growing concern among citizens around the world has impelled governments in many countries to move environmental issues higher up their policy agendas. Environmental policies introducing taxes and standards could prove important in controlling polluting emissions. The principal goal of such policies is to improve environmental outcomes and ensure sustainable growth by increasing the opportunity cost of pollution.

Responding to that challenge, in his engaging paper, Porter (1991, p. 168) argues that well-designed environmental regulation could increase competitiveness: "Strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it." This argument has stirred a great deal of interest and enthusiasm among influential policymakers. Vice President Gore (1992, p. 342) in his thoughtful book states that "3M, in its Pollution Prevention Pays program, has reported significant profit improvement as a direct result of its increased attention to shutting off all the causes of pollution it could find." Porter and van der Linde (1995, p. 98) go further, arguing that "that properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of compying with them" and presenting several case studies supporting this idea. Even if, as Ambec, Cohen, Elgie, and Lanoie (2013, p. 3) point out, "Porter was not the first to question mainstream economic views about the cost of environmental regulation", his work has inspired research into what is well known in the literature as the "Porter hypothesis".[1]

[1] See Ambec, Cohen, Elgie, and Lanoie (2013, p. 3) for details.

Palmer, Oates, and Portney (1995, p. 120) criticize this point of view for its lack of theoretical background, writing "we do not find Porter and van der Linde at all convincing concerning the pervasiveness of inefficiencies". In using a basic model in which firms can innovate in abatement technology, these authors show that adding a constraint to the production set of what is otherwise a profit-maximizing firm can only reduce its profits. They further argue that "making the model dynamic and/or introducing uncertainty does not overturn this result". In addition, these authors emphasize that the major empirical evidence in support of the argument is just a series of case studies which cannot establish conclusive proof of the Porter hypothesis.

In order to address the aforementioned criticisms, Jaffe and Palmer (1997) clarify Porter's argument and the theoretical concepts related to this hypothesis by introducing three versions of the Porter hypothesis. The "narrow" version focuses on the outcome but not on the process in arguing that certain types of environmental regulation are more likely to enhance innovation. The "weak" version states that environmental regulation may spur innovation without indicating whether such innovation is good or bad for firms in terms of profitability. The "strong" version of the hypothesis (henceforth SPH) rejects the profit-maximizing paradigm and states that regulation induces innovation the benefits of which exceed the costs, making regulation desirable for firms.

From an empirical point of view, we believe that investigating the validity of the SPH is not only challenging, but also closer to the Porter's original hypothesis. Accordingly our focus in this paper is on the SPH.

From overviews of empirical contributions to the SPH (e.g. Brännlund and Lundgren (2009) and Ambec, Cohen, Elgie, and Lanoie (2013) among others), we can draw an incontrovertible conclusion: their empirical results are inconclusive. Early studies using U.S. data concluded that stricter environmental policy reduced productivity. For example, Gollop and Roberts (1983) seek to quantify the impact of sulphur dioxide emission restrictions on productivity growth in a sample of 56 electric utilities for the period 1973-1976. Their results show that environmental regulation reduces annual average productivity growth by 0.59 percentage points.

By contrast, some recent empirical studies find evidence supporting the SPH. For example, Rassier and Earnhart (2015) seek to identify the relationship between clean water regulations and actual profitability in a sample of U.S. manufacturing industries. Their results suggest that stricter environmental policy actually increases profitability.

Even if the conflicting evidence might arise from methodological or measurement problems (e.g. Lankoski (2010)), we believe that these results echo the theoretical debate mentioned above. Since this original dispute, a large body of research has emerged in the literature focusing on its theoretical underpinnings. According to Ambec, Cohen, Elgie, and Lanoie (2013), the exploratory models developed in that literature so far can be roughly categorized as either (i) models that focus on behavioural arguments; (ii) models based on market failures (e.g. market power, asymmetric information, and R&D spillovers); or (iii) models based on organizational failure. Theories relating to the emerging behavioural economics literature (i) depart from the assumption of profit-maximization, in line with what Porter and van der Linde (1995) postulate, by assuming that managers behave in ways not conducive to profit maximization. More precisely, managers may be risk-averse (Kennedy (1994)), opposed to costly change (Aghion, Dewatripont, and Rey (1999)[2] and Ambec and Barla (2007)), or they may exhibit bounded rationality (Gabel and Sinclair-Desgagné (1998)). Theories within (ii) and (iii) maintain the assumption of profit-maximization in line with what Palmer, Oates, and Portney (1995) postulate.

