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A NOTE ON POLLUTION INTENSITY AND THE EFFECT OF TIGHTER ENVIRONMENTAL POLICY ON COMPARATIVE ADVANTAGE

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Abstract: This note reexamines the two-factor (capital and labor), three-sector (two final goods sector and a pollution abatement sector) model developed by Chua (2003, *Oxford Economic Papers* **55**, 25–35). By redefining pollution intensity, this note shows that an increase in the pollution tax rate unambiguously raises the price of a pollution-intensive good as long as the other (i.e., less pollution-intensive) good is least capital-intensive.

Keywords: Environmental policy, Comparative advantage, Pollution intensity.
JEL Classification Number: F18, Q28.

1. INTRODUCTION

In the literature on trade and the environment, the effect of tighter environmental policy (e.g., an increase in pollution tax) on a country's comparative advantage and trade pattern has been widely argued. A typical view on this issue is called the "pollution haven" hypothesis, which states that trade between two countries with different levels of environmental regulations will lead to the low regulation country specializing in pollution-intensive production because that country has a comparative advantage in more polluting goods. Recently, Chua (2003) provides a counterexample to this standard view. The author develops a two-factor (labor and capital), three-good (two final goods and an abatement service) general equilibrium model and shows that the autarky price of more polluting good does not necessarily increase in response to a higher pollution tax. The reason for this paradoxical result is that the pollution tax has two effects that may work in opposite directions: on the one hand it raises the price of the good with the higher tax burden; on the other hand it raises or lowers the relative wage-rental ratio depending on the factor intensity of each sector.

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Two key premises, however, are crucial in deriving the ambiguity of the effect of an increase in pollution tax on the autarky price. First, the author assumes that the amount of pollution emitted in each sector is proportional to output, independent of capital-labor intensities. Second, the author identifies more polluting good as one with a higher pollution-output ratio. However, as discussed in, e.g., Antweiler et al. (2001), pollution-intensive sectors are in general capital-intensive. Moreover, a number of empirical studies define pollution-intensive sectors as those which have incurred high levels of abatement expenditure per unit of output in the US and other OECD economies (e.g., Robison 1988; Tobey 1990; Low and Yeats 1992).

This note reexamines Chua's model, and by redefining pollution intensity of each sector in terms of its pollution control costs, shows a more clear-cut result; an increase in the pollution tax rate unambiguously raises the price of a pollution-intensive good as long as the other (i.e., less pollution-intensive) good is least capital-intensive.

2. A BRIEF REVIEW OF CHUA (2003) MODEL

Chua (2003) considers an economy in which two final-goods sector (sectors 1 and 2) and a pollution-abatement sector (sector 3) are operated. Two primary factors of production (capital and labor, total endowment of which are assumed to be fixed) are employed in each sector, with the production function given by the Cobb-Douglas form[1]:

$$y_1 = L_1^{\alpha} K_1^{1-\alpha}, \quad y_2 = L_2^{\beta} K_2^{1-\beta}, \quad A = L_3^{\gamma} K_3^{1-\gamma}, \quad 0 < \alpha, \beta, \gamma < 1, \tag{1}$$

where y_j and A denote output of good j $(j = 1, 2)$ and the abatement service, respectively, and L_j and K_j are allocations of labor and capital, respectively, to sector j $(j = 1, 2, 3)$. While each unit of final good produced generates $\lambda_j > 0$ units of pollution emissions, some of the pollution can be reduced by purchasing abatement services A_j from the abatement sector. Each final-good producer faces a tax τ on net emission of pollution $\lambda_j y_j - A_j$. Let us denote the price of the abatement service by p_A. Then, profit maximization implies that $p_A = \tau$ must hold if each final-good producer chooses positive and finite amount of demand for the abatement service. Assuming that good 1 is numeraire and denoting the price of good 2 by p, we have the following expressions for representative producers' profits in respective sectors:

$$\pi_1 = (1 - \tau\lambda_1)y_1 - wL_1 - rK_1, \tag{2a}$$

$$\pi_2 = (p - \tau\lambda_2)y_2 - wL_2 - rK_2, \tag{2b}$$

$$\pi_A = \tau A - wL_3 - rK_3. \tag{2c}$$

The firm in each sector determines optimal levels of L_j and K_j in order to maximize (2) subject to (1), $j = 1, 2, 3$. Because of the constant-returns technologies, the profit maximization behavior in each sector implies that in equilibrium, the price and the unit costs are equated:

[1] In order to guarantee the existence of equilibrium, we must assume $\alpha \neq \gamma$.

