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Heterogeneous Firms, the Porter Hypothesis and Trade

Hide-Fumi Yokoo

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Hide-Fumi Yokoo

Graduate School of Economics, Kyoto University

JSPS Research Fellow

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Abstract

I develop a monopolistic competition model with pollution to analyze the effects of environmental policy on the average productivity of a country. In the model, firms are heterogeneous in their productivity. I show that a stricter environmental policy will increase average productivity, and will have positive effects on the marginal decrease of profits and environmental damage. In addition, I show the optimal tax rate in a closed economy and the effect of international trade.

1 Introduction

Does a strong environmental policy improve a country's productivity? The first scholar to give much attention to this question was Michael Porter (1991). Since his short essay pointed out the issue, many studies have ex-

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amined the relationship between environmental policy and competitiveness. The so-called Porter hypothesis asserts that environmental regulations may benefit the competitiveness of a country. In addition, to understand his idea, it is useful to quote Porter and van der Linde (1995):

> ... ultimately companies and regulators must learn to frame environmental improvement in terms of resource productivity, or the efficiency and effectiveness with which companies and their customers use resources. Improving resource productivity within companies goes beyond eliminating pollution (and the cost of dealing with it) to lowering true economic cost and raising the true economic value of products. At the level of resource productivity, environmental improvement and competitiveness come together. (p. 106)

Several papers have developed a theoretical model of the Porter hypothesis. However, some are modelled in a restrictive way: for instance, they use models of either a monopoly producer or the two-country game (for example, Ulph (1996), Ambec and Barla (2002), Greaker (2006)). On the other hand, there exist studies that use a general framework (for example, Xepapadeas and de Zeeuw (1999), Mohr (2002), Feichtinger et al. (2005)). The essence of these general models is that environmental policy stimulates investment and therefore leads to innovation.

The purpose of this paper is to develop a model that derives a result that is consistent with the Porter hypothesis in a general framework, without considering investment in R&D. This model presents an alternative explanation of the hypothesis that environmental policy may generate average productivity gains for a country, because less productive firms will exit the market. In other words, I develop a model that is consistent with the hypothesis, by way of the short-term effects of environmental policy. In addition, I investigate the effect of environmental policy in an open economy.

I first consider a closed economy setting with monopolistically competitive firms. I then derive the industry equilibrium and study the effect of an environmental tax on the country's productivity. I show that the average productivity will rise when the tax rate increases. However, the revenue and profit of each firm will decrease with the increase in the tax rate. This is contrary to Porter's original idea. We then extend the model to a two-country setting, to analyze the effects of trade and environmental policy.

To the best of my knowledge, this paper is the first to address the relationships between heterogeneous firms and the environment. Although I am not aware of other papers on heterogeneous firms and environmental policy, my paper is closely related to the two strands in the theoretical literature in applied economics.

First, my paper contributes to the nascent literature that is concerned with intra-industry trade and the environment (for example, Gürtzgen and Raucher (2000), Haupt (2006), Benarroch and Weder (2006)). Second, my paper contributes to the recent and growing literature that is concerned with heterogeneous firms and international trade (for example, Melitz (2003), Helpman et al. (2004)).

The remainder of this paper is divided into four sections. The first section derives a general equilibrium model that follows Melitz (2003). The model adds the firm's pollution behaviour following Copeland and Taylor (1994). The second section investigates the effect of a stricter environmental policy on a country's average productivity, and the optimal tax rate in a closed economy. The third section extends the model to an open economy and the final section concludes.

2 The Model

There are L consumers with identical preferences in a country represented by

$$U = X - Z, \tag{1}$$

where X is an index of the aggregate consumption of a differentiated good, and Z is the total amount of pollution generated by the country. We are concerned with pollution that has only localized effects. Aggregate consumption is a constant elasticity of the substitution function

$$X = \left[\int x(h)^{\rho} dh \right]^{1/\rho}, \quad 0 < \rho < 1, \tag{2}$$

of the consumption of different varieties $x(h)$, where the range of h will be endogenously determined. The elasticity of substitution between any two varieties is $\sigma = 1/(1-\rho)$. Z is defined as:

$$Z = \int z(h) dh, \tag{3}$$

where $z(h)$ denotes the amount of the pollution which the hth firm generates. We assume that L is large enough so that no consumer can measurably change Z by changing her own behaviour. Therefore, each individual treats Z as if it were exogenous. Thus, using (2), we obtain the inverse demand function for each variety k:

$$p(h) = X^{1-\rho} x(h)^{\rho-1}. \tag{4}$$

The optimal expenditure decisions for individual variety are given by

$$r(h) = R^{\sigma}[p(h)X]^{1-\sigma}, \tag{5}$$

where R denotes aggregate expenditure.

