Economics Bulletin

Volume 35, Issue 1

Role of labor intensity interaction in the relation between abatement expenditure and production

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Abstract

Polluting industries are characterized by different levels of abatement expenditure. In countries such as the US with relatively strict environmental standards, theoretical models and intuition predict that industries that are forced to undertake greater abatement expenditure would have lower production. However this negative relation between abatement expenditure and production has been elusive in existing empirical research. The current paper starts from a standard theoretical model of production in the short run and incorporates abatement expenditure into it. This leads to an interaction term, that has been absent in existing empirical literature, which reflects that the effect of increased abatement expenditure increases the shadow price of the inputs that are immobile across industries. For the same abatement expenditure, industries more intensive in mobile labor can absorb the abatement expenditure more easily resulting in a smaller reduction in production. The empirical analysis based on the specification stemming from the theoretical model finds the coefficient of the interaction of labor intensity and abatement expenditure to be significant. Also the pure Pollution Haven effect that predicts a negative effect of abatement expenditure on production emerges to be stronger with this specification compared to the more common formulation where the interaction term is absent. Alternate specifications find the results to be robust and significant.

Citation: Bidisha Lahiri, (2015) "Role of labor intensity interaction in the relation between abatement expenditure and production", *Economics Bulletin*, Volume 35, Issue 1, pages 407-413
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Submitted: April 10, 2014. **Published:** March 11, 2015.

1. Introduction:

In a country with relatively strong environmental regulation such as the US, theoretical models predict a smaller production of the more pollution intensive industries. However the empirical literature examining the effect of environmental regulation on production of polluting industries has typically not found a robust relationship (See Manderson and Kneller, 2012 for an overview of the enormous literature).

The current paper derives the testable relation between abatement costs and production starting from the specific factor theoretical model and uncovers that a crucial interaction term has been missing from the existing empirical literature[1]. This term interacts the labor intensity of each industry with its abatement expenditure and indicates that the effect of abatement activity will be smaller for a more labor intensive industry. This happens because abatement use drives up the shadow price of sector specific resources whose endowments are fixed in the short term, and the capital intensive industries are more affected by this.

Using a five year panel data for US, inclusion of this additional term reveals the relation between production and abatement to be more strongly negative compared to the more standard specifications without the interaction term used in the exiting literature. This stronger relation is found to be robust to alternate dependent variables and methods of estimation.

I start with the Jones (1975) mathematical framework of the specific factor model with N goods and N+1 inputs. I extend this model to incorporate use of inputs for abatement purposes in addition to standard production use.[2] Following popular approach (see Antweiler et al. 2001, Copeland and Taylor 2004 and Umanskaya and Barbier 2008) I assume that the prevailing environmental policy regime affects the fraction of inputs that each industry devotes to abatement activity.

2. Method:

In Jones (1975) specific factor model, there are N industries and N+1 inputs. The N inputs – presumably capital K_i in each sector, are exogenous in the short run and are industry specific while labor input L_i is mobile across industries. In the original model without abatement, changes in production are caused by two forces: a positive endowment effect caused by greater availability of sector specific capital and a negative substitution effect generated by a higher real-wage (or relative wage) causing production to become more capital intensive. The substitution effect works opposite to the positive endowment effect and is stronger for a more labor-intensive sector.

The consideration of abatement activity generates similar effects in addition to the above effects, but in the opposite direction. When abatement activity uses up sector specific capital less capital is effectively available for production resulting in a negative endowment effect. However lower effective availability of capital for production raises the shadow rental of capital, causing producers to move toward more labor-intensive production similar to the substitution effect, thus partially alleviating the negative effective-endowment effect. A higher shadow price of capital hurts the capital intensive sectors more and hence the production reducing effect of abatement is lower for a more labor-intensive sector.

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[1] Ederington et. al.(2005) explore an interaction component in a different context. They find that more polluting industries are less mobile internationally.

[2] See Lahiri (2010) for the long run theoretical implications of abatement expenditure when inputs are perfectly mobile across industries.

Let α_{Li} and α_{Ki} denote units of labor and sector specific capital respectively used for every unit of production in industry-i. Additionally firms in each industry need to set aside a certain fraction of inputs, say a_i-*1* (where $a_i \geq 1$) for abatement purposes making the total use of labor and sector specific capital $a_i{*}\alpha_{Li}$ and $a_i{*}\alpha_{Ki}$ respectively. Hence given the availability of sector specific capital K_i, production is defined by $Y_i = K_i / (a_i \alpha_{Ki})$

Equation (1) captures the effect on production ($\hat{Y}_i$)[3]caused by exogenous change in sector specific capital ($\hat{K}_i$), abatement use ($\hat{a}_i$) of sector specific capital and change in capital use caused by changes in input prices ($\hat{\alpha}_{Ki}$). The first two terms underlie the endowment effect, while the third term generates the substitution effect.

