Title
Regulation, Factor Rewards, and International Trade

Journal
Journal of Public Economics, 17

Author
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Publication Date
1982

Peer reviewed

Journal of Public Economics 17 (1982) 335–354. North-Holland Publishing Company

REGULATION, FACTOR REWARDS, AND INTERNATIONAL TRADE

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Received February 1980, revised version received July 1981

This paper develops an approach for incorporating regulation into the theory of production, distribution, and trade, using environmental regulation as an example. Four major conclusions emerge in the course of the analysis.

1. Production process regulation is equivalent in its effect on other cooperating factors to *neutral technical regress* (i.e. negative progress).
2. Specific unambiguous income redistribution consequences follow from such regulation. If commodity prices are held constant, the factor used relatively intensively in the *non-regulated* industry will gain *absolutely* in terms of both goods.
3. Unilateral or uncoordinated regulation destroys the link between uniform world commodity prices and identical factor proportions/factors prices across trading countries or regions.
4. If any factor of production is freely mobile across frontiers, the least differential regulation as between countries will entirely drive out the regulated industry from the more to the less regulated economy.

1. Introduction

Policy-makers and policy analysts, as well as the public at large, have recently taken a heightened interest in the real burden and the real incidence of economic regulation. Who actually benefits and who loses from regulatory policies? And are the gains worth the costs? This paper develops an approach for a study of such questions using as an example environmental regulation. The approach developed here applies more generally, however, to any regulation of production processes, and to many service delivery processes.

The stages in the analysis are as follows: first, we characterize regulation as a control over utilization of one factor of production in an N-factor production function; second, we derive a resulting N-1 factor production function, describe its properties, and characterize the profit-maximizing

* This research was sponsored by the Bureau of Business and Economic Research, University of Maryland, under a grant from the Environmental Protection Agency. Support from the National Science Foundation, Grant SES 80–14238, also is gratefully acknowledged. I also thank A.B. Atkinson and a referee for helpful criticisms.

behavior of competitive firms with and without regulation; third, the general implications of such behavior in a closed two-sector economy are presented; fourth, we apply these conclusions to the standard Heckscher–Ohlin model of international trade, in which factors are not mobile across frontiers; and lastly we allow for international factor mobility.

Four major conclusions will emerge in the course of the analysis.

1. Production process regulation is equivalent in its effect on other cooperating factors to *neutral technical regress* (i.e. negative progress).

2. Specific unambiguous income redistribution consequences follow from such regulation by an extension of the Rybczynski and the Stolper–Samuelson theorems. If commodity prices are held constant the factor used relatively intensively in the *non-regulated* industry will gain *absolutely* in terms of both goods. However, if demand for the regulated product is sufficiently inelastic the factor used intensively in the regulated industry may gain.

3. Unilateral or uncoordinated regulation destroys the link between uniform world commodity prices and identical factor proportions/factor prices across trading countries or regions.

4. If any factor of production is freely mobile across frontiers, the least unilateral or differential regulation as between countries will entirely drive out the regulated industry from the more to the less regulated economy.

2. Regulation and the production function

The most comprehensive simple explanation of a country's economy remains the two-sector model and of its trade with the world, the two country Heckscher–Ohlin model (H–O). Our first task therefore will be to find the minimum change to these models necessary to incorporate environmental or regulated factors in their domain. Once this is accomplished we can describe the autarchic equilibrium and then the trading equilibrium which arises in the absence of all environmental controls. Then we can explore the effects of regulatory control, in turn under autarchy and free trade.

The model to be used is identical to H–O in all respects but one, namely the introduction of a regulated factor of production such as the environment. Thus, we will assume fixed factor supplies of L^A, L^B, K^A, K^B in two countries, A and B. (International factor mobility will be allowed later.) Identical linear homogeneous technologies produce two goods, X and Y, in the two countries. Perfect competition and factor mobility within countries entails equal unit-factor rewards across industries. Transportation costs are ignored. Free trade and competition among countries generates common world-wide commodity prices.[1]

[1] All factor and commodity market distortions in the economy are ruled out as are all possible perverse effects identified in Johnson and Mieszkowski (1970), Jones (1971), Magee (1971), and Neary (1978).

We now wish to make the minimum alteration in the H–O setup to accommodate the environmental factor. From one perspective pollution is an unwanted by-product or output from offending industrial processes. From another logically equivalent point of view, however, the environment is a factor of production, which is 'used up' in industrial and agricultural processes. Being a productive factor the environment will be used to the point that its value marginal product equals its price, which in the absence of any regulation is nil. To reduce environmental deterioration the environmental factor must be conserved, either indirectly through post-pollution clean up processes, or directly in the industrial process by substituting other valuable factors such as land, labor, capital, for the environmental factor. From this perspective, the environmental factor can be incorporated in H–O by adding the environment, T, as one factor in *one* industry. We choose X^i as the polluting industry in country i, and Y^i as the non-polluting industry. Accordingly, to represent production we can write

$$X^i = F(L_x^i, K_x^i, T^i), \qquad i = \text{A,B}, \tag{1}$$

$$Y^i = H(L_y^i, K_y^i), \tag{2}$$

where L_j^i denotes i's employment of labor in industry j. T^i, which indicates i's 'useage' or depletion of the environment, is measured in tons (or some physical quantity of effluent output). Whether A's or B's effluent degrades a common global environment (as in the case of atmosphere ozone depletion) or a local environment (rivers, for example) is important for the efficiency properties and normative evaluation of regulation but not for a positive description. This distinction therefore will be considered below. In either country the factor endowments $(L_x^i + L_y^i = L^i)$ and $(K_x^i + K_y^i = K^i)$ are fixed. But there is no constraining physical limit on the amount of effluent which can be discharged. In principle T^i could exceed all bounds. However, we will assume that even in the absence of regulation, pollution reaches a finite equilibrium level because of the technology of the polluting industry.