Thus in response to the opacity surrounding empirical contributions as well as the fundamental disagreement over the theoretical contributions about the assumption of profit-maximization, this paper is the first attempt to reach a comprehensive understanding of the validity conditions of the SPH by developing a unified framework that considers the opposing assumptions of profit-maximization. For that purpose, in the vein of Aghion, Dewatripont, and Rey (1999), we build a Schumpeterian endogenous growth model which we extend to allow for pollution and environmental policy so the SPH can be examined. The main rationale for this is that their models cover two types of firms: conservative firms in which managers choose just enough innovation to avoid bankruptcy; and profit-maximizing firms in which managers' decisions regarding innovation are to maximize profits.

Our main finding is that the stringency of the environmental policy affects both types of firm in opposing directions. Managers of conservative firms, who fear for their jobs, respond by increasing the size of innovation, which in turn boosts economic growth and downstream firms' profits. In contrast, managers of profit-maximizing firms are constrained to reduce the size of

[2] In a companion paper, Aghion, Dewatripont, and Rey (1997) focus on policy impact on the rate at which technological is adopted.

innovation, which in turn reduces economic growth and downstream firms' profits. Thus, the validity condition of the SPH depends on the prevalence of one effect relatively to the other.

The remaining part of the paper is organized as follows. Section 2 reviews the recent theoretical literature on the SPH. Section 3 sets out the basic model. Section 4 investigates the validity condition of the SPH by focusing on the effects of a stricter environmental policy on growth, pollution, and downstream firms' profits. Section 5 concludes.

2 Related literature

Although the authors do not say in so many words which version they model,[3] we survey the theoretical literature on the SPH using an R&D-driven endogenous growth model.[4] A very large majority of authors assume that firms pursue profit maximization in all markets. They include Nakada (2004) who allows for pollution and environmental policy in a framework *à la* Aghion and Howitt (1992). More precisely, the author builds his explanatory model on two key assumptions. First, he assumes that the agregate level of pollution is mainly driven by the level of intermediate inputs. Second, he also assumes that the government is to levy an environmental tax proportional to the level of pollution on the final good producer. The author shows the existence of two opposing effects. First, the "general equilibrium effect", i.e., the reallocation of labour from the intermediate sector to the R&D sector enhances innovation. Second, the "profitability effect", i.e., the loss in the profits of

[3]Except for Xepapadeas and de Zeeuw (1999) and Bianco and Salies (2016, 2017).
[4]See Ricci (2007a) for a survey.

the intermediate sector, reduces innovation. Overall a stricter environmental policy (in the form of an increase in environmental tax) stimulates innovation, which in turn boosts economic growth and reduces pollution. Although Nakada (2004) does not focus on the SPH, this version of the Porter hypothesis is confirmed by Bianco and Salies (2016, 2017) in the sense that the long-term effect of an increase in the tax rate on downstream firms' profits is positive.

Hart (2004, 2007) extends the multi-sector model of Aghion and Howitt (1996) to allow for environmental policy in responding to environmental damage caused by the firms' production. The author makes two key assumptions. First, there are two discrete R&D sectors, ordinary and environmentally-friendly, leading respectively to ordinary and environmentally-friendly innovations. This assumption allows the author to consider the direction of technological change. Second, fixed costs and decreasing returns to scale in the intermediate sector allow for a truncation of the number of vintages used. A stricter environmental policy (in the form of a higher sales tax) promotes recent and cleaner vintages, reducing environmental harm and boosting downstream firms' profits, which in turn spurs R&D firms to conduct research.

Ricci (2007b) extends Hart's (2004, 2007) multi-period framework in the sense that he takes into account flexibility in the technological choice of R&D firms. In this framework, the effect of an environmental policy (in the form of a tax on polluting emissions) impacts economic growth through two opposing effects. First, the "direct input effect", i.e., the incentive for R&D firms to design cleaner technologies, which reduces the marginal effect of R&D on productivity growth. Second, the "green crowding-out effect", i.e., the decrease in profits of older and dirtier vintage producers, which in turn spurs innovation through the reallocation of labour from the productive sector to the R&D sector. Although the overall effect of the environmental policy is a priori ambiguous, by means of simulations, the author shows that the "direct input effect" dominates the "green crowding-out effect". Thus, unlike in Hart (2004, 2007), the SPH is never supported.

Among non-endogenous growth models taking up the SPH, there is Xepapadeas and de Zeeuw (1999) who analyse the effect of environmental policy on capital accumulation. The authors build their explanatory model on two key assumptions. First they imagine two firms: a domestic firm that is regulated and a foreign firm that is not regulated. This assumption implies firms' decisions about production affect market prices. Second they assume a vintage composition of the firm's capital stock, where the newer vintage capital is more productive than the older vintage capital and pollutes less, too. The authors show that a stricter environmental policy leads to a reduction in a firm's capital stock ("downsizing effect"), which in turn increases the market price by reducing production. Moreover, the environmental policy increases average productivity by stimulating the retirement of older vintage capital ("modernization effect"). Overall the authors show that the "modernization effect" is insufficient to offset all the costs and thus it improves environmental performance but entails a negative effect for firms' profits. Feichtinger, Hartl, Kort, and Veliov (2005) who extend Xepapadeas and de Zeeuw (1999) to allow for nonlinear functional forms and technological change, do not validate the SPH either.

