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Effects of Trade Liberalization on the Environment in Developing Countries: A Theoretical Study in General Equilibrium Framework[ϒ]

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This paper theoretically examines the effects of trade liberalization on environment in developing countries. In a three sector general equilibrium model informal manufacturing sector is the polluting sector in the economy which supplies intermediate products to the formal manufacturing sector. A reduction in tariff rate for the product of the formal manufacturing sector leads to higher import of the competing goods causing shrinkage of the formal and polluting sectors. On the other hand, capital inflow results in expansion of both the formal manufacturing sector and the polluting informal sector. As a result, overall pollution increases. However, if pollution abatement cost is imposed on the formal manufacturing sector, returns to capital falls leading to decline of both polluting informal and formal manufacturing sectors.

Key Words: Tariff cut, Capital inflow, Manufacturing sector, Informal sector, Pollution tax.

JEL Classification: F64, F65, F68

1. Introduction

The agricultural sector plays an important role in the process of economic development in the developing countries although the percentage share of this sector in GDP is declining with economic growth. However employment

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generation in this sector is still very high. Another sector which also absorbs a large number of the workforce in the developing world is informal sector. At the same time, both agricultural and non-agricultural informal sectors are more polluting sectors. There may be environmental degradation in the form of excessive use of ground water, soil degradation and greater use of chemical inputs due to trade liberalization in agricultural commodities. While this is an important issue, it is, however, not the main focus of this paper. The present work is concerned mainly with the polluting informal manufacturing sector. The economies of the developing world are largely characterized by the growing informal sector which, in most cases, remains outside the control of environmental regulations. It is a sector where minimum wage laws are not adhered to. It operates outside the environmental laws and regulations of the formal manufacturing sector. To evade tax burden and bypass the environmental regulations the formal sector passes on the dirty production process to the informal sector on sub-contracting basis. Since government cannot regulate informal sector, it is easier for this sector to use back-dated harmful cheap technology and pollute the environment.

The problem of regulation of the informal sector has been discussed in detail in Marjit, Ghosh and Biswas (2007) and Marjit and Kar (2011). There is rich literature on the interaction between formal and informal sectors in the context of labour market (Marjit, 2003; Marjit, Kar and Acharyya, 2007). However, studies on the interaction between formal and informal sectors in the context of environmental equality are not large. Blackman and Bannister (1998), Blackman (2000), Gupta (2002), Chaudhuri and Mukhopadhyay (2006) have shown the interaction between informal sector and environmental pollution. The World Development Report (1995), based on the experiences of South African and Latin American countries, has argued that the size of the informal sector diminishes with economic development. Basically, the informal sector is a partial form of small and medium scale enterprises (SME), Perrings, Bhargava and Gupta (1995) have pointed out that SME is the main source of development and environmental pollution in LDCs. Existence of widespread informal sector implies that workers are under-nourished and poor in health. The nutritional efficiency of labour is adversely affected by pollution and health hazards. This is a very common phenomenon in less developed countries. So it will be more meaningful if the work force is measured in terms of nutritional efficiency.

The objective of this paper is to find out the impact of trade liberalization on environment in terms of tariff cut and inflow of foreign capital in such a context.

The reduction in tariff rates results in higher import of tradable goods which are likely to affect the production of import competing industry and also the environmental quality in the country. On the other hand, Foreign Direct Investment (FDI) is considered as an important indicator of economic prosperity in developing countries. At the same time, it may be responsible for pollution and environmental degradation in such countries. Kar and Majumdar (2016), however, show that trade and FDI are not always singularly important for environmental degradation. In modification of the work, pollution abatement cost has been introduced. Since formal manufacturing is the sole user of polluting intermediate input, a pollution tax has been imposed on the formal sector. It shows that as a result of the tax, returns to capital declines leading to decline of capital from FDI. In effect, both formal manufacturing and polluting informal sectors decline. On the whole, pollution declines as a result of pollution tax. The results of theoretical analysis on the above discussions are presented in section 2, 3 and 4, 5 and 6 provides the concluding remarks.

2. The theoretical model

Let us consider a small open economy with three sectors – agricultural sector (A), the formal manufacturing sector (M), and an informal polluting sector (Z). Agriculture uses land and labour. Formal manufacturing sector uses labour, hired at unionized fixed nominal wage rate, capital and final product of informal manufacturing sector as an intermediate input on the basis of a fixed input-output ratio. All other inputs that are used by various sectors have a variable-coefficient type of technology. Informal manufacturing sector uses labour with market determined wage and capital. Formal wage is greater than informal wage. Agriculture and informal sector pay the same wage rate.

Here, in this model, we have considered that the nutritional efficiency of the worker is a decreasing function of the economy's environmental quality. Pollution causes degradation of environmental quality. We assume that all the workers possess identical efficiency function and hence labour endowment is measured in efficiency unit. We have considered neo-classical production function with Constant Return to Scale (CRS) for each sector and competitive market conditions. Given these assumptions and that of a competitive small economy, we set up the following equations to describe the economic system. The following symbols, quite common in a standard general equilibrium framework, are used to describe the model.

P_j^* : world price of the product of j[th] sector, j = *A*, *M*
t : ad valorem tariff rate
$P_M = (1 + t) P_M^*$: domestic price (tariff inclusive) of the product of sector *M*
P_Z: price of non-traded intermediate product produced by sector *Z*
a_{ij}: quantity of i[th] input required for production of one unit of output of the jth sector, $i = L,K;\ j = A, M, Z$
θ_{ij} : share of the ith input in the price of commodity j in value terms ($i = L, K$ and $j = A, M, Z$)
λ_{ij} : proportion of ith factor used in the production of jth sector ($i = L, K$ and $j = A, M, Z$).
W : wage rate of workers in sector *A*, *Z*
$\overline{W}$: exogenously given wage rate of the workers of manufacturing sector
r : rate of return on capital
L, *K* : total labour and capital endowment in physical unit respectively
Ω : maximum allowable level of pollution in the economy
Q = total actual pollution in the economy
Ω_C = Pollution generated by the combined wastes of the products of agriculture and manufacturing sector as a result of consumption of the products of the two sectors.
h(.) : nutritional efficiency function of a representative worker from environmental quality.