We will assume therefore, as in the standard H–O case, that technologies in both industries are linear homogeneous, but particularly in the production of good X over some range of values, T, the effluent has positive marginal productivity, over another range T has zero productivity, and over a third range the marginal product of T is negative. Schematically if

$$F_T^i(L_x^i, K_x^i, T^i) \equiv \frac{\partial F(L_x, K_x, T^i)}{\partial T^i}.$$

Then, for some values of L, K, and T, $F_T^i \gtreqless 0$. Naturally, values of L, K, and T for which the marginal product of T is negative will be avoided under normal economic behavior.

In the absence of regulation the polluting industry's technology can be characterized by the two equations

$$X = F(L,K,T), \tag{3}$$

$$F_T(L,K,T) = \beta^0 = 0, \tag{4}$$

the first representing purely a technical relationship and the second a profit-maximizing decision when the price of polluting is zero. Eq. (4) gives an implicit relationship among the variables L, K, T, and the parameter β(0 in this case), which we write explicitly as

$$T = \phi(L,K,\beta^0). \tag{5}$$

By 'folding' eq. (5) into (3) the variable T can be eliminated to derive a mixed profit/production function

$$X = F[L,K,\phi(L,K,\beta^0)] = F^0[L,K]. \tag{6}$$

Eq. (6) shows the various combinations of labor and capital which produce designated amounts of X when T is 'automatically' adjusted for each L,K combination to bring $F_T = 0$. Fig. 1 is a pictorial representation of F^0. Everywhere on the surface $F_T = 0$, the marginal product of $T = 0$. The intersection of an L–K–T iso-product shell (not shown) with the surface $F_T = 0$ traces out one L–K isoquant which can be projected back into the L–K plane.

Note that F^0 is first degree homogeneous in L and K as was F in L, K and T.[2] The marginal product of L in F^0 now incorporates an optimal adjustment in T. Accordingly, $\partial F/\partial L \neq \partial F^0/\partial L$. Rather

$$F_L^0 = F_L + F_T \cdot \frac{\mathrm{d}T}{DL},$$

and similarly for the marginal product of capital.

[2] This is seen as follows. The function F^0 is first degree homogeneous provided

$$X = F_L^0 \cdot L + F_K^0 \cdot K$$
$$= \left[F_L + F_T \frac{\mathrm{d}T}{\mathrm{d}L}\right] L + \left[F_K + F^T \frac{\mathrm{d}T}{\mathrm{d}K}\right] K.$$

Since F is first degree homogeneous, the above will hold provided

$$T \cdot F_T = \left[\frac{\mathrm{d}T}{\mathrm{d}L} \cdot L + \frac{\mathrm{d}T}{\mathrm{d}K} \cdot K\right] F_T.$$

This equivalence obtains identically since F_T is homogeneous of degree zero. The terms $\mathrm{d}T/\mathrm{d}K$ come from the implicit relation in (4):

$$\frac{\mathrm{d}T}{\mathrm{d}L} = -F_{TL} \frac{-F_{TL}}{F_{TT}}; \qquad \frac{\mathrm{d}T}{\mathrm{d}K} = \frac{-F_{TK}}{F_{TT}}.$$

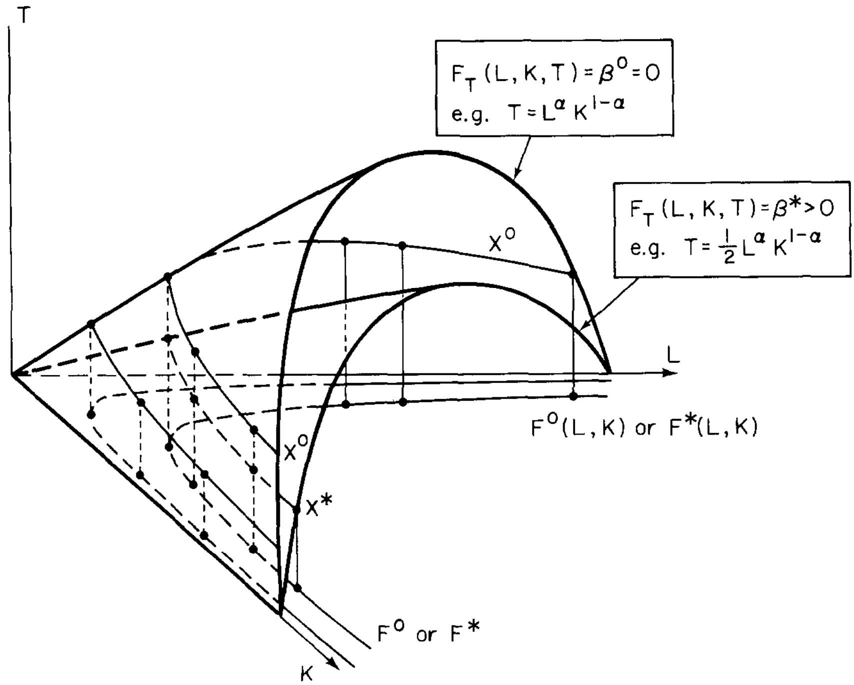

Fig. 1.

Before regulation, the polluting industry's technology in either country is characterized as above. Competition and factor mobility will drive factor allocations to a point such that

$$w = p_X F_L^0 = p_y H_L,$$

where w indicates wage rate and p_X,p_Y commodity prices. Since F^0 is linear homogeneous, factor payments to L and K will exhaust revenues.