Mohr (2002) uses a vintage capital framework with positive spillovers in production. The results obtained by the author are based on two main assumptions. First, he assumes that innovation implies newer, cleaner, and more productive technology. Second, the author assumes the existence of a learning effect, i.e., an increase in productivity depending on the collective experience of using capital goods. In sum, the author shows that an environmental policy can raise productivity, which in turn increases output and reduces pollution.

None of these papers, however, takes the behavioural argument described above into consideration.

In contrast to this literature, Bianco and Salies (2016, 2017) relax the assumption of profit-maximization regarding managers' decisions about innovation. The authors develop the Schumpeterian endogenous growth model of Aghion and Griffith (2005, chap.2)[5] with conservative managers only, which they extend to allow for pollution and environmental policy. Given this assumption, it is possible to demonstrate the SPH. Stricter environmental regulation (in the form of a higher pollution tax) makes the survival constraint of intermediate firms tighter; satisficing managers, who fear losing their jobs, respond by increasing the size of innovation, which in turn raises the quality of intermediate inputs and reduces pollution as well. Furthermore, a higher environmental tax increases economic growth and downstream firms' profits, thus confirming the SPH.

Finally none of the papers in the existing literature considers both con-

[5] More precisely, the model presented in section 2.1, page 34-38 which is drawn from Aghion, Dewatripont, and Rey (1999).

flicting behavioural arguments, i.e. profit-maximizing managers and satisficing managers when investigating the SPH.

3 The basic model

This section presents a basic model in which the economy is designed to illustrate the two main effects found in both the empirical and theoretical literature. In this framework, the economy consists of three agents. First, producers of the final good hire a set of differentiated intermediate inputs to produce that final good which is sold in the market at unit price. Second, each incumbent firm makes two related decisions: they choose the price of their good, facing the competitive fringe; and they adopt new technology enabling each innovating incumbent firm to produce the leading-edge intermediate input. Departing from the previous literature, we assume two types of intermediate firms: conservative firms in which managers' decisions regarding the size of innovation are just enough to avoid bankruptcy; and profit-maximizing firms in which the managers' objective aligns with the shareholders' aims, i.e., to maximize profits. Third, the government, whose objective is to reduce pollution, levies an environmental tax on the producer of the final good.

3.1 Production and the environment

At time t,[6] one homogenous final good y_t serving as the *numéraire* of the economy is produced competitively employing a continuum of inputs (or

[6] The model is set in discrete time.

intermediate goods) $i \in [0,1]$. The production technology of the final good is:

$$y_t = \int_0^1 A_{i,t}^{1-\alpha} x_{i,t}^{\alpha} di, \quad \alpha \in [0,1]. \tag{1}$$

In this equation, $x_{i,t}$ is the quantity of the input i and $A_{i,t}$ is its quality. We assume that only the highest quality version of each input i is used in the production function of the final good. Improvements in quality of inputs occur via one channel only: innovation by incumbent firms as we shall detail later.

We follow Nakada (2004) who assumes that pollution arises from the use of inputs in the production of the final good. An environmental technology index z relates the quantities of intermediate goods to pollution. However, we depart from Nakada (2004)[7] by assuming that pollution intensity z is endogenous, i.e., inversely proportional to the productivity parameter: $z = \frac{1}{A_{i,t}}$. This assumption allows us to obtain constant pollution over time and hence a permanent effect of environmental policy on pollution which is consistent with the Porter hypothesis.[8] In order to demonstrate this effect, we start by defining the structural pollution in each industry i as follows:

$$P_{i,t} = \frac{x_{i,t}}{A_{i,t}}. \tag{2}$$

Equation (2) means that the higher the index, the higher the level of pollution per unit of input. Environmental policy takes the form of a tax, $\tau_{i,t}$. The tax, which varies directly with polluting emissions $P_{i,t}$, is paid by downstream

[7] Our assumption is in line with Bianco and Salies (2016, 2017).

[8] See equation ($B.3$) in Appendix B.

firms to discourage pollution. As suggested by Porter and van der Linde (1995, p. 111), government should "regulate as late in the production chain as practical, which will normally allow more flexibility for innovation there and in the upstream stage".

From equation (1), the representative downstream firm's profit is:

$$\pi_t(y) = \int_0^1 A_{i,t}^{1-\alpha} x_{i,t}^{\alpha} - \int_0^1 p_{i,t} x_{i,t} di - \int_0^1 \tau_{i,t} \frac{x_{i,t}}{A_{i,t}} di, \tag{3}$$

where $p_{i,t}$ is the price of the input.