$$1 = \frac{1}{\alpha^\alpha(1-\alpha)^{1-\alpha}} w^\alpha r^{1-\alpha} + \tau\lambda_1 , \tag{3}$$

$$p = \frac{1}{\beta^\beta(1-\beta)^{1-\beta}} w^\beta r^{1-\beta} + \tau\lambda_2 , \tag{4}$$

$$\tau = \frac{1}{\gamma^\gamma(1-\gamma)^{1-\gamma}} w^\gamma r^{1-\gamma} . \tag{5}$$

The zero-profit conditions (3), (4), and (5) imply that if the equilibrium factor prices (w, r) are to be determined uniquely, the price of good 2 must satisfy the following expression:

$$p^* = \Delta\tau^{(\beta-\alpha)/(\gamma-\alpha)}(1-\tau\lambda_1)^{(\gamma-\beta)/(\gamma-\alpha)} + \tau\lambda_2 , \tag{6}$$

where

$$\Delta \equiv \left(\frac{\alpha}{\beta}\right)^\beta \left(\frac{1-\alpha}{1-\beta}\right)^{1-\beta} \left[\left(\frac{\gamma}{\alpha}\right)^\gamma \left(\frac{1-\gamma}{1-\alpha}\right)^{1-\gamma}\right]^{\frac{\beta-\alpha}{\gamma-\alpha}} .$$

Differentiating (6) with respect to τ gives

$$\frac{dp^*}{d\tau} = \Delta\tau^{(\beta-\gamma)/(\gamma-\alpha)}(1-\tau\lambda_1)^{(\alpha-\beta)/(\gamma-\alpha)} \left(\frac{\beta-\alpha}{\gamma-\alpha} - \tau\lambda_1\right) + \lambda_2. \tag{7}$$

While the second term in the right-hand side of (7) is positive, the sign of the first term and whether this term outweighs the second term are ambiguous. Therefore, even if good 2 is more polluting than good 1 in the sense that its pollution-output ratio is larger ($\lambda_2 > \lambda_1$), an increase in the pollution tax rate τ does not necessarily increase the equilibrium price p^*.

The ambiguity of the effect of an increase in τ on p^* comes from the fact that an increase in the pollution tax rate affects p^* via two channels. First, higher τ implies higher production costs in the final-goods sectors, which push the commodity prices upward, and this cost-push effect is larger for a sector with higher pollution-output ratio. Second, because $\tau = p_A$, higher τ also increases the price of the abatement service, which alters the factor prices in accordance with the Stolper-Samuelson theorem; if the abatement sector is more (less) capital-intensive than sector 1, an increase in τ increases r (w) and reduces w (r). The resultant change in commodity prices via changes in r and w is independent of the emission coefficients.

3. REDEFINITION AND REEXAMINATION

As stated in the Introduction, a number of empirical studies identify pollution-intensive sectors as those which have incurred high levels of abatement expenditure per unit of output. Therefore, let us define the pollution intensity in terms of pollution control costs as follows.

DEFINITION. Good 1 (resp. 2) is more *pollution-intensive* if $\tau\lambda_1 > \tau\lambda_2/p$ (resp. $\tau\lambda_1 < \tau\lambda_2/p$).

It is easily verified that the above definition of pollution intensity consistent with the empirical studies. That is, as the unit production cost of each good equals the price because of the constant-returns technologies, $\tau\lambda_1/1 = \tau\lambda_1$ and $\tau\lambda_2/p$ represent the ratio of pollution control costs in total costs for producing good 1 and 2, respectively[2].

Let us rewrite (7), making use of (6), as follows:

$$\frac{dp^*}{d\tau} = \frac{p^* - \tau\lambda_2}{(\gamma - \alpha)\tau}\left[\beta - \alpha + \frac{\tau\lambda_2}{p^* - \tau\lambda_2}(\gamma - \alpha) - \frac{\tau\lambda_1}{1 - \tau\lambda_1}(\gamma - \beta)\right]. \qquad (8)$$

Suppose that good 2 is more capital-intensive than good 1; $\alpha > \beta$. If good 2 is also more pollution-intensive than good 1, the difference between the last two terms in the square bracket of (8) is unambiguously negative because

$$\frac{\tau\lambda_1}{1 - \tau\lambda_1} - \frac{\tau\lambda_2}{p - \tau\lambda_2} = \frac{p\tau\lambda_1 - \tau\lambda_2}{(1 - \tau\lambda_1)(p - \tau\lambda_2)} < 0 \quad \Leftrightarrow \quad \tau\lambda_1 < \tau\lambda_2/p\,.$$

Therefore, if in addition the abatement service is more capital-intensive than good 1, i.e., $\alpha > \gamma$, the sign of (8) becomes unambiguously positive. To sum up, we have the following proposition.