Now suppose the government determines to regulate industry X. For the purpose of this analysis we will assume that the marginal social cost of pollution is a known *constant*. If the pollution in question created a pure global public bad, then the marginal social cost of pollution should be the same for all countries. If on the other hand the environmental damage was strictly local, then different countries might properly calculate different marginal social damages. In either case we wish to trace out the consequences of regulation in each country and in the world economic order. First, we will concentrate on a single country. Assume that the government wishes to economize on the environment; efficiency then requires that effluent be restricted up to the point that its value marginal productivity equal its marginal social cost. This restriction might be implemented by imposing the optimal pollution tax on metered effluents from industry X, with the revenues so collected disbursed to consumers. In this case regulation will have both income and substitution effects on the rewards to and productivity of the other factors. Alternatively, the optimal marginal productivity of environmental exploitation might be directly mandated. In this latter case no revenues are collected, the impact of regulation on factor productivities and rewards is limited to a substitution effect. For our analysis we assume regulation takes this latter form, of mandating a minimum allowable marginal productivity of pollution.

When an effective shadow price is placed on effluent output in one country this new cost or mandated conservation will cause industry X to conserve the environment so that its marginal product will have a positive value rather than zero. Whatever post-regulation combinations of K and L are chosen in industry X, a new level of polluting effluent corresponding to $F_T=\beta^*>0$ will be chosen, according to eq. (4), where β^* is a constant with some new higher value than before. That is to say, the imposition of a positive excise tax or an equivalent regulatory policy restricts the choice of other factor inputs to a new family of factor proportion rays, or to a new ruled surface, as in fig. 1. Accordingly, the new 'mixed' profit/production function is

$$X=F[L,K,\phi(L,K,\beta^*)]=F^*(L,K). \tag{7}$$

As before, F^* is linear homogeneous, and $F_L^*=F_L+F_T(\mathrm{d}T/\mathrm{d}L)$. F^* now indicates various combinations of L and K and their designated outputs of X when the environment is optimally exploited/conserved in response to government regulation of $F_T=\beta^*$. Fig. 1 shows the new surface $F_T=\beta^*$ as lying entirely below $F_T=0$.

3. The equivalence between regulation and negative neutral technical progress

Confining our attention to the function F^* and therefore to the representation of production in L–K space (that is the space of non-regulated factors of production), we can see that as the degree of regulation increases from, say, β^0 to β^*, the entire L–K isoquant map will shift outward, so that each L–K combination which produced, say, $X=X^0$ under condition β^0 will now produce some $X<X^0$ under condition β^*. It is not necessary that the new reduced output of X be the same for each of the original L–K combinations. For example, if both (L_1^0,K_1^0) and (L_2^0,K_2^0) produce X^0, the same combinations may yield different outputs under conditions β^*, i.e.

$$F^*(L_1,K_1)<F^0(L_1,K_1)=F^0(L_2,K_2)$$
$$>F^*(L_2,L_2): \qquad F^*(L_1,K_1)\neq F^*(L_2,K_2).$$

However, under certain conditions (which we will explore presently) a change in regulation, say an increase from β^0 to β^*, will shift L–K isoquants out *proportionately*. In this case the effect of regulation is simply to re-number each original isoquant, reducing each by the same proportion. Under these conditions therefore the L–K isoquant map would be geometrically stable, i.e. pictorially identical under different regulatory conditions; isoquants would not twist or wiggle and the relative marginal productivities of non-regulated factors of production as shown by the slopes of the isoquant maps would be invariant under diverse regulatory regimes. In these circumstances the effect of regulation is equivalent to *negative neutral technical progress*. This type of regulation is pictured in fig. 1. The unregulated isoquant X^0 is directly above X^* the regulated isoquant, so they both project the same curve in L–K space.

This type of neutrality will prove to be a 'knife-edge' case for further analysis of the effects of regulation on the autarchic general equilibrium and then on trading equilibrium. Therefore the specific conditions under which regulation is equivalent to neutral technical regress deserve further scrutiny.

4. General conditions under which regulation does not distort other factor productivities

Consider the regulation adjusted production function

$$X = F^* = F[L,K,\phi(L,K,\beta)] = G(L,K,\beta).$$

This adjusted production function has been obtained as a solution to the unconstrained $X = F(L,K,T)$ and the side condition $F_T(L,K,T) = \beta$, where β is a constant. Our concern is to examine the conditions under which $G(L,K,\beta)$ has the multiplicative form

$$G(L,K,\beta) = g(\beta)h(L,K),$$

since in this case a change in β simply would require re-numbering of L–K isoquants. The relative marginal products, therefore, of L and K would be independent of β, and independent of the degree of regulation, i.e. $G_L/G_K = h_L/h_K$. For G to have this multiplicative form requires

$$\frac{\partial\left[\frac{(\partial G/\partial\beta)}{G}\right]}{\partial L} = 0, \tag{8}$$

$$\frac{\partial\left[\frac{(\partial G/\partial\beta)}{G}\right]}{\partial K} = 0. \tag{9}$$

Differentiating (8) gives

$$G_L - \frac{G_{\beta L} \cdot G}{G_\beta} = 0, \tag{10}$$

and a symmetric condition from (9)

$$G_K - \frac{G_{\beta K} \cdot G}{G_\beta} = 0. \tag{11}$$

Application of implicit function theorems and substitution into (10) and (1) gives

$$\frac{F_K}{F_{TK}} + \frac{F \cdot F_{TTK}}{F_{TT}F_{TK}} = \frac{F_L}{F_{TL}} + \frac{F \cdot F_{TTL}}{F_{TT}F_{TL}} = \frac{F_T}{F_{TT}} + \frac{F \cdot F_{TTT}}{(F_{TT})^2} \tag{12}$$

as a condition on the unconstrained production function F, to be satisfied identically. Here F_{ijk} indicates a third cross partial deviative. Eq. (12) will be satisfied identically provided

$$F_K/F_{TK} = F_{KL}/F_{TL} = \gamma F/F_T, \tag{13}$$

where γ is the elasticity of complementarity. That (13) is a sufficient condition for (12) to be satisfied identically is shown as follows. Partial differentiation of (13) gives:

$$\begin{aligned} &\frac{\partial[F_L/F_{LT}]}{\partial T} = \frac{\partial[\gamma F/F_T]}{\partial T}, \\ &\frac{F_{LT}}{F_{LT}} - \frac{F_L \cdot F_{LTT}}{(F_{LT})^2} = \gamma\left(\frac{F_T}{F_T} - \frac{F \cdot F_{TT}}{(F_T)^2}\right), \\ &\frac{F_{TTL}}{F_{TT}} = F_{TL}\left[\frac{1-\gamma}{\gamma}\frac{F_T}{F_{TT} \cdot F} + \frac{1}{F_T}\right] = F_{TL}\sigma. \end{aligned} \tag{14}$$