For each input i, the representative downstream firm maximizes (3) with respect to $x_{i,t}$, given the technology in equation (1), up to the point where marginal productivity $\alpha \left(\frac{x_{i,t}}{A_{i,t}}\right)^{\alpha-1}$ is equal to the tax-inclusive marginal cost $p_{i,t} + \frac{\tau_{i,t}}{A_{i,t}}$. As in Bianco and Salies (2016), we define the quality-adjusted environmental tax as $\phi_t \equiv \frac{\tau_{i,t}}{A_{i,t}}$: a similar assumption can be found in the endogenous growth model with pollution and labour as input of Verdier (1995), who adjusts the tax to wages; see also Nakada (2004) and Bianco (2017). This assumption means that the environmental tax is heterogenous across firms, because of their different productivity parameters. In what follows, we assume that unadjusted tax $\tau_{i,t}$ rises at the same rate as the productivity parameter, which implies that the adjusted tax ϕ_t does not depend on time. Thus, we can write $\phi_t \equiv \phi$. Combining all these assumptions, the solution leads to the following inverse demand:

$$p_{i,t} = \alpha \left(\frac{x_{i,t}}{A_{i,t}}\right)^{\alpha-1} - \phi. \tag{4}$$

3.2 Incumbent firms' decisions

As in Bianco and Salies (2016, 2017), incumbents make two related decisions: the selling price which in turn gives the selling quantity (regardless of the degree to which this amount will degrade the environment) and the size of innovation.

3.2.1 Intermediate production decisions (for a given technology)

Incumbents produce input from the final good at a unit marginal cost. Innovation is assumed to be non-drastic[9] $\left(\chi < \frac{1+\phi(1-\alpha)}{\alpha}\right)$.[10] This assumption implies that the incumbent exerts its market power by charging the limit price, $p_{i,t} = \chi$, so as to prevent the competitive fringe of firms from entering their market. In addition to the variable cost of production, they incur a fixed cost of production equal to: $k_{i,t} = \kappa A_{i,t-1}$. κ is sufficiently large to allow for bankruptcy, in which case, managers would lose their jobs. Under these assumptions, the value for profit net of the fixed cost of production is: $\pi_{i,t} = [\chi - 1]\, x_{i,t} - \kappa A_{i,t-1}$. Then, using the limit price, we obtain partial equilibrium sales and profits of the monopolist in sector i:

$$x_{i,t} = \delta(\phi) A_{i,t}, \tag{5}$$

$$\pi_{i,t} = (\chi - 1)\delta(\phi) A_{i,t} - \kappa A_{i,t-1}, \tag{6}$$

where $\delta(\phi) \equiv \left(\frac{\chi+\phi}{\alpha}\right)^{\frac{1}{\alpha-1}}$ is constant over time.

[9]Notice that Bianco and Salies (2017) extend their model to include drastic innovation as well.

[10]Note that the price set by the incumbent would be $\frac{1+\phi(1-\alpha)}{\alpha}$, were the fringe to be ignored.

It is noteworthy that environmental tax ϕ reduces partial equilibrium sales, which in turn decreases the profit net of the fixed cost.

3.2.2 Entrepreneurial behaviours and the adoption of new technologies

Contrary to the literature mentioned above, i.e., Xepapadeas and de Zeeuw (1999), Mohr (2002), Nakada (2004), Feichtinger, Hartl, Kort, and Veliov (2005), Hart (2004, 2007), Ricci (2007b), who focus only on profit-maximizing managers, and Bianco and Salies (2016, 2017), who focus only on satisficing managers, we generalize all these models by examining an economy in which the industry consists of both satisficing and profit-maximizing managers. For the sake of simplicity, we split the intermediate goods sector between profit-maximizing managers who monopolize intermediate goods markets ($i \in [0, m]$) and satisficing managers who own the remaining markets ($i \in]m, 1]$). In addition, as in Aghion, Dewatripont, and Rey (1999), Aghion and Griffith (2005, chap.2), and Bianco and Salies (2016, 2017), we assume that incumbents are self-financed. This means that firms have enough initial endowments to finance their first innovation and then finance the subsequent innovations out of net profits.