PROPOSITION 1. *Suppose that a pollution-intensive sector and the abatement sector are more capital-intensive than the other (i.e., less pollution-intensive) sector. Then, an increase in the pollution tax rate unambiguously raises the price of the pollution-intensive good.*

Proposition 1 can be interpreted as follows. For a given τ, (3) and (5) determine w and r uniquely. If the abatement sector is more capital-intensive than sector 1, r is increasing in τ, as depicted by the upward-sloping curve $\bar{r}(\tau)$ in Figure 1[3]. In the meantime, (3) and (4) jointly determine a unique pair of w and r for given p and τ. According to the above definition of pollution intensity, an increase in τ reduces r if sector 2 is more pollution-intensive than sector 1, as drawn by the downward-sloping curve $\tilde{r}(\tau)$ in Figure 1. In addition, if good 2 is more capital-intensive than good 1, the $\tilde{r}(\tau)$–curve shifts upward when p rises. Suppose that the pollution tax rate is fixed at τ_0. Because the equilibrium rental price r_0^* must satisfy all three equilibrium conditions (3), (4) and (5), the $\bar{r}(\tau)$–curve and the $\tilde{r}(\tau)$–curve must intersect at $(\tau, r) = (\tau_0, r_0^*)$. In other words, the price of good 2, denoted by p_0^*, must be determined so that $\tilde{r}(\tau)$–curve goes through (τ_0, r_0^*). If the pollution tax rate goes up to τ_1, the rental rate rises to r_1^*, along the $\bar{r}(\tau)$–curve. The $\tilde{r}(\tau)$–curve must shift upward so that it runs through (τ_1, r_1^*), which requires a change in the price of good 2 from p_0^* to p_1^*. With the assumption that good 2 is more capital-intensive than good 1, in order to achieve the upward shift of the $\tilde{r}(\tau)$–curve, p^* must increase.

Although an alternative definition of pollution intensity makes it possible to obtain a clearer result than Chua's (2003), the result should be treated with caution. The definition of pollution intensity employed here depends on p, which is affected by the

[2] Since $p_A = \tau$, the total environmental costs (the sum of tax payment and abatement expenditure) become $\tau(\lambda_j y_j - A_j) + p_A A_j = \tau\lambda_j y_j$, $j = 1, 2$.

[3] For the properties of $\bar{r}(\tau)$– and $\tilde{r}(\tau)$–curves, see the Appendix.

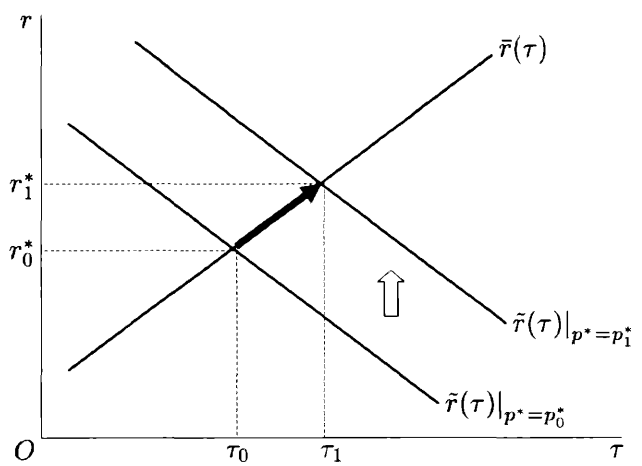

Figure 1. The effect of an increase in τ on p^*.

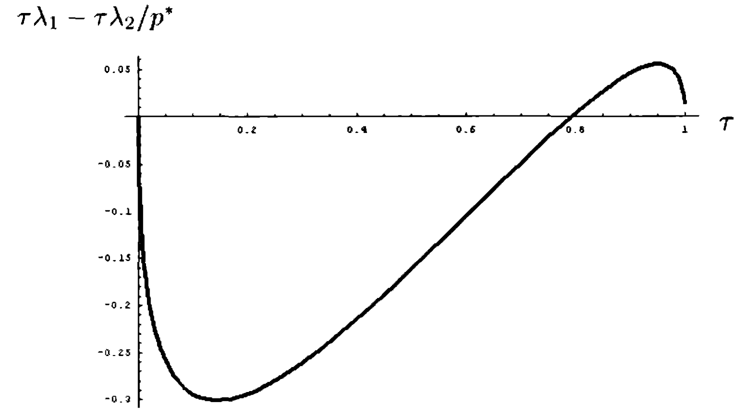

Figure 2. A numerical relationship between τ and the difference in pollution intensities.