The supply of differentiated goods is created by monopolistic competition sectors. There is a continuum of firms, each choosing to produce a different variety h. Production requires only 1 factor, labour. To start producing a variety, a firm needs to bear a fixed cost of entry f_E. All firms share the same entry cost f_E but have different productivity levels. Upon paying entry cost, the unique producer of variety h draws a productivity level φ from a known distribution $G(\varphi)$. [1] After observing this productivity level, the firm decides whether to exit the market or start producing. When the firm decides to produce, then an additional fixed cost f needs to be incurred. This fixed cost is equivalent across all firms.

Suppose that each firm produces 1 unit of a variant and 1 unit of pollution from 1 unit of the labour. However, abatement is possible, and so pollution intensity is a choice variable. To capture the possibility of abatement very simply, suppose that a firm can allocate an endogenous fraction θ of its inputs to abatement activity. Increases in θ reduce pollution, but at the cost of diverting primary factors from the production of the final goods. The joint production technology is given by

$$x(\varphi) = \varphi(1-\theta) \cdot l(\varphi), \tag{6}$$

$$z(\varphi) = (1-\theta)^{\frac{1}{\alpha}} \cdot l(\varphi), \tag{7}$$

[1] To be more precise, the unique producer of variety h draws a particular realization $\varphi(h)$ from the distribution $G(\varphi)$. However, I drop the variety index h in order to simplify the notation.

where $\theta \in [0,1]$, $\alpha \in (0,1)$, $x(\varphi)$ and $z(\varphi)$ denote an amount of a variant produced and pollution, $l(\varphi)$ an amount of the labour that is used for production and $\varphi > 0$ the productivity parameter that is firm-specific. The larger α is, the more intensive the industry in pollution. If $\theta = 0$, there is no abatement, and each unit of output generates 1 unit of pollution.

Regardless of its productivity, each firm faces a residual demand curve with constant elasticity σ, and thus chooses the same profit maximizing markup equal to $1/\rho$. This yields the pricing rule

$$p(\varphi) = \frac{w(1-\theta)^{-1} + \tau(1-\theta)^{\frac{1}{\alpha}-1}}{\rho\varphi}, \tag{8}$$

where w is the common wage rate, hereafter normalized to 1, and τ is the pollution tax rate. If the firms were unregulated, they would have no incentive to abate pollution and would always choose the point $\theta = 0$. We assume throughout, however, that governments regulate pollution and that firms chose interior solutions where they engage in at least a small amount of abatement.

Rearranging (7) for l and inserting it in (6), we obtain

$$x(\varphi) = \varphi^{1-\alpha} l^{1-\alpha} z^{\alpha}. \tag{9}$$

That is, although pollution is a joint output, we can equivalently treat it as an input. This allows us to make use of a familiar tool, the Cobb-Douglas production function. Rearrange the first order conditions of this type of production function to obtain

$$\frac{z}{l} = \frac{\alpha}{1-\alpha}\frac{1}{\tau}. \tag{10}$$

Using (7) and (10), we obtain

$$\theta = 1 - \left(\frac{\alpha}{1-\alpha} \frac{1}{\tau} \right)^{\alpha}. \tag{11}$$

This means that all the firms in this country are choosing same fraction θ to reduce pollution. Also, θ is an increasing function of pollution tax rate τ.

We can rewrite the pricing rule using (11)

$$p(\varphi) = \frac{1}{\rho\varphi} \tau^{\alpha} \alpha^{-\alpha} (1-\alpha)^{-(1-\alpha)}. \tag{12}$$

Firm profit is then

$$\pi(\varphi) = r(\varphi) - l(\varphi) - \tau z(\varphi) - f = \frac{r(\varphi)}{\sigma} - f, \tag{13}$$

where $r(\varphi)$ is firm revenue. Using (5), (12) and (13), we can write the firm revenue $r(\varphi)$ and profit $\pi(\varphi)$ as

$$r(\varphi) = R^{\sigma} \left(\frac{X}{\rho\varphi} \right)^{1-\sigma} \tau^{\alpha(1-\sigma)} \phi^{1-\sigma}, \tag{14}$$

$$\pi(\varphi) = \frac{R^{\sigma}}{\sigma} \left(\frac{X}{\rho\varphi} \right)^{1-\sigma} \tau^{\alpha(1-\sigma)} \phi^{1-\sigma} - f. \tag{15}$$

where $\phi = [\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}]$. Using (4), (6), (7) and (12), we obtain firm's pollution as

$$z(\varphi) = \frac{X}{\rho^{-\sigma}\varphi^{1-\sigma}} \tau^{\alpha(1-\sigma)-1} \alpha^{-\alpha(1-\sigma)+1} (1-\alpha)^{-(1-\alpha)(1-\sigma)}. \tag{16}$$