Assuming commodity *A* as the numeraire good, the competitive equilibrium price conditions are given by the following three equations:

$$1 = a_{LA}W + a_{KA}r \tag{1}$$

$$(1+t)P_M^* = a_{LM}\overline{W} + a_{KM}r + a_{ZM}P_Z \tag{2}$$

$$P_Z = a_{LZ}W + a_{KZ}r \tag{3}$$

Full employment conditions are:

$$K = a_{KA}X_A + a_{KM}X_M + a_{KZ}X_Z \tag{4}$$

$$Lh = a_{LA}X_A + a_{LM}X_M + a_{LZ}X_Z \tag{5}$$

$$X_Z = a_{ZM}X_M \tag{6}$$

The nutritional efficiency function is a decreasing function of the level of pollution which is given by

$$h = h\,(Q) \qquad (7)$$

where, $\partial h / \partial Q < 0$

Total pollution in the economy is:

$$Q = \alpha_A X_A + \alpha_M X_M + \Omega_C + \alpha_Z X_Z \qquad (8)$$

where, α_A, α_M and α_Z are share of pollution in production of A, M and Z respectively. It can be written as

$$Q = \Omega + a_Z X_Z \qquad (9)$$

where, $\Omega = \alpha_A X_A + \alpha_M X_M + \Omega_C$

It can be easily shown that the model implies decomposable structure.

From equation (6) we get $X_M = X_Z / a_{ZM}$. Substituting the value of X_M in equations (4) and (5) and then solving simultaneously we get the values of X_Z and X_A. Using the value of X_Z, we get the value of X_M from equation (6). Once the values of X_A, X_Z and X_M are known, we can obtain Ω_C from equation (9), Q from equation (8) and h from equation (7). This completes the working of the model.

3. Impact of Capital Inflow

Now we want to investigate the consequence of the trade liberalization in terms of capital inflow. Increase in capital inflow will ease capital constraint and create Rybczynski effect, resulting in an expansion of the manufacturing sector as it is capital intensive sector. Since informal manufacturing sector is dependent on the formal sector on subcontracting basis, it will also expand. This subcontracting concept of informal manufacturing sector by formal manufacturing sector is a reasonable assumption from the point of view of developing economies. As government can regulate formal sector, it cannot emit over the maximum allowable pollution level and hence the formal sectors contract out the dirty production process to the informal sector in order to avoid pollution tax. As government cannot regulate informal sector, it is easy for them to produce polluting goods under the shade of formal manufacturing sector. On the other hand, the labour intensive agriculture sector will contract to release labour for the expansion of the manufacturing sector, both formal and informal. The results can be derived from the model in the following way.

We can write equation (4) as,

$$K = a_{KA}X_A + a_{KM}X_M + a_{KZ}a_{ZM}X_M \qquad (4')$$

Taking total differentiation of (4′) we get

$$1 = a_{KA}dX_A / dK + (a_{KM} + a_{KZ}\ a_{ZM})\ dX_M / dK \qquad (10)$$

Similarly, equation (5) can be written as,

$$Lh = a_{LA}X_A + a_{LM}X_M + a_{LZ}\ a_{ZM}\ X_M \qquad (5')$$

Taking total differentiation of (5′) and after simplification, we get

$$0 = a_{LA}\ dX_A + (a_{LM} + a_{LZ}\ a_{ZM})\ dX_M \qquad (11)$$

Solving the equations (10) and (11) we get

$$dX_A\ /\ dK = (a_{LM} + a_{LZ}\ a_{ZM}) / |A| \qquad (12)$$

$$dX_M\ /\ dK = -a_{LA} / |A| \qquad (13)$$

where,

$$|A| = [a_{KA}\ (a_{LM} + a_{LZ}\ a_{ZM})] - [a_{LA}\ (a_{KM} + a_{KZ}\ a_{ZM})] \qquad (14)$$

In (14), $|A|$ is negative if $[\ a_{KA}(a_{LM} + a_{LZ}\ a_{ZM})] < [a_{LA}\ (a_{KM} + a_{KZ}\ a_{ZM})]$. It implies that agriculture sector is more labour intensive than formal and informal manufacturing sector, which is a plausible assumption. Hence, from (12) and (13) we get $dX_A / dK < 0$ and $dX_M / dK > 0$.

It can also be shown that, $dX_M / dK > 0$.
Now, we can summarize our results in the form of the following proposition.

Proposition 1: *An increase in foreign capital inflow leads to an expansion of polluting informal manufacturing sector and also the level of environmental pollution in the economy.*

A Secondary Rybczynski Effect will also follow from this capital inflow. As the overall environmental pollution in the economy increases as a result of expansion of the polluting informal sector following capital inflow, labour supply will decline in efficiency terms. Since agriculture is assumed to be more labour intensive compared to other sectors, production in agriculture will further decline due to decline of labour supply. But the result of higher pollution in the economy due to capital inflow will remain valid because agriculture is less polluting than informal manufacturing.