3.2.2.1 Profit-maximizing managers and the size of innovation.

Here we introduce the innovation process by positing a deterministic process at the firm level. When an incumbent achieves a technological breakthrough, the quality of the input jumps from $A_{m,t-1}$ to $A_{m,t} = \gamma_m A_{m,t-1}$, where $\gamma_m > 1$ represents the size of innovation (or the incremental improvement in quality). Let us denote the sunk cost of adopting the leading-edge technology by $\frac{\gamma_m^2}{2}A_{i,t-1}$. The firm's net profit flow is thus $\tilde{\pi}_{m,t} = (\chi - 1)\delta(\phi)A_{m,t} - \left[\kappa - \frac{\gamma_m^2}{2}\right]A_{m,t-1}$. Substituting for $A_{m,t}$ using the innovation process, and then maximizing gives us the optimal size of innovation:

$$\gamma_m = (\chi - 1)\delta(\phi). \tag{7}$$

It is noteworthy that the size of innovation decreases with the environmental tax ϕ. This means that environmental policy decreases incentive to innovate for profit-maximizing firms. This result that we henceforth call the "traditional effect" is in line with the basic argument developed in the literature which invalidates the Porter hypothesis (see Palmer, Oates, and Portney (1995), and specially the "profitability effect" developed by Nakada (2004)).

3.2.2.2 Satisficing managers and the size of innovation. Porter and van der Linde (1995) suggest organizational inertia and lack of control over managers are among the possible constraints that intermediate firms' owners will have to remove to comply with environmental policy. As in Bianco and Salies (2016, 2017), 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. Let us denote the private benefit a manager denotes from controlling the intermediate firm by B. And, let $B - \gamma_c$ denote this benefit net of innovation efforts. Managers, who fear losing their jobs, are mainly concerned with preserving a positive net benefit of control in intermediate firms; thus, as long as, $B > \gamma_c$, there is some room to reduce slack.

As in the previous subsection, we assume a deterministic innovation process at the firm level, given by: $A_{c,t} = \gamma_c A_{c,t-1}$, where $\gamma_c > 1$. Thus, the firm's net profit flow can be written: $\tilde{\pi}_{c,t} = \left[(\chi - 1)\delta(\phi)A_{c,t} - \kappa\right] A_{c,t-1}$. Substituting for $A_{c,t}$ using the innovation process into the firm's net profit, and modelling the decision of satisficing managers on the size of innovation as described above,[11] we get the following solution:

$$\gamma_c = \frac{\kappa}{(\chi - 1)\delta(\phi)}, \tag{8}$$

which nulifies the firm's net profit. It is particulary noteworthy that the size of innovation increases with environmental policy. This means that environmental policy prompts the satisficing manager to innovate. Except for Bianco and Salies (2016, 2017), this result henceforth called the "satisficing effect" is new in the literature on the SPH mentioned above.

In a nutshell, environmental policy in the form of a tax ϕ has a heterogenous impact on the size of innovation, depending on the manager's behaviour. While environmental policy spurs satisficing managers to innovate, this same policy discourages profit-maximizing managers from innovating. Notice that this result is consistent with empirical results found in the literature.

[11] More formally, that decision could be found by solving the classical program: $\max_{\gamma_c} \{B - \gamma_c : \tilde{\pi}_{c,t} \geq 0\}$ which leads to zero profit.

3.3 Growth rate of the economy

In our economy, the economy's gross domestic product equals the output of the final good y_t minus the amount used in producing each of intermediate goods. Since each intermediate good is produced from final output at marginal cost equal to one, we have: $GDP_t = \int_0^1 A_{i,t}^{1-\alpha} x_{i,t}^{\alpha} di - \int_0^1 x_{i,t} di$. Substituting for $x_{i,t}$ using (5), the economy's gross domestic product becomes:

$$GDP_t = \left(\frac{\chi + \phi}{\alpha} - 1 \right) \delta(\phi) \mathcal{A}_t, \tag{9}$$

where $\mathcal{A}_t \equiv \int_0^1 A_{i,t} di$ is the average productivity. In line with the Schumpeterian endogenous growth literature, equation (9) means that innovation is the only source of growth. Let us break down the average productivity into two groups in accordance with the manager's behaviour:

$$\mathcal{A}_t = \int_0^m A_{m,t} di + \int_m^1 A_{c,t} di. \tag{10}$$

From the definition of the growth rate of the economy,

$$g \equiv \frac{GDP_{t+1} - GDP_t}{GDP_t}, \tag{11}$$

and then using equations (9), (10),(11), we get:[12]

$$g = m\gamma_m + (1 - m)\gamma_c - 1. \tag{12}$$

[12] Without loss of generality, we normalize productivity parameters at date $t-1$ to unity.

This feature of the model is crucial to our result: environmental policy in the form of a tax ϕ has a heterogenous impact on the size of innovation, depending on the manager's behaviour, which in turn affects the economic growth rate in the opposite way. Hence, the overall effect of environmental policy on the growth rate depends on which effect dominates. If the "satisficing effect" dominates the "traditional effect", then environmental policy enhances innovation, otherwise the opposite result occurs.