Similarly

$$\frac{F_{TTK}}{F_{TT}} = F_{TK}\left[\frac{1-\gamma}{\gamma}\frac{F_T}{F_{TT} \cdot F} + \frac{1}{F_T}\right] = F_{TK}\sigma. \tag{15}$$

Since F is homogeneous of degree + 1, F_{TT} is homogeneous of degree −1:

$$\frac{F_{TTT}}{F_{TT}} = \frac{-1}{T} - \frac{K}{T}\frac{F_{TTK}}{F_{TT}} - \frac{1}{T}\frac{F_{TTL}}{F_{TT}} = \frac{-1}{T} - \frac{K}{T}\sigma F_{TK} - \frac{L}{T}\sigma F_{TL}. \tag{16}$$

However, F_T is homogeneous of degree zero so that

$$\frac{F_{TTT}}{F_{TT}} = \frac{-1}{T} + \sigma F_{TT} = \frac{-1}{T} + F_{TT}\left[\frac{1-\gamma}{\gamma}\frac{F_T}{F_{TT} \cdot F} + \frac{1}{F_T}\right]. \tag{17}$$

Substituting (13), (14), and (17) into (12) gives

$$\frac{\gamma F}{F_T}+F\cdot\sigma=\frac{F_T}{F_{TT}}-\frac{F}{TF_{TT}}+\sigma F,$$

or

$$\frac{\gamma F}{F_T}=\frac{TF_T-F}{TF_{TT}}=\frac{-LF_L-KF_K}{-LF_{LT}-KF_{KT}}.$$

From (13) this last expression is an identity. Note that this is a local condition on the production function F. At different locations on F, the value of γ may be different, provided it is a common value among factors. Eq. (12), therefore, describes a local CES property that partial elasticities of complementarity (and therefore also substitution elasticities) between the regulated factor and each other factor have a common value [See Sato and Koizumi (1973)]. This result will be referred to as the 'neutrality result'.

An alternative direct derivation of this result has been suggested to me by the referee. This derivation utilizes the dual approach as in Atkinson and Stiglitz (1980) or Dixit and Norman (1980). Here the cost minimizing function for X can be written as

$$C=c(r,w,\beta)\cdot X, \tag{18}$$

where c indicates average and marginal costs which are constant under constant returns to scale, r and w factor prices, and β is as defined above. If the unit cost function could be written as

$$c(r,w,\beta)=f(\beta)j(w,r)+\ell(\beta), \tag{19}$$

then the factor demand equations became

$$L=X\cdot f(\beta)\cdot\frac{\partial j}{\partial w},$$

$$K=X\cdot f(\beta)\cdot\frac{\partial j}{\partial r}. \tag{20}$$

Eq. (20) indicates that a cost-minimizing L–K factor input proportions depend only on the unit factor costs w–r, and not on the degree of regulation — which is the neutrality result. Assuming unit costs have the form of eq. (19), the partial elasticities of substitution become

$$\sigma_{KT}=\frac{c\cdot c_{r\beta}}{c_r c_\beta}=\frac{(f\cdot j+\ell)\dfrac{\partial f}{\partial\beta}\cdot\dfrac{\partial j}{\partial r}}{\left(f\cdot\dfrac{\partial j}{\partial r}\right)\left(\dfrac{\partial f}{\partial\beta}\cdot j+\dfrac{\partial\ell}{\partial\beta}\right)}. \tag{21}$$

Since the terms $\partial j/\partial r$ in the numerator and denominator of (21) cancel, $\sigma_{KT}=\sigma_{LT}$, which is the same sufficient condition as eq. (12).

5. Two examples of the equivalence between regulation and negative neutral technical progress

5.1 First example

Consider first a three-factor Cobb–Douglas production function:

$$F=L^{\frac{1}{2}}K^{\frac{1}{3}}T^{\frac{1}{6}}$$
$$F_L/F_T=\tfrac{3}{2}(K/L), \tag{22}$$
$$F_T=F/6T=\beta.$$

Here there is no natural limit on pollution in an unregulated situation; so we must impose one. Suppose therefore that with no regulation $\beta^0=1$. It follows from substitution that

$$F^0=(1/6)^{\frac{1}{5}}\cdot L^{\frac{3}{5}}K^{\frac{2}{5}},$$
$$F_L^0/F_K^0=\tfrac{3}{2}(K/L). \tag{23}$$

The derived, mixed profit/production function is linear homogeneous, and relative marginal productivities of L and K are identical as between F and F^0.

Now assume some regulation changes β to $\beta^*>1$. The result is

$$F^*=\left(\frac{1}{6\beta^*}\right)^{\frac{1}{5}}L^{\frac{3}{5}}K^{\frac{2}{5}}.$$

We observe that F^* is simply a reduced multiple of F^0. The higher the value of β^*, and the more conservation, the greater is the proportional reduction; but that same proportional reduction in output applies to all values of L and K. Similarly, the relative marginal products of the complementary factors L and K are not disturbed at all by regulation

$$\frac{F_L^*}{F_K^*}=\frac{F_L^0}{F_K^0}=\frac{F_L}{F_K}. \tag{24}$$

Therefore if we plot isoquants using L and K as factors, the effect of environmental regulation is simply to re-number those isoquants, reducing each number by the same proportion.