4. Impact of Tariff Cut

This theoretical exercise is intended to investigate the consequence of trade liberalization in terms of fall in tariff rate. A fall in tariff rate causes an increase in W and a fall in r (see the proof in appendix).We find that there is a fall in a_{Lj} and a rise in a_{Kj}, creating a shortage of capital and excess supply of labour. This creates a '*Rybczynski type effect*' resulting in an expansion of labour intensive sector and a contraction of the capital-intensive sector. Under the assumption that the formal manufacturing sector is more capital intensive, in direct and indirect terms, than the agricultural sector, i.e. $\{(a_{KM} + a_{KZ}a_{ZM}) / (a_{LM} + a_{LZ}a_{ZM})\} > (a_{KA} / a_{LA})$, we find that[1] the agricultural sector expands and the formal manufacturing sector contracts as a result of a fall in tariff rate. When the formal manufacturing sector contracts, the informal sector also contracts as it is dependent on the formal manufacturing sector. Contraction of the informal manufacturing sector reduces the level of environmental pollution from this sector. It creates an improvement in nutritional efficiency of the workers and hence increases effective labour endowment. We have already noted that $[(\lambda_{KM} + \lambda_{KZ}) / (\lambda_{LM} + \lambda_{LZ})] > (\lambda_{KA} / \lambda_{LA})$. The adjustment in nutritional efficiency factor is reflected in terms of the modified capital intensity condition $[(\lambda_{KM} + \lambda_{KZ}) / (\lambda_{LM} + \lambda_{LZ} - h'(.)Q\xi)] > (\lambda_{KA} / \lambda_{LA})$ where, $\xi = \alpha_Z X_Z / Q$. The term $[h'(.)Q\xi]$ implies the health impact in terms of pollution emits from polluting informal sector (for details see appendix). The increase in effective labour endowment creates a '*Secondary Rybczynski Effect*' resulting in again an increase in output of the agricultural sector and a reduction in the level of output of formal manufacturing sector (and also of the informal manufacturing sector). Thus finally, we find that a reduction in tariff rate reduces the size of the informal manufacturing sector and also the level of environmental pollution in the economy (For derivation of the results see appendix – A).

We can summarize our results in the form of the following proposition.

Proposition 2*: *Trade liberalization in the form of reduction in the tariff rate for the product of the import-competing formal manufacturing sector leads to a reduction in the size of the polluting informal sector and also the level of environmental pollution in the economy.

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[1] See Appendix

5. The Effect of Pollution Abatement Cost

In section 3, the results show that as FDI takes place, capital stock increases and due to Rybczynsky effect, the capital intensive formal sector X_M expands leading to expansion of polluting sector X_Z. But there is a permissible of pollution and if that limit is crossed the government may think of imposing a pollution abatement tax. This tax will be imposed on the formal manufacturing sector because it is the sole user of the polluting input X_Z. The price of X_M is internationally given. Now, to pay this pollution tax, either wage rate (W) or returns to capital (r) will decline. So, the model will be modified to show that as a result of pollution abatement tax, r will decline and W will rise. As r declines, FDI will fall with the result that formal manufacturing as well as polluting informal sector decline. On the other hand, the labour-intensive agricultural sector expands with decline in capital stock. X_A is also a polluting sector but it is less polluting than X_Z. On the whole, pollution will decline. However, welfare implication of this policy remains unclear. In original framework, labour has been considered in efficiency terms. Here, we use labour in normal form. The other specifications of the model remain unchanged.

V is pollution above permissible limit

$$V = V(X_Z), \; V'(X_Z) > 0$$

α is the rate of pollution tax per unit of X_M on excess pollution.

Competitive price equations are:

$$a_{LA} \cdot W + a_{KA} \cdot r = P_A \tag{15}$$

$$a_{LM} \cdot \overline{W} + a_{KM} \cdot r + a_{ZM} \cdot P_Z + \alpha \cdot \frac{V}{X_M} = P_M \tag{16}$$

$$a_{LZ} \cdot W + a_{KZ} \cdot r = P_Z \tag{17}$$

Full employment conditions are:

$$a_{KA} \cdot X_A + a_{KM} \cdot X_M + a_{KZ} \cdot X_Z = K \tag{18}$$

$$a_{LA} \cdot X_A + a_{LM} \cdot X_M + a_{LZ} \cdot X_Z = L \tag{19}$$

$$a_{ZM} \cdot X_M = X_Z \tag{20}$$

Given P_A, P_M, $\overline{W}$, K, L, α, the above six equations determine the six variables: W, r, P_Z, X, M, and Z.

From the results in appendix – B it is found that

$$\frac{\hat{W}}{\hat{\alpha}} > 0,\ \frac{\hat{r}}{\hat{\alpha}} < 0,\ \frac{\hat{X}_A}{\hat{\alpha}} > 0, \frac{\hat{X}_M}{\hat{\alpha}} < 0 \text{ and } \frac{\hat{X}_Z}{\hat{\alpha}} < 0 .$$

6. Concluding Remarks

This paper elaborates some theoretical issues related to trade liberalization both in the forms of a fall in tariff rate and increase in capital inflow. In this paper, the informal sector is a polluting sector in the economy. It is assumed that, this informal manufacturing sector is producing a non-traded intermediate product which is fully used as input in the formal manufacturing sector. Nutritional efficiency of labour has been introduced in this paper and it depends on the level of pollution level in the economy irrespective of education, skill, experience etc. It is assumed that efficiency of labour will decline if pollution increases in the country. Here, labour is measured in efficiency terms. However, in modified model with pollution abatement cost this assumption has been relaxed and labour has been measured in usual terms.

