

Does tighter environmental policy lead to a comparative advantage in less polluting goods?

By Swee Chua

Oxera Consulting Ltd, Blue Boar Court, Alfred Street, Oxford OX1 4EH, UK
email: swee.chua@oxera.co.uk

A two-factor model is developed to analyze the effects of environmental policy on patterns of comparative advantage. A pollution tax affects goods' prices via: (1) the tax burdens on each good, which depend on their respective polluting tendencies; and (2) changes in factor returns due to increased abatement activity. The good intensive in the factor whose returns have risen will tend to face a price increase, *ceteris paribus*. The net outcome depends on both effects. A higher tax will not always raise (lower) the autarky price of the more (less) polluting good. Therefore a country with the higher (lower) tax does not always have a comparative advantage in the less (more) polluting good.

1. Introduction

The effect of trade liberalization on the environment is a widely debated issue today. The rapid rise in trade over the last decades has led to fears that increased productive specialization may have deleterious impacts on the environment, especially of developing countries where efforts towards environmental protection are, at best, weak.

The trade-environment debate has generated much research. Theoretical analyses have often employed a framework based on the two-factor Heckscher-Ohlin model, modified so that pollution is treated as an 'artificial' factor alongside another 'real' factor. Using such a framework, existing theory generally predicts that trade liberalization will see the South, *ceteris paribus*, having an apparent comparative advantage in the more polluting good and the North in the less polluting good (see Pethig, 1976, Copeland and Taylor, 1994; and Chichilnisky, 1994). This leads to the second prediction that trade liberalization will cause a rise in pollution levels in the former and a decline in the latter. Copeland and Taylor (1997) extend the analyses to allow for two real factors of production. They suggest that, if environmental policy differences are small, patterns of comparative advantage will still be dominated by differences in factor abundance. However, these patterns would be reversed if policy differences are sufficiently large.

In contrast to the theory, empirical findings are more ambiguous. Empirical analyses on the effects of environmental regulation on trade patterns yield mixed

results. Some studies suggest that tighter environmental policy in the North has had insignificant effects on trade patterns (see Kalt, 1988; Tobey, 1990; Grossman-Krueger, 1993; and Van Beers and van den Bergh, 1997). Others, however, suggest that exports of ‘dirty’ goods from the South have risen disproportionately as environmental policy tightened in the North (Robison, 1988; Low, 1992; and Low and Yeats, 1992). In addition, trade liberalization is estimated to only have small environmental impacts; any increases in pollution due to trade liberalization are small compared to the increases attributed to growth and structural changes that would have occurred even without trade liberalization (see Grossman and Krueger, 1993; Beghin *et al.* 1995; Lee and Roland-Holst, 1997; Strutt and Anderson, 1998; Madrid-Aris, 1998; and Beghin *et al.* 1998).

Theory and evidence seem to clash. The weak empirical support for the theory may be partly explained by poor data and the relatively low compliance costs of environmental policy.¹ However, it may also be due to fact that the theoretical predictions are built upon some restrictive assumptions. Specifically, the treatment of pollution as an artificial factor implicitly imposes strong restrictions on the underlying functional forms, for example, the more resources devoted to abatement, the lower the marginal gross pollution from production (see Rauscher, 1997, for a discussion).²

This paper develops a two-factor model using a different framework to analyze the effects of environmental policy on patterns of comparative advantage. It shows that the relationship between environmental policy and patterns of comparative advantage are not as unambiguous as suggested by previous models.

As set out in Section 2, the model is essentially a Heckscher-Ohlin model with three sectors, two producing final goods and the third undertaking abatement activity. Final goods’ production leads to pollution which can be reduced by

¹ Pollution abatement capital expenditure (PACE) in the US manufacturing sector was estimated to be about \$7.6 billion in total. This amounted to 0.24% of total value of production and 7.4% of new capital expenditures. While there are sectoral differences, PACE in general is a relatively low percentage of output and capital expenditure (US Bureau of Census, 1996).

² As an example of the restrictiveness of these assumptions, consider the abatement function assumed by Copeland and Taylor (1994). In order to obtain a Cobb-Douglas integrated production function with labour L and emissions E as inputs

$$y = L^\alpha E^{1-\alpha}$$

where y indicates output, they had to assume the following underlying functional forms for production, gross emissions, d_0 , and abatement A

$$\begin{aligned} y &= \lambda^\alpha L_y \\ d_0 &= \lambda^{1-\alpha} y = \lambda L_y \\ A &= d_0(y) - \left(\frac{\lambda^{\alpha-1} d_0(y)}{((d_0(y)/\lambda) + L_a)^{1-\alpha}} \right)^{1/\alpha} \end{aligned}$$

where L_y and L_a indicate labour employed in the production and abatement respectively. As can be seen, the specification of the abatement function is highly specific.

employing resources in abatement activity. In contrast with previous models, the role of abatement as an activity is emphasised; pollution is not treated as an input. The emphasis is on positive analysis, hence an exogenously-set environmental policy in the form of a pollution tax is assumed throughout. This model is similar to that used by Corden and Neary (1982) in their analysis of the ‘Dutch disease’.³ The effect of employing resources in abatement activity is also similar to the effect of directly unproductive profit-seeking activities modelled by Bhagwati (1982), in that both reduce the resources available for the production of consumable goods.