4 The validity condition of the SPH

Predicting the SPH in our model requires finding that a stricter environmental policy, i.e., a higher ϕ, reduces pollution ($\frac{\partial P_t}{\partial \phi} < 0$), enhances growth ($\frac{\partial g}{\partial \phi} > 0$), and benefits firms in terms of profits. As in Bianco and Salies (2016, 2017), this latter condition only needs to be verified in the downstream sector since conservative firm's profits in the intermediate sector are set equal to zero by satisficing managers.[13] That is why we assume that pollution comes from the use of inputs. Proposition 1 below states that our model confirms these conditions.

Proposition 1 *If innovation is non-drastic, for $m < \tilde{m}$ sufficiently small, a stricter environmental policy*

(i) *enhances growth;*
(ii) *reduces pollution;*
(iii) *increases downstream firms' profits.*

Proof. See Appendix B. ■

[13]See Appendix A for the consistency with Porter's argument in terms of firms' net profits.

For simplicity's sake, we break these impacts up into direct and indirect effects. From equation (3) a higher environmental tax ϕ increases the cost of pollution, i.e., $\phi x_{i,t}$ for all i, which has a direct negative effect on downstream firms' profits. These firms respond by reducing their demand for intermediate goods, which can be seen from equation (5), holding $p_{i,t}$ constant. This shift in demand implies a fall in output y_t but also lower production costs $\left(\int_0^1 p_{i,t} x_{i,t} di\right)$ and a lower cost of the environmental policy $\left(\int_0^1 \phi x_{i,t} di\right)$ in the downstream sector, holding $A_{i,t}$ constant. Although it also reduces monopoly rents $(\chi - 1)x_{i,t}$ of both profit-maximizing and conservative incumbent intermediate firms, managers react in exactly the opposite way. In profit-maximizing firms, managers respond by reducing the size of innovation, which in turn reduces productivity $A_{m,t}$ ("traditional effect") while in conservative firms, satificing managers respond by raising the size of innovation just enough to avoid bankruptcy, which in turn raises productivity $A_{c,t}$ ("satisficing effect"). Thus, the effect of a stricter environmental policy on growth depends only upon which effect dominates. More precisely, environmental policy sustains growth provided that the "satisficing effect" dominates the "traditional effect", i.e., $m < \tilde{m}$. This explains part (i) of Proposition 1.

Consider the impact of environmental policy on pollution. Combining our assumption that pollution intensity is inversely proportional to the productivity parameter $A_{i,t}$ with the assumption about constant returns to scale in the production of the final good entails that the partial equilibrium sales of the monopolist in sector i is an increasing linear function of $A_{i,t}$ (see equation (5)), which in turn involves constant aggregate pollution (see equation

($B.2$)). Thus a stricter environmental policy decreases the demand for intermediate inputs, which in turn decreases aggregate pollution through $\delta(\phi)$ (see equation ($B.3$)). This explains part (ii) of Proposition 1.

Finally, it is obvious that the effect of the environmental policy on the downstream firms' profits is ambiguous, either positive or negative, depending upon the density of profit-maximizing firms, i.e., the parameter m.[14] Indeed, through the cost of environmental policy $\left(\phi \int_0^1 x_{i,t} di\right)$, the variable costs of production $\left(\int_0^1 p_{i,t} x_{i,t} di\right)$ and the output itself y_t, the impact of a stricter environmental policy can be broken up into two main effects, i.e., the "growth effect" including both "satisficing" and "traditional" effects and the "direct effect". While the former through the "satisficing effect" (respectively the "traditional effect") increases (respectively decreases) downstream firms' profits, the latter through the "direct effect", i.e., $F(\phi)$ always decreases the downstream firms' profits. As a consequence, a stricter environmental policy increases downstream firms' profits provided that the "satisficing effect" offsets both "traditional" and "direct" effects, i.e., $\tilde{\tilde{m}} < \tilde{m}$. This explains part ($iii$) of Proposition 1.

Table 1 below summarizes the various effects described above by using the density of profit-maximizing firms in the economy, i.e., the parameter m. This latter allow us to present the validity condition of the SPH. Indeed, this condition is confirmed provided that the density of profit-maximizing firms is low enough ($m < \tilde{m}$). In this case, a stricter environmental policy increases growth as well as dowstream firms' profits whereas it decreases pollution. This result is consistent with the empirical literature, for instance, Rassier

[14]For details, see equation (B.1) in Appendix B.

and Earnhart (2015) and more recently Cohen and Tubb (2018) who perform a meta-analysis of 103 publications relating to the Porter hypothesis. In the other cases, at least one condition of the SPH is invalidated either the effect on growth is negative for $m > \tilde{m}$ or the effect on downstream firms' profits is also negative for $m > \tilde{\tilde{m}}$.

m	0		$\tilde{\tilde{m}}$		$\tilde{m}$		1
P_t		$-$		$-$		$-$	
g		$+$		$+$	0	$-$	
$\pi_t(y)$		$+$	0	$-$		$-$	

Table 1: The validity conditions of the SPH.