The interesting point is that here we find exactly opposite results for the two policies related to trade liberalization. In case of foreign capital inflow, informal polluting sector expands and in effect, overall pollution in the economy increases. On the other hand, for tariff cut policy, informal polluting sector contracts and it reduces the level of emission of pollution from this sector. As a result, overall pollution in the economy declines. However, if a pollution abatement cost is imposed on the formal manufacturing sector, returns to capital declines and in effect both formal manufacturing and polluting informal sectors decline. The welfare implications of these policies are unknown.

Appendix – A: Impact of tariff cut

Let us consider equation (1)

$$P_A = 1 = a_{LA}\, W + a_{KA}\, r$$

Differentiating this equation we get

$$0 = a_{LA} dW + a_{KA}\, dr$$

After some manipulation we get

$$0 = \frac{a_{LA}\, W}{P_A} \frac{dW}{W} + \frac{a_{KA} \cdot r}{P_A} \frac{dr}{r}$$

or, $$0 = \theta_{LA}\, \hat{W} + \theta_{KA}\, \hat{r} \quad \text{(A1)}$$

Similarly, from eqn. (2) and (3) we get

$$\hat{P}_M = \theta_{KM} \hat{r} + \theta_{ZM}\, \hat{P}_Z \quad \text{(A2)}$$

$$\hat{P}_Z = \theta_{LZ} \hat{W} + \theta_{KZ} \hat{r} \quad \text{(A3)}$$

Given, $P_M = P_M^* \left(1+t\right)$, it is easy to check that

$$\hat{P}_M = \frac{t}{1+t}\, \hat{t}$$

Using this value of $\hat{P}_M$ in equation (A2) we get

$$\frac{t}{1+t}\, \hat{t} = \theta_{KM} \hat{r} + \theta_{ZM}\, \hat{P}_Z \quad \text{(A4)}$$

Using the value of $\hat{P}_Z$ from equation (A3) in equation (A4) we get,

$$\frac{t}{1+t}\, \hat{t} = \theta_{KM}\, \hat{r} + \theta_{ZM} \left(\theta_{LZ}\, \hat{W} + \theta_{KZ}\, \hat{r}\right)$$

After simplification this becomes

$$\frac{t}{1+t}\, \hat{t} = \theta_{ZM}\, \theta_{LZ}\, \hat{W} + \left(\theta_{KM} + \theta_{ZM}\, \theta_{KZ}\right) \hat{r} \quad \text{(A5)}$$

Equation (A1) and (A5) can be written as:

$$\theta_{LA} \frac{\hat{W}}{\hat{t}} + \theta_{KA} \frac{\hat{r}}{\hat{t}} = 0$$

$$\theta_{ZM}\, \theta_{LZ} \frac{\hat{W}}{\hat{t}} + \left(\theta_{KM} + \theta_{ZM} \cdot \theta_{KZ}\right) \frac{\hat{r}}{\hat{t}} = \frac{t}{1+t}$$

Solving these above equations by Cramer's rule we get

$$\frac{\hat{W}}{\hat{t}} = \frac{\begin{vmatrix} 0 & \theta_{KA} \\ \frac{t}{1+t} & \theta_{KM} + \theta_{ZM} \cdot \theta_{KZ} \end{vmatrix}}{|\Delta|} = \frac{-\theta_{KA}\left(\frac{t}{1+t}\right)}{|\Delta|} \tag{A6}$$

$$\frac{\hat{r}}{\hat{t}} = \frac{\begin{vmatrix} \theta_{LA} & 0 \\ \theta_{ZM} \cdot \theta_{LZ} & \frac{t}{1+t} \end{vmatrix}}{|\Delta|} = \frac{\theta_{LA}\left(\frac{t}{1+t}\right)}{|\Delta|} \tag{A7}$$

where,

$$|\Delta| = \begin{vmatrix} \theta_{LA} & \theta_{KA} \\ \theta_{ZM}\theta_{LZ} & \theta_{KM} + \theta_{ZM} \cdot \theta_{KZ} \end{vmatrix}$$

or, $|\Delta| = \theta_{LA}\left(\theta_{KM} + \theta_{ZM} \cdot \theta_{KZ}\right) - \theta_{KA}\left(\theta_{ZM}\ \theta_{LZ}\right)$

or, $|\Delta| = \theta_{LA} \cdot \theta_{KM} + \theta_{LA} \cdot \theta_{ZM}\ \theta_{KZ} - \theta_{KA}\ \theta_{ZM}\ \theta_{LZ}$

Under the assumption that, sector A is more labour intensive than sector *Z* (i.e. $\theta_{LA}/\theta_{KA} > \theta_{LZ}/\theta_{KZ}$) we get | Δ | > 0. Hence we have $(\hat{W}/\hat{t}) < 0$ and $(\hat{r}/\hat{t}) > 0$ from (A6) and (A7). It implies that a fall in tariff would cause an increase in W and a fall in *r*. A fall in tariff rate (*t*) causes the domestic price of the manufacturing sector, P_M to decrease. It is to be noted that as $P_Z = P_Z(r)$, the right hand side of the equation (2) can be expressed as a function of $\overline{W}$ and *r*. Again the fall in P_M creates a '*Stolper-Samuelson type effect*', due to which *r* decreases, as $\overline{W}$ is exogenously given and manufacturing sector is capital intensive.

We now want to analyze the impact of change in the tariff rate on output levels of different sectors.

