



A model to analyze the environmental policy of resource reallocation and pollution control based on firms' heterogeneity

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ABSTRACT

This paper presents an environmental policy model with heterogeneous firms to analyze the problem of “development–pollution”. The model shows how the policy corresponding to firms' productivity affects total output, resource consumption and pollution emission. We find that with the implementation of simple pollution tax, the lowest productive firms will exit from the market, at the same time total resource consumption and pollution emission will decrease at the loss of total output. The loss in total output leads some economies, especially the developing countries to fall into a development dilemma. However, if government subsidizes the more productive firms by reallocating tax revenue, total output will increase back to “ex-tax” situation. And more importantly, resource consumption and pollution emission in production could be below “ex-tax” situation. Our main finding are: (1) environmental policy reduces resource consumption and pollution emission; (2) total output could be maintained at a certain level if environmental policy is implemented appropriately.

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Introduction

The relationship between environment and economic growth has been the subject of intense debate over the past few decades. The general consensus is that environmental policy has implications for environmental quality and economic growth. The Environmental Kuznets Curve (EKC) hypothesis, which suggests an inverted-U relationship between pollution and per capita income, is a significant perspective in theoretical and empirical studies (Roy and Kooten, 2004; Maddison, 2006; Shen, 2006; Akbostanci et al., 2009; Kijima et al., 2010). The importance of environmental policy has been highlighted by a number of studies. For example, Calmette and Pécoux (2007) have argued that environmental policy may be counterproductive. Fullerton and Kim (2008) have investigated the interaction among several factors, including environmental regulation, public investment in abatement R&D and economic growth, in an endogenous growth model. Other recent related studies include Soytaş and Sari (2009), Acaravci and Öztürk (2010) and Greenstone et al. (2012). While the existing studies have considered a number of issues, most available studies have not fully discussed the relationship among policy, total output, resource consumption and pollution emission in context of firms' heterogeneity.

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This paper attempts to extend the existing literatures by considering the implications of environmental policy on total output, resource consumption and pollution emission when firms are heterogeneous. Within the context of environmental economics, recent studies have taken firms' heterogeneity into account. Using firm level data from UK, Manderson and Kneller (2012) have argued that environmental regulations have an insignificant impact on FDI outflow. Other related studies include Wu (2000), Montero (2005), Restuccia and Rogerson (2008), and Li and Shi (2011). This paper presents a model based on the framework of firms' heterogeneity, which is different from most existing studies on environmental policy, to analyze the relationship among total output, resource consumption and pollution emission.

A basic model with pollution tax

In order to explore the implications of environmental policy in the presence of firms' heterogeneity, we present a model in this section. The basic framework of this model is based on the pioneering work of Dixit and Stiglitz (1977) and Melitz (2003). However, to focus on the role of resource consumption and pollution emission, we introduce some hypotheses. Suppose: (1) firms produce similar goods in an industry; (2) firms are heterogeneous in productivity; (3) elasticity of substitution between any two goods is constant and firms set price based on the rule of marginal cost markup price; (4) production requires only one factor, namely resource, which is perfect elastically

supplied. The market for resource is perfectly competitive and the price of a unit of the resource is γ .

Assume that all the goods in market are the set Ω and each firm produces only one product ω ($\forall \omega \in \Omega$). The preference of a representative consumer is given by C.E.S. utility function $U = [\int_{\omega \in \Omega} q(\omega)^\rho d\omega]^{1/\rho}$, where $q(\omega)$ indicates the individual consumption of good ω and the parameter ρ satisfies the condition $0 < \rho < 1$. The elasticity of substitution between any two goods is $\sigma = (1/(1-\rho)) > 1$ which is constant. According to the form of utility function, quantity index can be written as $X \equiv U = [\int_{\omega \in \Omega} q(\omega)^\rho d\omega]^{1/\rho}$. Assume that the price of any good ω is $p(\omega)$, the price index Y can be written as a function of the elasticity of substitution, such as $Y = [\int_{\omega \in \Omega} p(\omega)^{1-\sigma} d\omega]^{(1/(1-\sigma))}$. From the work of Dixit and Stiglitz (1977) and Melitz (2003), demand $q(\omega)$ for good ω is:¹

$$q(\omega) = X \left[\frac{p(\omega)}{Y} \right]^{-\sigma} \quad (1)$$

Consumers' spending on good ω , i.e. the sales revenue of good ω is:

$$r(\omega) = p(\omega)q(\omega) = p(\omega)X \left[\frac{p(\omega)}{Y} \right]^{-\sigma} = XY \left[\frac{p(\omega)}{Y} \right]^{1-\sigma} = R \left[\frac{p(\omega)}{Y} \right]^{1-\sigma} \quad (2)$$

where $R = XY = \int_{\omega \in \Omega} r(\omega) d\omega$ is the gross expenditure in demand market, which also represents all firms' sales revenue.

In production, resource consumption is a linear function of output q , such as $(q/\varphi) + f$. Where f is the fixed input, and $s = (q/\varphi)$ is the variable input which is related to output q and firm's productivity φ .