It is noteworthy that our theoretical results are also consistent with the weak version of the Porter hypothesis. For in-between density of profit-maximizing firms, i.e., $\tilde{\tilde{m}} < m < \tilde{m}$, a stricter environmental policy still increases growth whereas it reduces both pollution and downstream firms' profits. For instance, this results is consistent with the empirical work of Lee, Veloso, and Hounshell (2011). In addition to these results, our theoretical results are also consistent with another case in which the Porter hypothesis is not supported at all. For a large density of profit-maximizing firms in the economy, i.e., $m > \tilde{m}$, a stricter environmental policy reduces growth, pollution, and downstream firms' profits as well. This result is still consistent with another part of the empirical literature, for instance, Gollop and Roberts

(1983).

5 Concluding remarks

This paper is the first attempt to reach a comprehensive understanding of the validity condition of the SPH by developing a unified framework that makes two opposing assumptions about profit-maximization, i.e. profit-maximizing and conservative managers. These assumptions enable us to show that managers behaviour can radically affect the impact of environmental policy: with profit-maximizing managers, a more stringent environmental policy tends to reduce innovation and thus both growth and profit, whereas with satisficing managers, both effects are reversed. As a consequence, our theoretical results predict the SPH that a stricter environmental policy (a higher tax in our model) improves growth, the environment, and induces profitable innovations provided that the density of profit-maximizing firms does not exceed a threshold, otherwise the lack of evidence supporting the SPH emerges. However, even in this case, our theoretical results are also consistent with either the weak version of the Porter hypothesis, for in-between density of profit-maximizing firms or the lack of evidence supporting the Porter hypothesis for a high density of profit-maximizing firms.

The analysis in this paper should nevertheless be extended to a welfare analysis, given the public nature of the environment and the negative external effects of pollution on welfare that we have ignored in this paper. This and other extensions of the analysis in this paper are left for future research.

A Consistency with Porter's argument

For the sake of consistency with Porter's argument, we have to impose a condition whereby the profit-maximizing firms' net profit must be greater than the conservative firms' net profit, whatever the quality-adjusted environmental tax ϕ. Given that the satisficing managers' behaviour leads to a zero net profit, then the substitution for γ_m using (7) into the profit-maximizing firm's net profit flow gives us the condition of consistency with Porter's argument:

$$\kappa < \frac{[(\chi - 1)\delta(\phi)]^2}{2}, \tag{A.1}$$

which is always positive.

B Proof of Proposition 1

(i). A stricter environmental policy enhances growth provided that $m < \tilde{m}$. Differentiating the growth rate of the economy (12) with respect to ϕ, gives:

$$\frac{\partial g}{\partial \phi} = m \underbrace{\frac{\partial \gamma_m}{\partial \phi}}_{\text{traditional effect}} + (1 - m) \underbrace{\frac{\partial \gamma_c}{\partial \phi}}_{\text{satisficing effect}}. \tag{B.1}$$

As the traditional effect which is equal to $(\chi - 1)\frac{\partial \delta(\phi)}{\partial \phi}$, is negative while the satisficing effect which is equal to $\frac{-\kappa(\chi-1)\frac{\partial \delta(\phi)}{\partial \phi}}{[(\chi-1)\delta(\phi)]^2}$ is positive, the sign of $\frac{\partial g}{\partial \phi}$ is either positive or negative depending upon the value of m. A stricter environmental policy enhances growth provided that $m < \frac{1}{1+\frac{[(\chi-1)\delta(\phi)]^2}{\kappa}} \equiv \tilde{m}$, otherwise the opposite effect emerges. Notice that $0 < \tilde{m} < 1$, which proves the co-existence of two opposing effects and thus part (i) of Proposition 1.

(ii). A stricter environmental policy reduces pollution.

Let us first compute aggregate pollution. Substituting for $x_{i,t}$ using (5) into (2), pollution in sector i is:

$$P_{i,t} = \delta(\phi), \tag{B.2}$$

which is constant over time and across sector i. Aggregate pollution $\int_0^1 P_{i,t} di$, which we denote by P_t, is thus equal to $\delta(\phi)$ as well. Differentiating P_t with respect to ϕ, we get:

$$\frac{\partial P_t}{\partial \tau} = \frac{\partial \delta(\phi)}{\partial \phi}, \tag{B.3}$$

which is clearly negative (because of $\frac{\partial \delta(\phi)}{\partial \phi} < 0$) and thus proves part (ii) of Proposition 1. Notice that this result reflects the one in Bianco and Salies (2016, 2017) meaning that a stricter environmental policy permanently reduces aggregate pollution.