5.2 Second example

A problem with the Cobb–Douglas example is that pollution is not self-limiting in the absence of regulation. According to eqs. (3) and (4) in the production of X there will be some critical family of factor proportions separating production space into two regions, one where using the environment is productive and another where it is counter-productive. Along the crucial factor proportions ray or family of rays the marginal product of polluting is zero. No CES production function could represent such a technology since variable elasticity of substitution is essential to the reversal of factor productivity.

One variable elasticity production function which meets our requirement is

$$F = T^{1-\exp[1-K^{1-\alpha}L^{\alpha}/T]} L^{\alpha\exp[1-K^{1-\alpha}L^{\alpha}/T]} K^{(1-\alpha)\exp[1-K^{1-\alpha}L^{\alpha}/T]}; \qquad 0<\alpha<1. \tag{25}$$

This rather ungainly function is linear homogeneous. Consider first the exponents on T, L, and K, respectively, namely

$$1-e^{1-K^{1-\alpha}L^{\alpha}/T},$$
$$\alpha\, e^{1-K^{1-\alpha}L^{\alpha}/T},$$
$$(1-\alpha)\, e^{1-K^{1-\alpha}L^{\alpha}/T}.$$

These exponents add up to one, yet a proportional increase in all factors leaves each exponent unchanged. Next, consider the surface in T–L–K space defined by

$$K^{1-\alpha}L^{\alpha}/T=1. \tag{26}$$

This is a ruled surface, a family of proportion rays through the origin. Whenever eq. (26) is satisfied, the exponent on T in (25) is zero. Accordingly, along this ruled surface the marginal product of pollution is zero. (In fig. 1 this is the surface $F_T=0$.) Now consider other families of factor proportion rays different from (26). For each family of factor proportion rays defined by $K^{1-\alpha}L^{\alpha}/T=a<1$ the marginal product of pollution has a constant negative value, whereas for $K^{1-\alpha}L^{\alpha}/T=a>1$ the marginal product of pollution is positive, being a constant for each value of a. Another way of seeing this is to take logs of (25)

$$\log F=(1-e^{1-x})\log T+\alpha\, e^{1-x}\log L+(1-\alpha)\, e^{1-x}\log K,$$

where $x=K^{1-\alpha}L^{\alpha}/T$,

$$\frac{1}{F}\frac{\partial F}{\partial T}=\frac{(1-e^{1-x})}{T}+e^{1-x}\,[\alpha\log L+(1-\alpha)\log K\text{-}\log T]\left(\frac{\partial x}{\partial T}\right),$$

where $\partial x/\partial T<0$. If $x=1$, then the first term is zero and $T=K^{1-\alpha}L^{\alpha}$, so that the second term is also zero. If $x>1$, then the first term is positive and the second term is also (conversely $x<1$ implies that both are negative).

Before environmental regulation, competition and profit maximization will insure exploitation of the environment until the marginal product of pollution is zero. Setting $\partial F/\partial T=0$ in (25) and solving for T shows that a competitive profit-maximizing X-industry will choose a value of T corresponding to $K^{1-\alpha}L^{\alpha}$ whatever values of K and L happen to be chosen because they too maximize profits. Substitution of $T=K^{1-\alpha}L^{\alpha}$ into (25) reduces the production function to

$$F(L,K,T^0)=F^0(L,K)=L^{\alpha}K^{1-\alpha}; \qquad T^0=K^{1-\alpha}L^{\alpha}, \tag{27}$$

The marginal technical rate of substitution becomes

$$\frac{F_L}{F_K}\equiv\frac{F_L^0}{F_K^0}=\frac{\alpha}{1-\alpha}\cdot\frac{K}{L}. \tag{28}$$

By 'folding' the optimal $T=T^0$ into the original production function, one variable T is eliminated. Note again that F^0 is first degree homogeneous in L and K, as was F in L, K, and T; the marginal product of L in F^0 incorporates an optimal adjustment in T. Accordingly, $\partial F/\partial L\neq\partial F^0/\partial L$. Rather,

$$F_L^0=F_L+F_T\cdot\frac{\partial T^0}{\partial L}. \tag{29}$$

Now to take an example of regulatory control. Suppose pollution is constrained such that the new value of $a=2$. The production function adjusted for newly constrained environmental exploitation therefore becomes

$$F=T^{1-e^{-1}}L^{\alpha e^{-1}}K^{(1-\alpha)e^{-1}} \qquad \text{(Note that } e^{-1}\simeq 0.36). \tag{30}$$

The marginal product of polluting, F_T, is obtained by evaluating $\partial F/\partial T$ at $L^{\alpha}K^{1-\alpha}=aT$:

$$F_T=[a^{e^{1-a}}][1-e^{1-a}(1-a\,\mathrm{Ln}(a))]=\beta^*, \tag{31}$$

which makes a an implicit function of β^*;$a=\phi(\beta^*)$.

Now with production constrained by

$$T=\tfrac{1}{2}L^{\alpha}K^{1-\alpha} \tag{32}$$

we can substitute for T in the production function to give

$$\begin{aligned}(F^*|a=2)&=(\tfrac{1}{2})^{0.64}(L^{\alpha}K^{1-\alpha})^{0.64}K^{0.36\alpha}K^{0.36(1-\alpha)}\\&=(\tfrac{1}{2})^{0.64}L^{\alpha}K^{1-\alpha}.\end{aligned} \tag{33}$$

Again the ratio of marginal products is the same as when $a=1$:

$$\frac{F_L}{F_K}=\frac{F_L^0}{F_K^0}=\frac{F_L^*}{F_K^*}=\frac{\alpha}{1-\alpha}\frac{K}{L}.$$