Section 3 analyses the effects of a higher pollution tax on relative autarky goods prices. This is used to infer the effect of policy on patterns of comparative advantage. Specifically, it is found that tighter environmental regulation does not always increase the relative autarky price of the more polluting good. Consequently, a tighter environmental policy in the North does not necessarily lead to the South (North) having a comparative advantage in the more (less) polluting good. This is because a higher pollution tax affects relative goods prices in two ways. First, the good with higher gross emissions will incur a higher burden from the tax. All else equal, its relative price rise will tend to rise. Second, the expansion of abatement activity will increase the returns to the factor used more intensively in the abatement sector. This will have a corresponding effect on the relative prices of final goods, depending on their factor-intensities. The net outcome on final goods prices will depend on both these effects. Section 4 concludes.

Of existing trade-environment models, that by Antweiler *et al.* (2001) comes closest in structure to the model presented in this paper in that they apply a separate abatement sector and do not treat pollution as an input. Nonetheless, they still find that countries with stricter pollution policy will have a comparative advantage in clean goods. It turns out that their model is a special case of the model presented here. This is discussed in Section 3.3.

2. The autarky solution

The economy is endowed with fixed supplies of two factors, capital K and labour L which are perfectly mobile between sectors. There are two final goods sectors and one abatement services sector. Subscripts $j = 1, 2, 3$ refer to final goods 1, 2 and the abatement sectors respectively. Full employment conditions dictate that

$$K = K_1 + K_2 + K_3 \quad (1)$$

$$L = L_1 + L_2 + L_3 \quad (2)$$

where L_j and K_j refer to allocations of labour and capital respectively to sector $j = 1, 2, 3$. Each sector is perfectly competitive and produces homogenous output.⁴

³The effect of an exogenous rise in the pollution tax is similar to the effect of a resource boom in Corden and Neary (1982). In this model, however, there is the added feature of differences in the polluting tendencies across goods in addition to differences in factor-intensities.

⁴The assumption of perfectly competitive market underlies the results of the model.

Therefore, all firms in each sector can be represented by one representative firm. Production in each sector is of Cobb-Douglas form

$$y_1 = L_1^\alpha K_1^{1-\alpha} \quad (3)$$

$$y_2 = L_2^\beta K_2^{1-\beta} \quad (4)$$

$$A = L_3^\gamma K_3^{1-\gamma} \quad (5)$$

where y_j denotes output of good $j = 1, 2$ and A is the level of abatement.

Each unit of final good j produced leads to λ_j units of gross emissions. However, some of this pollution can be abated by purchasing abatement services from the abatement sector.⁵ The output A of the abatement sector is measured in terms of the amount of emissions reduced. Final goods' producers then face a tax τ on each unit of net emissions E_j released to the atmosphere. The tax τ is exogenously set. It is assumed that it is set high enough so that some resources are allocated to abatement, but also that it is not set so high that all emissions will be abated. In other words, the case of an interior solution with non-zero amounts of resources allocated to both final goods and abatement sectors will be analyzed. For simplicity, abatement activity itself is assumed to be non-polluting. Using Good 1 as the numeraire, let p and p_A denote the relative prices of good 2 and abatement respectively. Therefore, profits π_j of each sector are as below

$$\pi_1 = y_1 - \tau(\lambda_1 y_1 - A_1) - wL_1 - rK_1 - p_A A_1 \quad (6)$$

$$\pi_2 = p y_2 - \tau(\lambda_2 y_2 - A_2) - wL_2 - rK_2 - p_A A_2 \quad (7)$$

$$\pi_3 = p_A A - wL_3 - rK_3 \quad (8)$$

It can be seen from (6) and (7) that the equilibrium value of p_A equals τ . This makes intuitive sense—since each unit of emissions released incurs a charge τ , the final goods' producers will be willing to pay up to τ for each unit of emissions abated by the abatement sector.

Substituting $p_A = \tau$ into (6), (7) and (8), the expressions for profits of the final goods and abatement sectors can be reduced to

$$\pi_1 = y_1(1 - \tau\lambda_1) - wL_1 - rK_1 \quad (9)$$

$$\pi_2 = y_2(p - \tau\lambda_2) - wL_2 - rK_2 \quad (10)$$

$$\pi_3 = \tau A - wL_3 - rK_3 \quad (11)$$

Substituting in the Cobb-Douglas functions of (3) to (5) into (9) to (11) and differentiating, we obtain the following first order conditions

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⁵ Having only one abatement sector common to both final goods' sectors implies the assumption that identical abatement technology can be applied to both final goods' sectors. This assumption is made for simplicity. Allowing for different abatement technologies across final goods' sectors increases the algebraic complexity without adding more to the results. Furthermore, this analysis assumes that abatement services is provided by a separate sector, external to the final goods sector. However, it would make no difference theoretically if abatement activity was assumed to be undertaken internally by the final goods producers themselves.