(iii). A stricter environmental policy increases downstream firms' profits provided that $m < \tilde{\tilde{m}}$.

Let us first compute the reduced form of downstream firms' profits. Starting by substituting for $x_{i,t}$ using (5) into (3) and then using the definition of the adjusted environmental tax rate, i.e., $\phi \equiv \frac{\tau_{i,t}}{A_{i,t}}$, we obtain:

$$\pi_t(y) = \left[(1-\alpha)\delta(\phi)^{\alpha}\right] \mathcal{A}_t, \tag{B.4}$$

where $\mathcal{A}_t \equiv \int_0^1 A_{i,t} di$ represents the average productivity. Then, substituting for $\mathcal{A}_t$ using (10), we get:

$$\pi_t(y) = [(1-\alpha)\delta(\phi)^{\alpha}] \left[\int_0^m A_{m,t} di + \int_m^1 A_{c,t} di\right], \tag{B.5}$$

which in turn can be rewritten with the help of the innovation process using $A_{m,t} = \gamma_m A_{m,t-1}$ and $A_{c,t} = \gamma_c A_{c,t-1}$ and the assumption of normalization of the productivity parameters at date $t-1$, i.e., $A_{m,t-1} = A_{c,t-1} = 1$, as follows:

$$\pi_t(y) = F(\phi)\left[m\gamma_m + (1-m)\gamma_c\right], \tag{B.6}$$

where $F(\phi) \equiv (1-\alpha)\delta(\phi)^{\alpha}$ is a decreasing function of the quality-adjusted environmental tax ϕ.

Now, differentiating downstream firms' profits ($B.6$) with respect to ϕ, we get:

$$\begin{aligned}\frac{\partial \pi_t(y)}{\partial \phi} = & \underbrace{F(\phi)\left[m\frac{\partial \gamma_m}{\partial \phi} + (1-m)\frac{\partial \gamma_c}{\partial \phi}\right]}_{\text{growth effect}} \\ & + \underbrace{\frac{\partial F(\phi)}{\partial \phi}\left[m\gamma_m + (1-m)\gamma_c\right]}_{\text{direct effect}}.\end{aligned} \tag{B.7}$$

At this stage, the sign of this derivative is ambiguous. Indeed, a stricter environmental policy, through the growth effect, impacts downstream firms' profits positively or negatively depending on the parameter m (see part *(i)* of Proposition 1). In addition to this ambiguous effect, through the direct effect, a stricter environmental policy always reduces downstream firms' profits (because $m\gamma_m + (1-m)\gamma_c > 0$ and $\frac{\partial F(\phi)}{\partial \phi} = \frac{\alpha F(\phi)}{\delta(\phi)}\frac{\partial \delta(\phi)}{\partial \phi} < 0$, because of

$\frac{\partial \delta(\phi)}{\partial \phi} < 0$).

Inserting $F(\phi)$ and the derivative of $F(\phi)$ with respect to ϕ in (B.7), we get:

$$\frac{\partial \pi_t(y)}{\partial \phi} = \left\{ m \left[\frac{\partial \gamma_m}{\partial \phi} + \alpha \frac{\partial \delta(\phi)}{\partial \phi} \frac{1}{\delta(\phi)} \gamma_m \right] \right.$$
$$\left. + (1-m) \left[\frac{\partial \gamma_c}{\partial \phi} + \alpha \frac{\partial \delta(\phi)}{\partial \phi} \frac{1}{\delta(\phi)} \gamma_c \right] \right\} F(\phi), \tag{B.8}$$

then, using the definition of γ_c and γ_m and their derivative with respect to ϕ simplifies (B.8) as follows:

$$\frac{\partial \pi_t(y)}{\partial \phi} = \left[\frac{-\delta(\phi)}{\alpha} \right] \left[m\gamma_m(1+\alpha) + (1-m)\gamma_c(\alpha-1) \right]. \tag{B.9}$$

Finally, substituting for γ_c and γ_m using (7) and (8) into (B.9), we can demonstrate that (B.9) is positive provided that $m < \frac{1}{1+\frac{1+\alpha}{1-\alpha}\frac{[(\chi-1)\delta(\phi)]^2}{\kappa}} \equiv \tilde{\tilde{m}}$, otherwise the opposing effect emerges. This proves part (iii) of Proposition 1. In addition to the sign of the previous derivative, as the denominator is greater than one, it obvious that $\tilde{\tilde{m}} < 1$ which proves the co-existence of the two effects described above.

Let us now compare the two values of m. As we assume that $0 < \alpha < 1$, it can easily be shown that $\frac{1+\alpha}{1-\alpha} > 1$, which in turn by comparaison with the definition of $\tilde{m}$ proves that $\tilde{\tilde{m}} < \tilde{m}$. ■

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