More generally, eliminating T from the production function by use of the marginal productivity constraint yields

$$F^* = (\tfrac{1}{2})^{1-e^{1-\alpha}}[L^\alpha K^{1-\alpha}]^{1-e^{1-\alpha}}[L^\alpha K^{1-\alpha}]^{e^{1-\alpha}} \tag{34}$$

or

$$F^* = \Psi[\phi(\beta^*)]L^\alpha K^{1-\alpha}. \tag{35}$$

As before, the effect of change in $F_T = \beta^*$ is multiplicative on the output from any L–K combination. This example confirms the general result. Environmental regulation which constrains the allowable level of pollution to some given marginal product is equivalent to *negative neutral technological progress*, requiring a simple proportional re-numbering of L–K isoquants. This result is not an accident due to the particular production

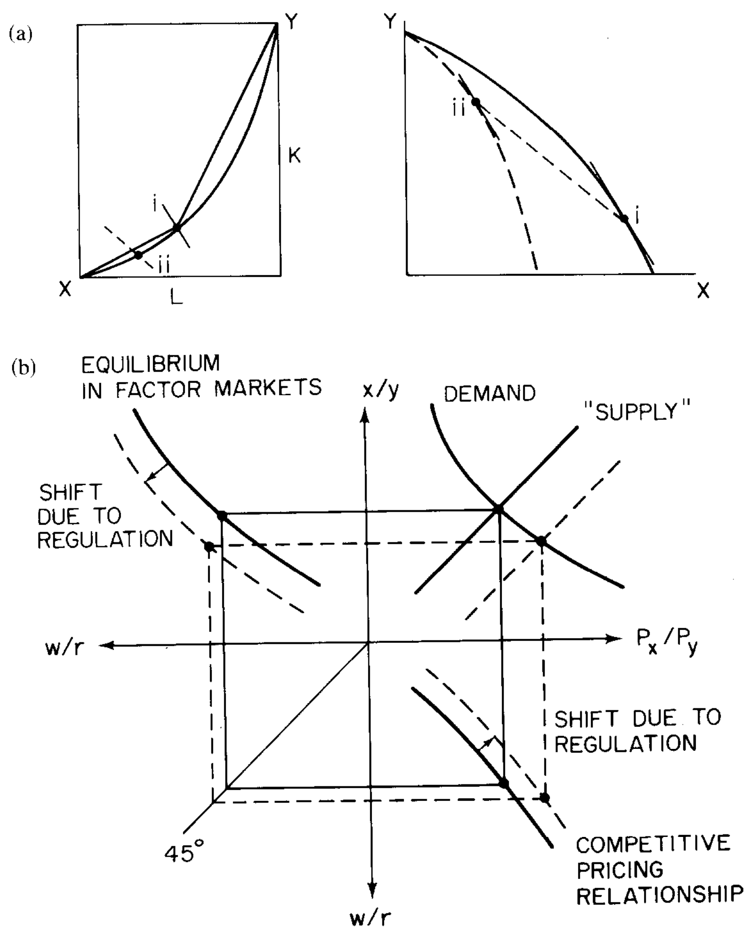

Fig. 2.

functions chosen for illustration. Rather, it is a general feature of all linear homogeneous production functions with equal pairwise elasticities of substitution.

6. Implications of regulation for a closed economy

The general equilibrium effects of factor input regulation are readily examined through the four-quadrant diagram employed by Atkinson and Stiglitz (1980, pp. 171–7). Fig. 2 shows the situation before regulation in unbroken lines. Fig. 2(a) shows the Edgeworth production box and the corresponding transformation curve, fig. 2(b) the four quadrant diagram. Now introduce regulation and re-number the isoquants in the Edgeworth box. Assuming technology in accord with eq. (13), the X-isoquants shift proportionally outward; or, equivalently, each X-isoquant only need be re-numbered, its value reduced by the same proportion as all others. Since the geometry of X- and Y-isoquants in the production box is unaffected by the introduction of a shadow price on T, the contract curve also is unaffected. The effect of regulation is shown in broken lines.

In view of the re-numbering of the X-isoquants there must be an inward shift in the production possibility curve due to regulation [fig. 2(a)]. It follows by Rybcinski's theorem that to maintain the same relative rewards, and the same allocation of factors between X and Y, the relative price of X must increase. Correspondingly, to maintain the same relative commodity prices the return to the factor used intensively in the regulated industry must diminish absolutely in terms of both goods, while the return to the factor used intensively in the unregulated pollution-free industry will increase *absolutely* in terms of both goods.[3] This effect is shown in fig. 2(a) by

[3] To see this, note in each country equilibrium before *and* after regulation requires

$$\frac{P_x}{P_y}=\frac{MP_L^Y}{MP_L^X}=\frac{MP_K^Y}{MP_K^X}=\text{constant}. \tag{1.m}$$

The price ratio P_x/P_y is constant because of the perfectly elastic demand assumption. Now the first-order effect of regulation is to reduce the marginal productivities of L and K in X since less cooperating factor T is available. Therefore both MP_L^Y/MP_L^X and MP_K^Y/MP_K^X are too high. To re-establish the equilibrium conditions given by (1.m), output of X will decline X being relatively labor-intensive. Therefore, MP_K^Y will *increase* since its $(L/K)_y$ ratio will rise. Therefore, MP_K^X must increase above its pre-regulation level to re-establish the equality MP_K^Y/MP_K^X = constant. Similarly, MP_L^Y must fall as Y becomes more labor-intensive. Accordingly, MP_L^X must fall still farther to re-establish the equilibrium MP_L^Y/MP_L^X = constant. It follows that capital benefits absolutely in terms of both goods X and Y, while labor suffers absolutely from the imposition of environmental controls. Evidently, if the demand elasticity for X is highly inelastic the capital/labor ratio in X must increase to compensate for production lost through environmental regulation. In this case regulation may even increase the equilibrium real wage to the factor used intensively in the regulated industry. Contrastingly, if X is relatively capital-intensive, while demand for X is perfectly elastic, labor/capital ratios will fall in both X and Y, real wages will rise, and real rents will fall.

movement from i to ii, two points of identical commodity-price ratios. With constant commodity prices, regulation causes production to shift from i to ii, which changes factor proportions as shown. The assumption of perfect demand elasticity of course implies that the entire 'burden' of regulation will fall not on consumers, but on factors of production. These effects will be attenuated with more of the burden of regulation falling on consumers the closer to zero the price-elasticity of demand for good X. A more general picture of the combined effects of factor income changes together with variable demand conditions is shown in fig. 2(b) by the downward shift in the N.W. quadrant and the rightward shift in the S.E. quadrant. This produces a new 'supply' curve, a higher wage/rent ratio, and a higher relative price of the regulated product. Depending on the relative strength of the effect of regulation on costs and on factor markers, however, wages/rent might decline.