It follows from these equations that the ratios of any two firms' revenues and pollution depend only on the ratio of their productivity levels:

$$\frac{r(\varphi_1)}{r(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}, \quad \frac{z(\varphi_1)}{z(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}. \tag{17}$$

In summary, a more productive firm (higher φ) will be larger (earn higher revenues), charge a lower price, earn higher profits, but generate more pollution than a less productive firm.

3 The Porter Hypothesis and Optimal Environmental Policy

3.1 Equilibrium in a Closed Economy

An equilibrium will be characterized by a mass N of firms (and hence N goods), and a distribution $\eta(\varphi)$ of productivity levels over a subset of $(0, \infty)$. This type of equilibrium is first described by Hopenhayn (1992). There is a large (unbounded) pool of prospective entrants into the industry. Prior to entry, firms are identical. To enter, firms must first make an initial investment, modelled as a fixed entry cost $f_E > 0$, which is hereafter sunk. Firms then draw their initial productivity parameter φ from a common distribution $g(\varphi)$, which has positive support over $(0, \infty)$, and has a cumulative distribution $G(\varphi)$.

Upon entry with a low productivity draw, a firm may decide immediately to exit and not produce. Any entering firm drawing a productivity level $\varphi < \varphi^*$ will exit. This threshold productivity φ^* will be referred to as the zero cutoff level. The zero cutoff level is implicitly defined by

$$\pi(\varphi^*, X) = 0. \tag{18}$$

This threshold productivity level depends on the industry's aggregate consumption index X, that is $\varphi^*(X)$. In equilibrium, the expected operating profits of a potential entrant equal the fixed cost of entry. Firms with $\varphi \geq \varphi^*(X)$ stay in the economy and the free-entry condition can be expressed as

$$\int_{\varphi^*(X)}^{\infty} \pi(\varphi, X) g(\varphi) d\varphi = f_E. \tag{19}$$

The zero cutoff profit condition (18) and the free entry condition (19) provide an implicit solution to the threshold productivity level of surviving entrants φ^*. Note that the economy's aggregate revenue is fixed by the size of the labour force: $R = L$, where $R = \int_0^\infty r(\varphi) N \eta(\varphi) d\varphi$. Using the aggregate consumption index X, we then can calculate all the variables of interest.

3.2 The Average Productivity Level of a Country

Our concern is to examine how the average productivity of the country is affected by the environmental policy. Thus, we consider a weighted average of the firm productivity levels, defined by Melitz (2003) as

$$\tilde{\varphi} = \left[\int_0^\infty \varphi^{\sigma-1} \eta(\varphi) d\varphi \right]^{\frac{1}{\sigma-1}}. \tag{20}$$

A weighted average productivity $\tilde{\varphi}$ represents aggregate productivity, and summarizes the information in the distribution of productivity levels $\eta(\varphi)$.

Since subsequent firm exit is assumed to be uncorrelated with productivity, the exit process will not affect the equilibrium productivity distribution $\eta(\varphi)$. This distribution must then be determined by the initial productivity draw, conditional on successful entry. Hence, we obtain

$$\eta(\varphi) = \frac{g(\varphi)}{1 - G(\varphi^*)}. \tag{21}$$

This defines the average productivity level $\tilde{\varphi}$ as a function of the cutoff level φ^*:

$$\tilde{\varphi}(\varphi^*) = \left[\frac{1}{1 - G(\varphi^*)} \int_{\varphi^*(X)}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi \right]^{\frac{1}{\sigma-1}}. \tag{22}$$

This shows how the endogenous range of productivity levels (indexed by the cutoff φ^*) affects the average productivity level. Also, we can see from equation (22) that the average productivity $\tilde{\varphi}$ is completely determined by the cutoff productivity level φ^*.