Taking total differentiation of equation (4) in the text we get

$$0 = a_{KA}dX_A + a_{KM}dX_M + a_{KZ}dX_Z + X_A da_{KA} + X_M da_{KM} + X_Z da_{KZ}$$

or, $$a_{KA}dX_A + a_{KM}dX_M + a_{KZ}dX_Z = -\left(X_A da_{KA} + X_M da_{KM} + X_Z da_{KZ}\right)$$

$$\Rightarrow \frac{X_A\, a_{KA}}{K}\cdot\frac{dX_A}{X_A} + \frac{X_M \cdot a_{KM}}{K}\cdot\frac{dX_M}{X_M} + \frac{X_Z \cdot a_{KZ}}{K}\frac{dX_Z}{X_Z}$$

$$= \quad -\left(\frac{X_A \cdot a_{KA}}{K}\cdot\frac{da_{KA}}{a_{KA}} + \frac{X_M \cdot a_{KM}}{K}\frac{da_{KM}}{a_{KM}} + \frac{X_Z a_{KZ}}{K}\cdot\frac{da_{KZ}}{a_{KZ}}\right)$$

$$\Rightarrow \lambda_{KA}\,\hat{X}_A + \lambda_{KM}\,\hat{X}_M + \lambda_{KZ}\,\hat{X}_Z = -\left(\lambda_{KA}\,\hat{a}_{KA} + \lambda_{KM}\,\hat{a}_{KM} + \lambda_{KZ}\,\hat{a}_{KZ}\right) \tag{A8}$$

where, $\lambda_{Kj} = \dfrac{Kj}{K}$ is the share of jth sector in total capital employment.

Now, define, elasticity of factor substitution with respect to factor price ratio in Sector A as,

$$\sigma_A = \frac{d\left(K_A/L_A\right)\big/\left(K_A/L_A\right)}{d\left(W/r\right)\big/\left(W/r\right)}$$

$$= \frac{d\,\log\left(K_A/L_A\right)}{d\,\log\left(W/r\right)}$$

$$= \frac{d\,\log\left(aK_A/aL_A\right)}{d\,\log\left(W/r\right)}$$

$$\sigma_A = \frac{\hat{a}_{KA} - \hat{a}_{LA}}{\hat{W} - \hat{r}} \tag{A9}$$

From envelope condition it follows:

$$Wda_{LA} + rda_{KA} = 0$$

or, $\frac{W \cdot a_{LA}}{P_A} \frac{da_{LA}}{a_{LA}} + \frac{ra_{KA}}{P_A} \cdot \frac{da_{KA}}{a_{KA}} = 0$

or, $\theta_{LA}\hat{a}_{LA} + \theta_{KA}\,\hat{a}_{KA} = 0$

or, $\hat{a}_{LA} = -\frac{\theta_{KA}}{\theta_{LA}} \cdot \hat{a}_{KA}$

Using the value of $\hat{a}_{LA}$ in equation (A9) we get

$$\sigma_A = \frac{\hat{a}_{KA} - \left[-\frac{\theta_{KA}}{\theta_{LA}} \cdot \hat{a}_{KA}\right]}{\hat{W} - \hat{r}}$$

or, $(\hat{W} - \hat{r})\sigma_A = \hat{a}_{KA} + \frac{\theta_{KA}}{\theta_{LA}} \cdot \hat{a}_{KA}$

or, $(\hat{W} - \hat{r})\sigma_A = \frac{\hat{a}_{KA}\,(\theta_{LA} + \theta_{KA})}{\theta_{LA}}$

or, $\theta_{LA}\,(\hat{W} - \hat{r})\sigma_A = \hat{a}_{KA}$ (A10)

$(\because\ \theta_{LA} + \theta_{KA} = 1)$

Similarly,

$$\hat{a}_{KZ} = \theta_{LZ}\,(\hat{W} - \hat{r})\sigma_Z \quad \text{(A11)}$$

$$\hat{a}_{KM} = -\theta_{LM}\,\hat{r}\,\sigma_M \quad \text{(A12)}$$

Substituting the values of $\hat{a}_{KA}, \hat{a}_{KM}$ and $\hat{a}_{KZ}$ in equation (A8) we get

$$\lambda_{KA}\,\hat{X}_A + \lambda_{KM}\,\hat{X}_M + \lambda_{KZ}\,\hat{X}_Z = -\left\{ \begin{aligned} &\lambda_{KA}\,\theta_{LA}\,(\hat{W} - \hat{r})\sigma_A - \lambda_{KM}\,\theta_{LM}\,\hat{r}\sigma_M \\ &+ \lambda_{KZ}\,\theta_{LZ}\,(\hat{W} - \hat{r})\sigma_Z \end{aligned} \right\}$$

After simplification we can write

$$\lambda_{KA}\frac{\hat{X}_A}{\hat{t}}+\lambda_{KM}\frac{\hat{X}_M}{\hat{t}}+\lambda_{KZ}\frac{\hat{X}_M}{\hat{t}} = \frac{\hat{r}}{\hat{t}}\left\{\begin{array}{l}\lambda_{KA}\theta_{LA}\sigma_A+\lambda_{KM}\theta_{LM}\sigma_M+\lambda_{KZ}\theta_{LZ}\sigma_Z \\ \qquad -\frac{\hat{W}}{\hat{t}}\left\{\lambda_{KA}\theta_{LA}\sigma_A+\lambda_{KZ}\theta_{LZ}r_Z\right\}\end{array}\right\}$$

or, $$\lambda_{KA}\frac{\hat{X}_A}{\hat{t}}+\left(\lambda_{KM}+\lambda_{KZ}\right)\frac{\hat{X}_M}{E} = \frac{\hat{r}}{\hat{t}}\left(A+B+C\right)-\frac{\hat{W}}{\hat{t}}\left(A+C\right) \qquad \text{(A13)}$$

where, $A = \lambda_{KA}\,\theta_{LA}\,\sigma_A$

$B = \lambda_{KM}\,\theta_{LM}\,\sigma_M$

$C = \lambda_{KZ}\,\theta_{LA}\,\sigma_Z$

λ_{ij} implies share of ith input out of total factor endowment (in physical terms) in the jth sector (for all $i = L, K$ and $j = A, M, Z$) and σ_j is the elasticity of factor substitution in sector j (for all $j = A, M, Z$)