$$\hat{Y}_i = \hat{K}_i - (\hat{a}_i + \hat{\alpha}_{Ki}) \tag{1}$$

Assumption of perfect competition in the Jones model leads to the zero profit condition. Presence of abatement expenditure implies that the market price p_i covers the cost of production and abatement as shown in equation (2) with the percentage change form given by equation (3). W denotes the economy-wide price of sectorally mobile labor while R_{Ki} denotes the rental cost of sector i specific capital. θ_{Ki} and θ_{Li} represent, respectively, the distributive share of the specific factor (capital) and mobile factor (labor) in the i-th industry.

$$p_i = a_i(W\alpha_{Li} + R_{Ki}\alpha_{Ki}) \tag{2}$$

$$\hat{p}_i = \hat{a}_i + (\hat{W}\theta_{Li} + \hat{\alpha}_{Li}\theta_{Li} + \hat{R}_{Ki}\theta_{Ki} + \hat{\alpha}_{Ki}\theta_{Ki}) \tag{3}$$

$$\hat{\alpha}_{Li}\theta_{Li} + \hat{\alpha}_{Ki}\theta_{Ki} = 0 \tag{4}$$

Use of the cost minimizing condition provided in equation (4) eliminates some terms from equation (3) allowing it to be written in the form of (5).

$$\hat{W} - (\hat{p}_i - \hat{a}_i) = \theta_{Ki}(\hat{W} - \hat{R}_{Ki}) \tag{5}$$

The standard Jones model uses two elasticity concepts to solve for changes in input coefficients: the elasticity of substitution under cost minimization g_i defined as $(\hat{\alpha}_{Ki} - \hat{\alpha}_{Li})/(\hat{W} - \hat{R}_{Ki})$ and the elasticity of demand for labor γ_{Li} defined as $(\hat{\alpha}_{Ki} - \hat{\alpha}_{Li})/(\hat{W} - \hat{p}_i)$. These two elasticities are related as $g_i = \theta_{Ki}\gamma_{Li}$. Using of the definition of g_i and the cost minimizing condition given by (4), $\hat{\alpha}_{Ki}$ is solved to be $\hat{\alpha}_{Ki} = g_i\theta_{Li}(\hat{W} - \hat{R}_{Ki})$. Substituting g_i in terms of γ_{Li}, the solution for $\hat{\alpha}_{Ki}$ is expressed by equation (6).

$$\hat{\alpha}_{Ki} = (\theta_{Ki}\gamma_{Li})\theta_{Li}(\hat{W} - \hat{R}_{Ki}) \tag{6}$$

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[3] For any variable X, $\hat{X} = (dX)/X$

$(\hat{W} - \hat{R}_{Ki})$ in equation (6) is eliminated using equation (5) and inputting the resultant expression for $\hat{\alpha}_{Ki}$ back in (1) expresses the change in production of a sector as equation (7).

$$\hat{Y}_i = \hat{K}_i - \hat{a}_i + \theta_{Li}\gamma_{Li}\hat{a}_i - \theta_{Li}\gamma_{Li}(\hat{W} - \hat{p}_i) \qquad (7)$$

Hence equation (7) shows the decomposition of the substitution effect into a component driven by change in real wages and a component generated by abatement activity. $\hat{a}_i$ appears twice in equation (7). The first appearance of $\hat{a}_i$ without any interaction will be henceforth referred to as the "endowment" effect: it indicates that if abatement uses part of the sector specific resource, then an increase of environmental strictness reduces the output of the sector. The other term involving the abatement effect is $\hat{a}_i$ in equation (7) has labor intensity coefficient θ_{Li} attached to it and is henceforth referred to as the "interaction" term. This term indicates that the more an industry is dependent on sector specific inputs, the more it will be hurt by the increased opportunity cost of capital. Hence production in industries intensive in mobile labor will be less adversely affected for similar increases in abatement expenditure.

The assumption that the elasticity of labor demand is constant for every industry is required to express the theoretical expression (7) in the form of the estimating equation (8) in a panel data setup. The empirical estimation examines whether inclusion of these two abatement terms provides a better understanding of the Pollution Haven effect compared to the weak evidence found in the existing literature that uses a single abatement expenditure term to reflect an approximation of the overall direction.

$$\hat{Y}_{it} = \beta_0 + \underset{(+)}{\beta_1\hat{K}_{it}} + \underset{(-)}{\beta_2\hat{a}_{it}} + \underset{(+)}{\beta_3\theta_{Li}\hat{a}_{it}} + \beta_4\theta_{Li}(\hat{W}_{it} - \hat{p}_{it}) + m_i + d_t + \varepsilon_{it} \qquad (8)$$

The signs in parentheses are the expected signs of the coefficients. The empirically observed wage rate differs across industries and over time and is denoted by W_{it}. The error term ε_{it} reflects both approximation error, standard measurement error and error caused due to aggregation of the net production data $\hat{Y}_{it}$ to the SIC-4 level while m_i and d_t are the industry and time fixed-effects.