pollution tax rate τ. This means that there may exist a reversal of pollution intensities, as indicated by the following expression:

$$\frac{\partial[\tau\lambda_1 - \tau\lambda_2/p^*]}{\partial\tau} = \frac{p^*\lambda_1 - \lambda_2}{p^*} + \frac{\tau\lambda_2}{p^{*2}}\frac{\partial p^*}{\partial\tau}. \tag{9}$$

If the conditions in Proposition 1 are satisfied, the first term in the right-hand side of (9) is unambiguously negative by assumption and the second term is unambiguously positive by Proposition 1. Then, sector 2 will not be any longer more pollution-intensive than sector 1 if the second term outweighs the first term. In fact, a numerical example, where $\alpha = 0.8$, $\beta = 0.7$, $\gamma = 0.6$, $\lambda_1 = 1$ and $\lambda_2 = 2$, shows that for larger values of

τ the sign of $\tau\lambda_1 - \tau\lambda_2/p^*$ can be positive (see Figure 2). Figure 2 also suggests that whereas Proposition 1 is valid in a *local* analysis where a small change in the pollution tax rate is considered, it may be invalid in a *global* analysis because the pollution-intensity ranking can be reversed if the government increases τ to a large extent.

4. CONCLUSION

By redefining pollution intensity in terms of pollution control costs and connecting it with factor intensity, we demonstrated that in Chua (2003) model an increase in the pollution tax rate unambiguously raises the price of a more pollution-intensive good as long as the other (i.e., less pollution-intensive) good is least capital-intensive. The condition that less pollution-intensive goods are least capital-intensive goods seems quite consistent with the actual industrial structure. In addition, the proposition that we showed does not require the factor-intensity ranking between the pollution-intensive sector and the abatement sector. This will be also consistent with reality because it is arguable whether pollution-intensive sectors are more capital-intensive than abatement sectors.

As Chua (2003) states, empirical findings on the relationship between environmental policy and trade patterns yield mixed results. This theoretical note suggests that alternative definitions of pollution intensity may yield different outcomes.

APPENDIX

Logarithmic differentiation of (3), (4), and (5) yields[4]

$$\alpha\hat{w} + (1-\alpha)\hat{r} = -\frac{\tau\lambda_1}{1-\tau\lambda_1}\hat{\tau}\,, \tag{A.1}$$

$$\beta\hat{w} + (1-\beta)\hat{r} = \frac{p}{p-\tau\lambda_2}\hat{p} - \frac{\tau\lambda_2}{p-\tau\lambda_2}\hat{\tau}\,, \tag{A.2}$$

$$\gamma\hat{w} + (1-\gamma)\hat{r} = \hat{\tau}\,. \tag{A.3}$$

Solving (A.1) and (A.3), we obtain

$$\hat{w} = \frac{\frac{(1-\gamma)\tau\lambda_1}{1-\tau\lambda_1} - (1-\alpha)}{\alpha-\gamma}\hat{\tau}\,, \quad \hat{r} = \frac{\alpha + \gamma\frac{\tau\lambda_1}{1-\tau\lambda_1}}{\alpha-\gamma}\hat{\tau}\,. \tag{A.4}$$

If the abatement sector is more capital-intensive than sector 1, $\hat{r}$ is increasing in $\hat{\tau}$; the $\bar{r}(\tau)$–curve is upward-sloping.

Solving (A.1) and (A.2), we have

$$\hat{w} = \frac{-\frac{(1-\alpha)p}{p-\tau\lambda_2}\hat{p} + \left[\frac{(1-\alpha)\tau\lambda_2}{p-\tau\lambda_2} - \frac{(1-\beta)\tau\lambda_1}{1-\tau\lambda_1}\right]\hat{\tau}}{\alpha-\beta}\,,$$
$$\hat{r} = \frac{\frac{\alpha p}{p-\tau\lambda_2}\hat{p} + \left(\beta\frac{\tau\lambda_1}{1-\tau\lambda_1} - \alpha\frac{\tau\lambda_2}{p-\tau\lambda_2}\right)\hat{\tau}}{\alpha-\beta}\,. \tag{A.5}$$

[4] $\hat{z} \equiv dz/z$ denotes the percent change of a variable z.

If sector 2 is more capital- and pollution-intensive than sector 1, $\hat{r}$ is decreasing in $\hat{\tau}$; the $\tilde{r}(\tau)$–curve is downward-sloping. In addition, $\hat{r}$ is increasing in $\hat{p}$; when p rises, the $\tilde{r}(\tau)$–curve shifts upward.

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