7. The effect of regulation on trade and factor rewards: Immobile factors of production

With the advent of concern over the stress which modern industrial processes place on the environment, many countries have imposed standards or taxes on producers to control their destructive by-products. Very often these controlled products are important in international trade (steel, paper and lumber products, and agriculture come to mind). Characteristically, environmental restrictions may vary widely both in form and effect among different countries. This divergence might be due to differences in perception of a threat to the environment or to differences in the evaluation of such threats. Yet these different producers are linked together by common world commodity prices and world trade. The concern of this section therefore is to analyze the consequences of differential regulation on factor rewards between countries and therefore on comparative advantage, relative specialization, and the location of production between them.

The effect of regulation on trade, production, and factor rewards is unambiguous if the technologies for X^A and X^B are assumed to have the properties of eq. (12). We begin with the supposition that factors are immobile across countries.

Before regulation the standard Heckscher–Ohlin results apply. Identical technologies and free trade lead to identical capital/labor ratios in each industry wherever located, to common commodity prices, and to factor-price equalization; this is shown by points i in fig. 3. Under the H–O assumptions, country B produces the most of good X (the pollution-generating commodity) since B is relatively well-endowed in L, the factor which is used intensively in X (fig. 3).

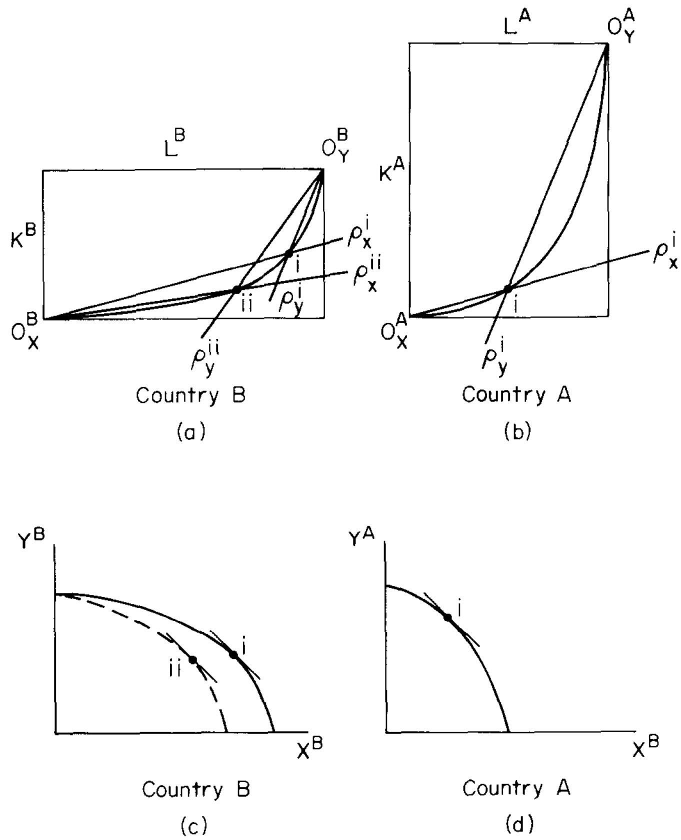

Fig. 3.

7.1. *Coordinated environmental control*

Suppose first that in both countries *the same* shadow price is levied on T in the production of X. The effect of a proper shadow price on T is to cause the X-producing manufacturers to conserve the environment, raising the value of its marginal product to the optimizing price. Therefore, β in eq. (6) rises. Provided both countries levy *the same tax* on pollution, the qualitative implications of the H–O model are unchanged. A new trade equilibrium will follow from the pollution tax, but the post-tax equilibrium will still feature equal factor proportions and equal factor prices as between countries. The effect of coordinated (equal) regulation on L and K factor incomes now depends on two parameters: the elasticity of demand for good X and the relative capital/labor intensity of X in comparison with Y.

7.2. Uncoordinated or unilateral regulation

Now consider the case of non-uniform, non-coordinated pollution taxes. As a paradigm of this situation suppose only one country (B) imposes a shadow price (or establishes equivalent controls). Then (returning to fig. 3), to maintain world prices requires production at point ii in country B and at point i in country A. At this configuration, however factor proportions and factor prices differ between countries. Moreover, there is no new world commodity price which can equalize factor proportions and therefore equalize factor prices between countries A and B. In other words, non-uniform regulation destroys factor-price equalization. No new interior allocation of factors can simultaneously achieve equal commodity prices and equal factor prices among nations. This is a stark conclusion. For a small country with no influence over world commodity prices regulation of production definitely injures some factor of production and unambiguously benefits others. For a large country its unilateral regulation will raise the world commodity price of the regulated product and elsewhere in the world the factor used intensively in the production of the regulated product will benefit unambiguously.