Expenditure to abate air pollution at SIC-4 level for years 1988-1993 comes from U.S. Census Bureau's Current Industrial Reports: Pollution Abatement Costs and Expenditures, MA-200 (PACE). I use the NBER productivity database for quantities and prices of outputs and inputs at the SIC-4 digit level.

I check for multicollinearity between the two terms involving the abatement expenditure. Also heteroscedasticity robust estimation is used to control for any industry specific components in the error term.

3. Results:

Since the form of the theoretical equation (6) was derived in percentages, log of the variables are considered for estimation purposes. A joint F-test supports use of fixed effects over a pooled OLS estimation while choice between the fixed and random effects estimation was made on the basis of the Hausman test.

The first column of Table 1 corresponds to estimations done without the interaction term in the manner of traditional Pollution Haven analyses. It finds that a one percent increase in abatement expenditure reduces production by 0.027 percent. The second column in the Table 1 presents the coefficients with the interaction term. A one percent increase in abatement expenditure is found to decrease production by about 0.048 percent which is almost double the effect estimated by the traditional Pollution haven specification. For a more labor intensive industry the abatement expenditure can be more easily passed on to labor. This is captured by the coefficient on the interaction term which shows that production lowering effect of a one percent increase in abatement costs is mitigated by 0.17 percent for an industry whose labor intensity variable is one unit higher. In checking for multicollinearity, I find the average VIF to be 2.92 and the maximum VIF to be 6.86 indicating that multicollinearity is not a problem while interpreting the coefficients.

The theoretical model predicts that a bigger capital stock should raise production by an equal amount while an increase in abatement expenditure should lower production by an equal amount. While the estimated coefficients are significant and have the right signs, jointly testing for unit values of these coefficients finds that these coefficients are different from one.

The relation between output and real wages is found to be procyclical indicating that instead of higher cost of labor leading to lower production, a higher production might be resulting in higher real wages. To control for endogeneity of wages I instrument for wages. With fixed effects included, my instrument must have both time and sector variation. Variation in homeownership rates are related with prevailing wages but are not expected to have direct effect on industrial production. However homeownership rates vary by region rather than by industry. To construct my instrument, for each sector I take a weighted average of state homeownership rate (h_{st}), where the weights are the sector's value of shipments in the various states (v_{is}) in 1987 which is at the beginning of the sample period. By using beginning-of-period weights, all variation over time comes from changes in state characteristics. Instruments have been created using this technique in Taylor and Levinson (2008).

$$I_{it}^{1} = \sum_{s=1}^{48} \frac{h_{st} v_{is,87}}{v_{i,87}}$$

The data for state-level homeownership for various years comes from U.S. Census Bureau's Current Population Survey/Housing Vacancy Survey.

Additionally, as noted in the existing literature, domestic abatement costs are endogenous to the model. Foreign relocation of dirty industries and economies of scale in abatement technology could result in higher observed pollution abatement expenditures in industries with lower observed levels of domestic production. In searching for suitable instruments, I note that U.S. environmental policy is set by states. Variation in state level per capita income affects the demand for a clean environment and consequently the state level environmental policy. This variation in state level regulation will affect pollution abatement cost. Similar to Taylor and Levinson (2008), I construct the instrument as the weighted average of the incomes per capita in the states. The weights are sector i's value added in each state in 1987.

$$I_{it}^{2} = \sum_{s=1}^{48} \frac{(pci)_{st} v_{is,87}}{v_{i,87}}$$

Table 1: Estimation Results

Dependent variable:	Log Production Fixed Effect		Log Production IV		Log Production Exclude Non-traded		Log Production First Difference		Log Net Export Fixed Effects	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
Log Capital	0.641**	0.643**	0.619**	0.618**	0.749**	0.744**	0.290**	0.293**	-0.154	-0.179
	(0.119)[a]	(0.118)	(0.067)	(0.067)	(0.085)	(0.084)	(0.098)	(0.098)	(0.350)	(0.349)
Log Abate. Expenditure	-0.027**	-0.048**	-0.022**	-0.048**	-0.023**	-0.060**	-0.013**	-0.031**	-0.059*	-0.221**
	(0.006)	(0.011)	(0.004)	(0.009)	(0.005)	(0.010)	(0.003)	(0.008)	(0.031)	(0.091)
†Interaction1		0.171*		0.207**		0.307**		0.149**		1.549**
		(0.098)		(0.063)		(0.076)		(0.059)		(0.774)
†Interaction2	4.779**	4.778**	5.059**	5.081**	-4.847**	-4.699**	-3.128**	-3.138**	19.021**	19.575**
	(1.359)	(1.364)	(0.844)	(0.839)	(1.034)	(1.030)	(1.399)	(1.406)	(5.697)	(5.721)
Constant	1.666	1.643	1.882**	1.868**		1.028	0.003	0.002	13.526**	13.520**
	(1.252)	(1.246)	(0.595)	(0.592)		(0.696)	(0.005)	(0.005)	(2.749)	(2.754)
††Joint- test for unit value	28934.5**	7030.5**	65353.4**	11899.8**	45217.4**	8290.2**	45320.5**	7962.6**	970.9**	92.5**
Number of Observations	2466	2466	2466	2466	2088	2088	2466	2466	2466	2466