For a firm with productivity φ produces output q , total cost C is:

$$C = \gamma \cdot (s + f) = \frac{\gamma}{\varphi} \cdot q + \gamma f \quad (3)$$

Marginal cost of the firm is $MC = (\partial C / \partial q) = (\gamma / \varphi)$. Given that the elasticity of substitution of any two goods is constant, the price elasticity of demand for goods is also constant. The firm sets the price for its good according to the rule of marginal cost markup price. The price is:

$$p = MC \cdot \frac{1}{1-1/\sigma} = \frac{\gamma}{\varphi} \cdot \frac{\sigma}{\sigma-1} = \frac{\gamma}{\rho\varphi} \quad (4)$$

Substituting Eqs. (4) into (1), we get the output q , which maximizes the firm's profit. The output is:

$$q = X \left(\frac{p}{Y} \right)^{-\sigma} = X \left(\frac{Y\rho\varphi}{\gamma} \right)^{\sigma} \quad (5)$$

According to Eqs. (4) and (2), firm's sales revenue r can be written as:

$$r = R \left(\frac{Y\rho\varphi}{\gamma} \right)^{\sigma-1} \quad (6)$$

The relationship between profit π and sales revenue r is:

$$\pi = r - C = r - \frac{\gamma}{\varphi} \cdot q - \gamma f = r - (\rho p)q - \gamma f = (1-\rho)r - \gamma f = \frac{r}{\sigma} - \gamma f \quad (7)$$

Substituting Eqs. (6) into (7), we get the firm's maximum profit π as a function of its productivity φ :

$$\pi = \frac{R}{\sigma} \left(\frac{Y\rho\varphi}{\gamma} \right)^{\sigma-1} - \gamma f \quad (8)$$

In-equations $(\partial p / \partial \varphi) < 0$, $(\partial q / \partial \varphi) > 0$, $(\partial r / \partial \varphi) > 0$, and $(\partial \pi / \partial \varphi) > 0$ are obtained from Eqs. (4)–(6) and (8). Therefore, firms with higher productivity will set lower price for their goods, produce

more output and gain larger sales revenue and profit. The price of goods, the quantity of output, the sales revenue and the profit are only influenced by firm's productivity. Any two firms make the same decision if their productivities are equal. A representative firm which pursues to maximize its profit, will exit immediately if its productivity φ is less than $\varphi_0 = \inf\{\varphi : \pi(\varphi) > 0\}$. On the contrary, if a firm with productivity $\varphi > \varphi_0$, it will produce goods and gain positive profit. Therefore, only firms with productivity in the range (φ_0, ∞) will produce.

Total output produced by all firms in the industry is $Q = \int_{\omega \in \Omega} q(\omega) d\omega$. Denote the quantity of firms which could produce is M , and these firms draw their productivity φ from a common distribution $\mu(\varphi)$. Hence, total output Q can be written as:

$$Q = \int_{\varphi_0}^{\infty} q(\varphi) M \mu(\varphi) d\varphi \quad (9)$$

Total resource S used by all firms produced in the industry is:

$$S = \int_{\varphi_0}^{\infty} \left[\frac{q(\varphi)}{\varphi} + f \right] M \mu(\varphi) d\varphi = \int_{\varphi_0}^{\infty} \frac{q(\varphi)}{\varphi} M \mu(\varphi) d\varphi + Mf \quad (10)$$

The two sections in Eq. (10) respectively measure the gross variable input and the gross fixed input about resource.

Production may cause some environmental problems such as pollution emission. Pollution is a by-product of production as the general assumption of environmental economics. However, we assume that any firm's pollution h depends on its resource input, rather than its output. This hypothesis dues to the increasing return to scale where input is not strictly proportional to output. More resource consumption will lead to more pollution in production. Pollution mainly depends on the variable input because fixed input is low and constant to all firms in production. Suppose $h = \tau s = (\tau q) / \varphi$, where τ is "pollution intensity" which measures the amount of pollution caused by per unit input in production. Total pollution H emitted by all firms is:

$$H = \int_{\varphi_0}^{\infty} h(\varphi) M \mu(\varphi) d\varphi \quad (11)$$

Substituting Eq. (5) into $s = q/\varphi$, we get:

$$s = \left[X \left(\frac{Y\rho\varphi}{\gamma} \right)^{\sigma} \right] / \varphi = X \left(\frac{Y\rho}{\gamma} \right)^{\sigma} \varphi^{\sigma-1} \quad (12)$$

Likewise, substituting Eq. (5) into $h = (\tau q) / \varphi$, we get:

$$h = \left[\tau \cdot X \left(\frac{Y\rho\varphi}{\gamma} \right)^{\sigma} \right] / \varphi = \left[\tau \cdot X \left(\frac{Y\rho}{\gamma} \right)^{\sigma} \right] \varphi^{\sigma-1} \quad (13)$$

In-equations $(\partial s / \partial \varphi) > 0$ and $(\partial h / \partial \varphi) > 0$ are obtained from the condition $\sigma > 1$, i.e. firms with higher productivity will use more resource and emit more pollution.

In our discussion, the only cost of firms in production is the payment for resource consumption in factor market. With the purpose of internalizing the externality of pollution emission, government has motivation to impose environmental policies such as pollution tax. For expositional simplicity, suppose the tax on unit pollution is t , and is an exogenous variable.

If government levies tax t per unit of pollution, firm with productivity φ pays total cost in production as:

$$C' = \frac{\gamma}{\varphi} \cdot q + t \cdot h + \gamma f = \frac{\gamma + t\tau}{\varphi} \cdot q + \gamma f \quad (14)$$

The new marginal cost is $MC' = (\gamma + t\tau) / \varphi$ according to Eq. (14). The price p' of good is:

$$p' = \frac{\gamma + t\tau}{\rho\varphi} \quad (15)$$

¹ For details, see Dixit and Stiglitz (1977).

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