3.3 Parameterization of Technology

All the results so far hold for any distribution of productivity $G(\varphi)$. However, to simplify some of the ensuing analysis, we use a specific parameterization for this distribution. Following Helpman et al. (2004), we assume that productivity draws φ follow a Pareto distribution with lower productivity bound b and shape parameter k. In particular, we assume that shape parameter k is larger than $\sigma - 1$. This implies a distribution of productivity draws φ given by

$$G(\varphi) = 1 - \left(\frac{b}{\varphi} \right)^k, \quad for \quad \varphi \geq b > 0. \tag{23}$$

Then the probability distribution function is obtained as

$$g(\varphi) = \frac{k\, b^k}{\varphi^{k+1}} \tag{24}$$

Now we can rewrite the average productivity level (22) using (24) and the assumption $k > \sigma - 1$:

$$\tilde{\varphi}(\varphi^*) = \left(\frac{k}{k - \sigma + 1} \right)^{\frac{1}{\sigma-1}} \varphi^*. \tag{25}$$

Reflection on equation (25) will make it clear that the average productivity level $\tilde{\varphi}$ is an increasing function of the zero cutoff level φ^*.

3.4 Pollution Tax and the Average Productivity

Given the parameterization (23) and $R = L$, the zero cutoff productivity level, determined by the two conditions (18) and (19), is then

$$\varphi^* = (\frac{k}{k-\sigma+1} - b^k)^{\frac{1}{k}} L^{-1} \sigma^{-\frac{1}{\rho^2\sigma^2}} \tau^{\alpha(\sigma-1)} \phi^{\sigma-1} f^{\frac{k-\sigma+1}{\sigma^2\rho^2 k}} f_E^{-\frac{1}{k}}. \tag{26}$$

From this equation, we can clearly say that the zero cutoff productivity level φ^* increases with the pollution tax rate τ. It should be concluded, from the observations on equations (25) and (26), that a stricter environmental policy (higher rate of τ) will increase the country's average productivity level $\tilde{\varphi}$.

The aggregate consumption index X, defined by (2), is then

$$X = (\frac{k}{k-\sigma+1} - b^k)^{\frac{1}{k}} L^{\frac{1}{\rho}} \sigma^{-\frac{1}{\rho\sigma}} \tau^{-\alpha} \phi^{-1} f^{\frac{k-\sigma+1}{\sigma\rho k}} f_E^{-\frac{1}{k}}. \tag{27}$$

Using the definition of φ in (20) and the relationship between the ratio of pollution and productivity levels (17), we can rewrite the total amount of pollution Z as

$$Z = X^\rho x(\tilde{\varphi})^{-\rho} z(\tilde{\varphi}). \tag{28}$$

Substituting (6), (7), (11) and (16), and using (27) we obtain

$$Z = \frac{\alpha\rho X}{\tau} \tag{29}$$

$$= (\frac{k}{k-\sigma+1} - b^k)^{\frac{1}{k}} L^{\frac{1}{\rho}} \sigma^{-\frac{1}{\rho\sigma}} \rho\tau^{-\alpha-1} \left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha} f^{\frac{k-\sigma+1}{\sigma\rho k}} f_E^{-\frac{1}{k}}. \tag{30}$$

The total amount of pollution Z decreases with the pollution tax rate τ.

In conclusion, a stricter environmental policy will improve both the average productivity and the environmental quality of the country. However, we should notice that each firm's revenue and profit will decrease as the tax rate increases.

Next, we investigate the optimal tax rate in a closed economy. If the social planner can observe the technology distribution given by (23), then the planner will set the pollution tax to maximize the utility function (1). Using (27) and (29), we can derive the optimal tax rate as

$$\tau = \rho(1 + \alpha). \tag{31}$$

4 Trade, Pollution and the Average Productivity

4.1 The open economy model

In this section, we investigate the effects of international trade on welfare, environmental quality and firm productivity. To this end, we extend the model of the previous section to a two-country setting. Although all firms in our model are exporters, this is not true in the models of Melitz (2003).

There are two countries, country 1 and country 2. In each country, there is a mass L of identical consumers with preferences given by (1). I assume that both countries share the same wage, which is still normalized to 1. In both countries, the distribution of productivity level in the population of firms is given by the distribution function $G(\varphi)$. The joint production function of a firm with productivity level φ is again given by (6) and (7). In addition to production costs, firms need to incur a specific tariff (or transport cost). This transport cost or tariff is modelled in the standard iceberg formulation, whereby $t > 1$ units of a good must be shipped in order for 1 unit to arrive at the destination. Transport costs and tariffs have to be incurred only for exports from one country to the other. We assume that each firm can segment the two markets. Unlike the model of Melitz (2003), in this model each firm will find it optimal to sell in both countries, since there is no fixed cost for export. Each firm's pricing rule in its domestic market is given, as before, by (12). Firms will set higher prices in the foreign country to reflect the increased marginal cost t of serving these markets: $p_f(\varphi) = tp_d(\varphi)$, where $p_d(\varphi)$ denotes the price in the domestic market and $p_f(\varphi)$ denotes the price in the foreign market. We can write the combined revenue $r(\varphi)$ for a firm as

$$r(\varphi) = r_d(\varphi) + r_f(\varphi) = (1 + t^{1-\sigma})r_d(\varphi). \tag{32}$$