Robust standard errors clustered around SIC-4 industries in parentheses
**p<0.05, *p<0.1

† Interaction1 is (Log abatement expenditure)X (labor intensity), Interaction2 is (Log real wage)X (labor intensity)
†† F-test for non-instrumented and Chi(2)-test for instrumented estimations for the joint test of Log Capital=1, Log Abate-Expenditure= -1

Year Dummies and Industry fixed-effects are included but not presented

Columns (iii) and (iv) of Table 1 report estimation results using instrumental variable for specifications without and with the interaction term respectively. The standard errors are heteroscedasticity robust and clustered around the industries. The traditional Pollution Haven specification without the interaction term predicts that a one percent increase in abatement expenditure is estimated to decrease production by an average effect of 0.022 percent. The corresponding coefficient from my proposed model with interaction term is 0.048 percent which is more than double than that of the traditional specification. The reduction of the production mitigating effect for a more labor intensive industry is found to be 0.21 percent.

Table 2.Test of Weak Instruments

	Cragg-Donald F Statistic (p-value)	
	(i)	(ii)
	911.52	903.91
	(0.00)	(0.00)

Critical values for the Stock and Yogo (2003) weak-instrument test (5-percent significance) are 16.38, 8.96, 6.66 and 5.53 for the 10-percent, 15-percent, 20-percent, and 25-percent sizes respectively.

NOTE: Columns (i) and (ii) correspond to estimations without and with the interaction term respectively.

I test for endogeneity of the included regressor using the Hausman test to compare the instrumental variables estimation against the uninstrumented estimation. The test statistic is found to be significant at the 5% level of significance implying that the use of instrumental variables is appropriate in my analysis. Also the the Stock-Yogo statistic (displayed in Table 2) is 903.91 which is much higher than the Stock-Yogo tabulated value for a 5% Wald test for a maximal size greater than 10%. Therefore I can safely conclude that my instrument is free from the weak instrument problem.

4. Robustness checks:

A variety of robustness tests confirm the estimation results. Since the Pollution Haven prediction is more relevant for traded commodities, similar pair of estimations is done by excluding the non-traded sectors (Columns (v) and (vi) of Table 1). Estimation based on the first-differenced variables suggests itself as another robustness check since the theoretical model was formulated in percentage differences (Columns (vii) and (viii) of Table 1). The last sensitivity test uses net export instead of production as the dependent variable[4] (Columns (ix) and (x) of Table 1) since this is a common dependent variable in the Pollution Haven literature. The estimated coefficients all have the expected signs and the interaction term is significant in all specifications. The outcome of the predicted negative relation between production and abatement cost under the current specification being much larger than the average effect of the Pollution

[4] If expenditure on different commodities in US remains approximately constant over the six year period, then net exports by US can proxy for production.

Haven specification[5] without the interaction term emerges to be robust in the different specifications.

5. Conclusion:

The theoretical model decomposes the effects of abatement expenditure into two distinct components: the endowment effect and the interaction effect. Use of sector specific inputs leaves effectively less for production causing the negative endowment effect on production. However, a lower availability of sector specific inputs increases the shadow price of capital and encourages firms to use more labor. This higher opportunity cost of capital hurts the capital intensive industries more. Thus the interaction term indicates that in the short run, equal expenditure on abatement activities by two different industries will result in a smaller percentage reduction in the overall production for the more labor intensive industry.

The theoretical prediction is tested using US abatement expenditure and production data. The coefficient on the labor-intensity interacted abatement expenditure term is found to be significant. The traditional negative relation between abatement costs and production as predicted by the Pollution Haven hypothesis is also found to be stronger and more significant in this specification compared to the usual specification that omits the interaction term. This indicates that the interaction term might be one missing piece to the puzzle of the elusive Pollution Haven effect.

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[5] The coefficient on the Pollution Haven coefficient without interaction is not significant at 5% level for the estimation that uses net-exports as the dependent variable.