Let us recall full employment equation for labour as,

$$Lh\left(Q\right) = a_{LA}X_A + a_{LM}X_M + a_{LZ}X_Z \qquad (5)$$

Substituting the value of Q from equation (9) in the text we get

$$Lh\left(\Omega+\alpha_Z\ X_Z\right) = a_{LA}X_A + a_{LM}X_M + a_{LZ}X_Z \qquad (5)'$$

Total differentiation yields,

$$Lh'\left(\cdot\right)\alpha_Z dX_Z = a_{LA}dX_A + a_{LM}dX_M + a_{LZ}dX_Z + X_A da_{LA} + X_M da_{LM} + X_Z da_{LZ}$$

$$h'(\cdot)Q\cdot\frac{\alpha_Z X_Z}{Q}\cdot\frac{dX_Z}{X_Z} = \frac{a_{LA}\cdot X_A}{L}\frac{dX_A}{X_A}+\frac{a_{LM}X_M}{L}\cdot\frac{dX_M}{X_M}+\frac{a_{LZ}X_Z}{L}\frac{dX_Z}{X_Z}$$

or,

$$+\frac{X_A a_{LA}}{L}\frac{da_{LA}}{a_{LA}}+\frac{X_M a_{LM}}{L}\cdot\frac{da_{LM}}{a_{LM}}+\frac{X_Z a_{LZ}}{L}\cdot\frac{da_{LZ}}{a_{LZ}}$$

or, $$h'(\cdot)Q\xi\hat{X}_Z = \lambda_{LA}\hat{X}_A+\lambda_{LM}\hat{X}_M+\lambda_{LZ}\hat{X}_Z+\lambda_{LA}\hat{a}_{LA}+\lambda_{LM}\hat{a}_{LM}+\lambda_{LZ}\hat{a}_{LZ}$$

where, $\alpha_Z X_Z/Q=\xi$

or, $$h'(\cdot)Q\xi\hat{X}_M = \lambda_{LA}\left\lfloor\hat{X}_A+\hat{a}_{LA}\right\rfloor+\lambda_{LM}\left\lfloor\hat{X}_M+\hat{a}_{LM}\right\rfloor+\lambda_{LZ}\left\lfloor\hat{X}_M+\hat{a}_{LZ}\right\rfloor \quad \text{(A14)}$$

Again, from equation (6) in the text reproduced below,

$$X_Z = a_{ZM}X_M \quad (6)$$

it can be shown that,

$$\hat{X}_Z=\hat{X}_M$$

Now, (A14) can be written as

$$h'(\cdot)Q\xi\,\hat{X}_M = \lambda_{LA}\left\lfloor\hat{X}_A-\theta_{KA}\left(\hat{W}-\hat{r}\right)\sigma_A\right\rfloor+\lambda_{LM}\left\lfloor\hat{X}_M+\theta_{KM}\,\hat{r}\,\sigma_M\right\rfloor+\lambda_{LZ}\left\lfloor\hat{X}_M-\theta_{KZ}\left(\hat{W}-\hat{r}\right)\sigma_Z\right\rfloor$$

Or, $$h'(\cdot)Q\,\xi\,\hat{X}_M = \lambda_{LA}\hat{X}_A+\lambda_{LM}\hat{X}_M+\lambda_{LZ}\,\hat{X}_M-\lambda_{LA}\theta_{KA}\left(\hat{W}-\hat{r}\right)\sigma_A$$
$$+\lambda_{LM}\,\theta_{KM}\,\hat{r}\,\sigma_M-\lambda_{LZ}\,\theta_{KZ}\left(\hat{W}-\hat{r}\right)\sigma_Z$$

Or,

$$\hat{X}M\left[h'(\cdot)\,Q\,\xi-\lambda_{LM}-\lambda_{LZ}\right]-\lambda_{LA}\,\hat{X}_A=-\lambda_{LA}\,\theta_{KA}\hat{W}\,\sigma_A+\lambda_{LA}\theta_{KA}\hat{r}\sigma_A+\lambda_{LM}\theta_{KM}\,\hat{r}\,\sigma_M$$

$$-\lambda_{LZ}\theta_{KZ}\hat{W}\sigma_Z+\lambda_{LZ}\theta_{KZ}\,\hat{r}\,\sigma_Z$$

Or,

$$H\hat{X}_M-\lambda_{LA}\hat{X}_A=-\hat{W}\left(\lambda_{KA}\theta_{KA}\sigma_A+\lambda_{LZ}\theta_{KZ}\sigma_Z\right)+\hat{r}\left(\lambda_{LA}\theta_{KA}\sigma_A+\lambda_{LM}\theta_{KM}\sigma_M+\lambda_{LZ}\theta_{KZ}\sigma_Z\right)$$

where, $H = \left(h'(\cdot)Q\xi - \lambda_{LM} - \lambda_{LZ}\right)$

Or, $$H\,\frac{\hat{X}_M}{\hat{t}} - \lambda_{LA}\,\frac{\hat{X}_A}{\hat{t}} = \frac{\hat{r}}{\hat{t}}\left(\beta+\gamma+\rho\right) - \frac{\hat{W}}{\hat{t}}\left(\beta+\rho\right) \qquad \text{(A15)}$$

where, $\beta = \lambda_{LA}\,\theta_{KA}\,\sigma_A$

$\gamma = \lambda_{LM}\,\theta_{KM}\,\sigma_M$

$\rho = \lambda_{LZ}\,\theta_{KZ}\,\sigma_Z$

Solving equation (A13) and (A15) by Cramer's rule:

$$\frac{\hat{X}_M}{\hat{t}} = \frac{\begin{vmatrix} \frac{\hat{r}}{\hat{t}}\left(\beta+\gamma+\rho\right) - \frac{\hat{W}}{\hat{t}}\left(\beta+\rho\right) & -\lambda_{LA} \\ \frac{\hat{Y}}{\hat{t}}\left(A+B+C\right) - \frac{\hat{W}}{\hat{t}}\left(A+C\right) & \lambda_{KA} \end{vmatrix}}{\left|\psi\right|} \qquad \text{(A16)}$$

$$\frac{\hat{X}_A}{\hat{t}} = \frac{\begin{vmatrix} H & \frac{\hat{r}}{\hat{t}}\left(\beta+\gamma+\rho\right) - \frac{\hat{W}}{\hat{t}}\left(\beta+\rho\right) \\ \lambda_{KM}+\lambda_{KZ} & \frac{\hat{r}}{\hat{t}}\left(A+B+C\right) - \frac{\hat{W}}{\hat{t}}\left(A+C\right) \end{vmatrix}}{\left|\psi\right|} \qquad \text{(A17)}$$

Where,

$$\left|\psi\right| = \begin{vmatrix} H & -\lambda_{LA} \\ \left(\lambda_{KM}+\lambda_{KZ}\right) & \lambda_{KA} \end{vmatrix}$$

$$= H\cdot\lambda_{KA} + \lambda_{LA}\left(\lambda_{KM}+\lambda_{KZ}\right)$$

$$= \left\{h'(\cdot)Q\xi - \lambda_{LM} - \lambda_{LZ}\right\}\cdot\lambda_{KA} + \lambda_{LA}\left(\lambda_{KM}+\lambda_{KZ}\right)$$

$$= h'(\cdot)Q\xi\,\lambda_{KA} - \lambda_{KA}\left(\lambda_{LM}+\lambda_{LZ}\right) + \lambda_{LA}\left(\lambda_{KM}+\lambda_{KZ}\right)$$

Or, $$\left|\psi\right| = \lambda_{LA}\left(\lambda_{KM}+\lambda_{KZ}\right) - \lambda_{KA}\left[\left(\lambda_{LM}+\lambda_{LZ}\right) - h'(.)Q\xi\right]$$

$$= \lambda_{LA}\left(\lambda_{KM} + \lambda_{KZ}\right) - \theta \cdot \lambda_{KA}$$

$$= \theta \lambda_{LA}\left[\frac{\lambda_{KM} + \lambda_{KZ}}{\theta} - \frac{\lambda_{KA}}{\lambda_{LA}}\right]$$

$$= \theta\lambda_{LA}\left[\frac{\lambda_{KM} + \lambda_{KZ}}{\lambda_{LM} + \lambda_{LZ} - h' Q \xi} - \frac{\lambda_{KA}}{\lambda_{LA}}\right]$$

As sector A is labour intensive and sector M is capital intensive, it follows

$$\frac{\lambda_{KM} + \lambda_{KZ}}{\lambda_{LM} + \lambda_{LZ} - h' Q \xi} \rangle \frac{\lambda_{KA}}{\lambda_{LA}}$$

Therefore, $|\psi| \rangle 0$

Thus from (A16) and (A17), we get

$$\frac{\hat{X}_M}{\hat{t}} > 0 \text{ and } \frac{\hat{X}_A}{\hat{t}} < 0$$

As tariff rate declines, *M* sector also contracts leading to contraction of the *Z* sector. In effect, pollution in the economy declines. Again, as both *M* and *Z* sectors declines, *A* sector expands and if it is less polluting than Z sector then the overall environment in the country improves.

Appendix – B

Differentiating (5.1) we get

$$\frac{a_{LA} \cdot W}{P_A} \cdot \frac{dW}{W} + \frac{a_{KA} \cdot r}{P_A} \cdot \frac{dr}{r} = 0$$

or $$\theta_{LA} \cdot \hat{W} + \theta_{KA} \cdot \hat{r} = 0 \qquad \text{(B.1)}$$

In the same way from (5.3) and (5.2) we get

$$\theta_{LZ} \cdot \hat{W} + \theta_{KZ} \cdot \hat{r} = \hat{P}_Z \qquad \text{(B.2)}$$

and

$$\theta_{KM} \cdot \hat{r} + \theta_{ZM} \cdot \hat{P}_Z + \frac{V \cdot d\alpha}{X_M \cdot P_M} + \frac{\alpha}{P_M} \cdot \frac{dV}{dX_M} = 0 \tag{B.3}$$

Putting the value of $\hat{P}_Z$ of (B.2) in (B.3), it becomes

$$\theta_{ZM} \cdot \theta_{LZ} \cdot \hat{W} + \left(\theta_{KM} + \theta_{ZM} \cdot \theta_{KZ}\right)\hat{r} = -\left(S + T\right) \tag{B.4}$$

where, $\frac{V \cdot d\alpha}{X_M \cdot P_M} = S$ and $\frac{\alpha}{P_M} \cdot \frac{dV}{dX_M} = T$

Dividing (B.1) and (B.4) by $\hat{\alpha}$, we get

$$\theta_{LA} \cdot \frac{\hat{W}}{\hat{\alpha}} + \theta_{KA} \cdot \frac{\hat{r}}{\hat{\alpha}} = 0 \tag{B.5}$$

$$\left(\theta_{ZM} \cdot \theta_{LZ}\right)\frac{\hat{W}}{\hat{\alpha}} + \left(\theta_{KM} + \theta_{ZM} \cdot \theta_{KZ}\right)\frac{\hat{r}}{\hat{\alpha}} = -\frac{\left(S + T\right)}{\hat{\alpha}} \tag{B.6}$$

Following Acharyya and Kar (2014) and Caves, Frankel and Jones (2002), we can determine the comparative static results.