Firm profit is then given by

$$\pi(\varphi) = \pi_d(\varphi) + \pi_f(\varphi) = (1 + t^{1-\sigma})\frac{r_d(\varphi)}{\sigma} - f. \tag{33}$$

where $\pi_d(\varphi)$ is profit earned from domestic sales, and $\pi_f(\varphi)$ is profit earned from export sales.

4.2 Equilibrium and the impact of trade

All the exogenous factors affecting firm entry, exit and productivity levels remain unchanged by trade. Prior to entry, firms face the same ex-ante distribution of productivity levels $g(\varphi)$. As in the closed economy case, φ^* identifies the cutoff productivity level for successful entry. In this case, the cutoff firm earns zero total profit, which implies $\pi(\varphi^*) = \pi_d(\varphi^*) + \pi_f(\varphi^*) = 0$. Substituting the new profit function (28) into the zero cutoff profit condition (18), we can describe an equilibrium condition in the open economy. The free entry condition is identical in both, the closed and the open economy.

Inspection of the equations for the equilibrium immediately reveals that the zero cutoff profit level will increase. In other words, exposure to trade induces an increase in the cutoff productivity level φ^*. The impact of trade on a firm φ can be evaluated by revenues. Let φ_a^* and $r_a(\varphi)$ denote the zero cutoff level and revenue in autarky. Recall that $r_a(\varphi) = (\varphi/\varphi_a^*)^{\sigma-1}\sigma f \quad (\forall\varphi \geq \varphi_a^*)$ in autarky and that $r_d(\varphi) = (\varphi/\varphi^*)^{\sigma-1}\sigma f \quad (\forall\varphi \geq \varphi^*)$ in the open economy equilibrium. This immediately yields $r_d(\varphi) < r_a(\varphi)$ since $\varphi^* > \varphi_a^*$. Thus, all firms incur a loss in domestic sales in the open economy. Next, we find that $r(\varphi)$ decreases as t increases[2]. Since the autarky equilibrium is obtained as the limiting equilibrium as t increases to infinity, $r_a(\varphi) = \lim_{t\to+\infty} r_d(\varphi) = \lim_{t\to+\infty} r(\varphi)$. Therefore, $r_a(\varphi) < r(\varphi)$ for any finite t. This implies that each firm makes up for its loss of domestic sales by export sales and increases its total revenues. In contrast, the least productive firms, with productivity levels between φ_a^* and φ^*, can no longer earn positive profits in the new trade equilibrium and therefore exits. In conclusion, the average productivity level in an open economy is higher than that in a closed economy.

According to Melitz (2003), trade always generates a higher consumption level than autarky. Thus, the amount of pollution Z increases in an open economy (see (29)). The impact of trade on welfare depends on the country's pollution tax rate. Assuming that both countries adopt the same tax rate, then if $\tau > \alpha\rho$, trade generates a welfare gain. By contrast, in the case with $\tau < \alpha\rho$, trade will induce a welfare loss. If both countries adopt the domestically optimal tax rate $\tau = (1 + \alpha)\rho > \alpha\rho$, then welfare will be

[2]See Melitz (2003) for proof.

improved by trade.

5 Conclusion

In this paper, I have described and analyzed a new channel for the impact of environmental policy on a country's average productivity. Since this channel works through the selection of the least productive firms, it can only be studied within a model that incorporates firm level heterogeneity. I also show the optimal environmental policy in a closed economy and the impact of trade on the country's productivity and welfare.

The model mainly highlights the short-run effects of a stronger environmental policy, not such long-run effects as the stimulation of innovation. Little attention has been paid to the Porter hypothesis associated with firm heterogeneity. Therefore, it is important to have a model that can predict the short-term impact of a pollution tax on a country's productivity, in order to design appropriate environmental policies. In addition, I hope that this model provides a useful foundation for future empirical investigations.

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by Hide-Fumi Yokoo

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