8. The effect of uncoordinated regulation when factors are mobile

We have just concluded that non-uniform regulation when factors are immobile will cause factor prices to diverge across countries. This difference in factor returns will provide labor and/or capital an incentive to migrate away from low reward areas to high reward areas. If we now relax the factor immobility assumption it is clear that differential regulation will cause labor or capital to move into or out of the regulated country. Multinational companies, for example, may easily transfer capital across borders, where non-uniform regulation provides systematic incentives to re-locate. Note that the direction of migration is not necessarily out of the country imposing regulation. Regulation may attract factors of production. If the factor that is hurt is mobile one should expect migration out of the regulated area. If, however, it is the factor which benefits that is mobile, one should expect migration of that factor into the regulating country. The direction of migration depends on relative factor proportions in the regulated industry. For example, in fig. 3 the effect of regulation is to raise the rent-to-wage ratio in country B, since the regulated industry is assumed to be relatively labor-intensive. Imagine, now, that capital is supplied perfectly elastically to country B; that is, suppose capital flows freely across borders in response to rent/profit differentials. Before regulation, capital just earned its required return (measured in terms of good Y as numeraire). Therefore capital will flow into country B and out of country A until this return is re-established.

To examine the process of factor migration, let us make a corollary 'knife-edge' assumption that world commodity-price ratios are constant. We can call on the Rybczynski theory of a one-to-one correspondence between commodity and factor prices when production is linearly homogeneous. Imagine that when capital flows into country B the manufacture of both goods X and Y continues. To produce at world commodity prices, factor proportions in country B must correspond to ρ_x^{ii} and ρ_y^{ii} in industries X and Y, respectively. To absorb any new capital at these proportions, country B must reduce its output of X and increase its output of Y. The intermediate effect of a capital inflow of ΔK_B^1 into country B is shown as point iii in fig. 4. Evidently, point iii is not a new equilibrium since factor-price ratios between countries A and B are still not equalized. *Capital will continue to flow into B until production of the regulated good reaches zero,* as shown in fig. 5. This requires ΔK_B^2 of new capital. Even at this level, however, factor prices have not been equalized since B specializes in Y at the proportions ρ_y^{ii}. Therefore, still more capital will migrate into B until factor proportions return to ρ_y^{i}. As fig. 5 illustrates, attainment of this new equilibrium requires a capital inflow of ΔK_B^3.

The inflow of capital necessary to equalize factor prices might have come from outside the two-country system. Assuming, however, that A and B constitute the whole world, the capital inflow ΔK_B^3 into B is matched by an equal outflow from A. Again, the Rybczynski theorem insures that proportions ρ_x^{i} and ρ_y^{i} will be maintained, which entails an expansion of X^A and a contraction of Y^A. The conclusion emerges that *the combined effect of unilateral regulation, and factor mobility at a given commodity price ratio is to drive the regulating country out of production of good X entirely.*

Suppose, next, that labor rather than capital was mobile and again that labor is the factor used relatively intensively in the regulated industry. Now, labor will migrate out of B into A; B's Edgeworth production box will close

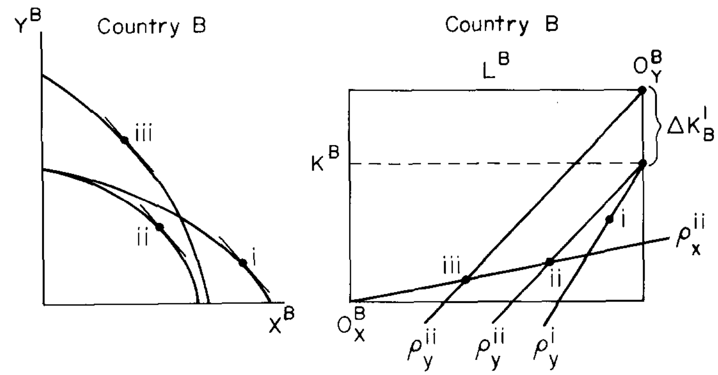

Fig. 4.

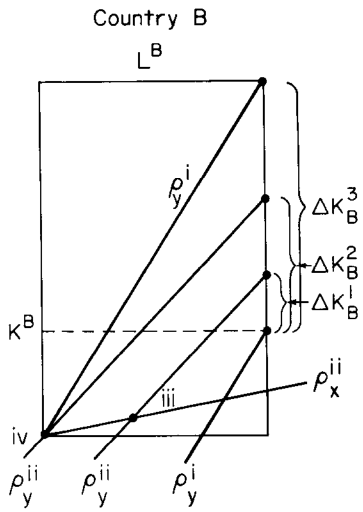

Fig. 5.

up horizontally along the L-axis and A's will expand. Again, a new world equilibrium is reached only when enough labor has migrated out of B to concentrate all B's remaining resources in the production of good Y at factor proportion ρ_y^i. The result emerges that *unilateral regulation, together with factor mobility of any one factor, will drive the regulating country out of producing the regulated good.*

One might think that this result depends on the assumption of fixed commodity prices, but in fact it does not. With less than infinite demand elasticities, unilateral regulation will cause the world price of X to rise and of Y to fall. Production of X will decrease and production of Y will increase. Factor allocations in both countries prior to migration will move along the contract curves toward the origins O_X^A and O_X^B, respectively. But factor proportions and therefore factor prices will diverge between the two countries even after these internal reallocations. Once migration is allowed into the picture, it will proceed until the non-regulating country produces all of good X and the regulating country specializes in the production of Y.

9. Normative and policy conclusions

The normative and/or policy implications of our analysis depend categorically first on whether the factor being regulated creates a local bad (generating disutility only to the consumers in country A or B) or an international public bad, and second, on whether factors of production are mobile or fixed.

If the pollution in question creates a common international global public bad and factors are mobile across national boundaries, then unilateral or uncoordinated regulation is inefficient and ultimately ineffective and useless (subject to all the caveats on realism in the H–O world). When unilateral regulation is undertaken in these circumstances, precisely tailored tax, trade, or commercial policies may compensate for the incentive industry would have to re-locate to control-free havens. The leverage which one country might have on world-wide pollution would then depend on its predominance in the traded goods and on supply and demand elasticities at home and abroad.

If, on the other hand, the environmental damage is local, then factor mobility is desirable from an efficiency standpoint. Differential regulations which reflect differences in local utility loss due to pollution will transfer polluting production processes to regions where the utility cost is low.

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