In matrix form (B.5) and (B.6) can be written as

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{bmatrix} \begin{bmatrix} \frac{\hat{W}}{\hat{\alpha}} \\ \frac{\hat{r}}{\hat{\alpha}} \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \end{bmatrix} \tag{B.7}$$

$a_{11} = \theta_{LA},\; a_{12} = \theta_{KA},\; a_{21} = \theta_{ZM} \cdot \theta_{LZ},\, a_{22} = \theta_{KM} + \theta_{ZM} \cdot \theta_{KZ},\, d_1 = 0, d_2 = \frac{S + T}{\hat{\alpha}}$

$|\Delta|$ is positive on the assumption that X_A is more labour intensive than X_Z and X_M is highly capital-intensive.

d_2 is assumed to be positive (plausible assumption) and $d_1 = 0$.

Using Cramer's rule, we get

$$\frac{\hat{W}}{\hat{\alpha}} = \frac{d_1 \cdot a_{22} + d_2 \cdot a_{12}}{|\Delta|} > 0 \tag{B.8}$$

$$\frac{\hat{r}}{\hat{\alpha}} = \frac{-a_{11} \cdot d_2}{|\Delta|} < 0 \tag{B.9}$$

Total differential of (5.4) gives

$$da_{KA} \cdot X_A + a_{KA} \cdot dX_A + da_{KM} \cdot X_M + a_{KM} \cdot dX_M + da_{KZ} \cdot X_Z + a_{KZ} \cdot dX_Z = dK$$

or, $$\hat{a}_{KA} \cdot \lambda_{KXA} + \lambda_{KXA} \cdot \hat{X}_A + \hat{a}_{KXM} \cdot \lambda_{KXM} + \lambda_{KXM} \cdot \hat{X}_M + \hat{a}_{KXZ} \cdot \lambda_{KXZ} + \lambda_{KXZ} \cdot \hat{X}_Z = \hat{K} \tag{B.10}$$

From (5.6), $\lambda_{ZXM} \cdot \hat{X}_M = \hat{X}_Z$ (B.11)

Putting the value of $\hat{X}_Z$ in (B.10), we get

$$\lambda_{KXA} \cdot \hat{X}_A + (\lambda_{KXM} + \lambda_{ZXM})\, \hat{X}_M = \hat{K} - \{\hat{a}_{KA} \cdot \lambda_{KXA} + \hat{a}_{KXM}\ \lambda_{KXM} + \hat{a}_{KXZ}\ \lambda_{KXZ}\} \tag{B.12}$$

In the same way from (5.5) we get

$$\lambda_{LXA} \cdot \hat{X}_A + (\lambda_{LXM} + \lambda_{ZXM})\, \hat{X}_M = -\{\hat{a}_{LA} \cdot \lambda_{LXA} + \hat{a}_{LXM} \cdot \lambda_{LXM} + \hat{a}_{LXZ} \cdot \lambda_{LXZ}\} \tag{B.13}$$

Dividing (B.12) and (B.13) by $\hat{\alpha}$ and writing in matrix form, we get

$$\begin{bmatrix} b_{11} & b_{12} \\ b_{12} & b_{22} \end{bmatrix} \begin{bmatrix} \dfrac{\hat{X}_A}{\hat{\alpha}} \\ \dfrac{\hat{X}_M}{\hat{\alpha}} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} \tag{B.14}$$

$$b_{11} = \lambda_{KXA},\ b_{12} = \lambda_{XM} + \lambda_{ZXM},$$

$$b_{21} = \lambda_{LXA},\ b_{22} = \lambda_{LXM} + \lambda_{ZXM}$$

$$C_1 = \frac{\hat{K}}{\hat{\alpha}} - \frac{\{\hat{a}_{KA} \cdot \lambda_{KXA} + \hat{a}_{KXM} \cdot \lambda_{KXM} + \hat{a}_{KXZ} \cdot \lambda_{KXZ}\}}{\hat{\alpha}}$$

$$C_2 = \frac{-\{\hat{a}_{LA} \cdot \lambda_{LXA} + \hat{a}_{LXM} \cdot \lambda_{LXM} + \hat{a}_{LXZ} \cdot \lambda_{LXZ}\}}{\hat{\alpha}}$$

$|\Delta| < 0$ on the assumption that X_M is highly capital intensive andX_A is highly labour intensive.

$C_1 < 0$ if $\frac{\hat{K}}{\hat{\alpha}}$ is sufficiently negative.

$\hat{\alpha}$ may be assumed to be positive. As tax rate increases, FDI sufficiently declines.
Now, using Cramer's rule, we get

$$\frac{\hat{X}_A}{\hat{\alpha}} = \frac{C_1 \cdot b_{22} - C_2 \cdot b_{12}}{|\Delta|} > 0 \qquad \text{(B.15)}$$

$$\frac{\hat{X}_M}{\hat{\alpha}} = \frac{b_{11} \cdot C_2 - b_{21} \cdot C_1}{|\Delta|} < 0 \qquad \text{(B.16)}$$

From (A-11), it is found that

$$\hat{X}_Z = \lambda_Z X_M \hat{X}_M < 0 \qquad \text{(B.17)}$$

Therefore as tax rate on the excess pollution per unit of X_M increases, rate of return to capital declines. In effect, FDI falls and X_M sector shrinks. This leads to shrinkage of the polluting sector X_Z.

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