$$\left(\frac{K_1}{L_1}\right)^{1-\alpha} \alpha(1-\tau\lambda_1) = w \quad (12)$$

$$\left(\frac{K_2}{L_2}\right)^{1-\beta} \beta(p-\tau\lambda_2) = w \quad (13)$$

$$\left(\frac{K_3}{L_3}\right)^{1-\gamma} \gamma\tau = w \quad (14)$$

$$\left(\frac{K_1}{L_1}\right)^{-\alpha} (1-\alpha)(1-\tau\lambda_1) = r \quad (15)$$

$$\left(\frac{K_2}{L_2}\right)^{-\beta} (1-\beta)(p-\tau\lambda_2) = r \quad (16)$$

$$\left(\frac{K_3}{L_3}\right)^{-\gamma} (1-\gamma)\tau = r \quad (17)$$

where w and r denote the wage rate of labour and returns to capital respectively. From (12) to (17), we get an expression for relative factor returns, $\varpi = w/r$

$$\frac{\alpha K_1}{(1-\alpha)L_1} = \frac{\beta K_2}{(1-\beta)L_2} = \frac{\gamma K_3}{(1-\gamma)L_3} = \varpi \quad (18)$$

By appropriate substitution and rearrangement (see the Appendix for the derivation), the following expressions for ϖ and p can be obtained⁶

$$\varpi = \Delta_1 \left(\frac{\tau}{(1-\tau\lambda_1)} \right)^{1/(\gamma-\alpha)} \quad (19)$$

$$p = \Delta_2 \tau^{(\beta-\alpha)/(\gamma-\alpha)} (1-\tau\lambda_1)^{(\gamma-\beta)/(\gamma-\alpha)} + \tau\lambda_2 \quad (20)$$

where

$$\Delta_1 = \left(\frac{\gamma^\gamma (1-\gamma)^{1-\gamma}}{\alpha^\alpha (1-\alpha)^{1-\alpha}} \right)^{1/(\gamma-\alpha)} > 0$$

$$\Delta_2 = \left(\left(\frac{1-\gamma}{1-\alpha} \right)^{1-\gamma} \left(\frac{\gamma}{\alpha} \right)^\gamma \right)^{(\beta-\alpha)/(\gamma-\alpha)} \left(\frac{1-\alpha}{1-\beta} \right)^{1-\beta} \left(\frac{\alpha}{\beta} \right)^\beta > 0$$

⁶These derivations rely on the assumption of perfectly competitive markets. In addition, note that with pollution tax τ exogenously set and good 1 used as the numeraire, p must be as shown above if the output of each sector is to be strictly positive. Demand conditions and resource endowments do not enter in the expression for p ; they only affect the allocation of resources in each sector.

An alternative expression for p can also be obtained and is as follows

$$p = \Delta_3 \varpi^{\beta-\alpha} (1-\tau\lambda_1) + \tau\lambda_2$$

where

$$\Delta_3 = \left(\frac{\alpha}{1-\alpha} \right)^{\beta-\alpha} \left(\frac{1-\alpha}{1-\beta} \right)^{1-\beta} \left(\frac{\alpha}{\beta} \right)^\beta > 0$$

Finally, consumer utility U is assumed to be weakly separable in consumption goods and emissions, $U = (f(x_1, x_2)) \cdot g(\bar{E})$ where x_j denotes consumption of goods $j = 1, 2$ and \bar{E} is sum of net emissions from production. \bar{E} is treated as exogenous by the consumer. $f(x_1, x_2)$ is a homothetic function and $g(\bar{E})$ is decreasing in \bar{E} . An example of such a utility function is

$$U = x_1^\theta x_2^{1-\theta} \bar{E}^{-\nu} \quad (21)$$

where $0 < \theta < 1$ and $\nu > 0$. The representative consumer is assumed to maximize (21) subject to the budget constraint⁷

$$x_1 + px_2 = wL + rK + \tau(\lambda_1 y_1 + \lambda_2 y_2 - A)$$

which leads to the following demand ratio

$$\frac{x_1}{x_2} = \frac{\theta p}{1 - \theta} \quad (22)$$

3. Effect of a tax increase on relative goods' prices

The effect of a pollution tax on p can be derived by differentiating (20) with respect to τ , which gives

$$\frac{\partial p}{\partial \tau} = \Delta_2 \tau^{(\beta-\gamma)/(\gamma-\alpha)} (1 - \tau \lambda_1)^{(\alpha-\beta)/(\gamma-\alpha)} \left(\frac{\beta - \alpha}{\gamma - \alpha} - \tau \lambda_1 \right) + \lambda_2 \quad (23)$$

Rearranging (23), it can be shown that $\partial p / \partial \tau \lesseqgtr 0$ depending on whether

$$\lambda_2 \lesseqgtr \Delta_2 \tau^{(\beta-\gamma)/(\gamma-\alpha)} (1 - \tau \lambda_1)^{(\alpha-\beta)/(\gamma-\alpha)} \left(\tau \lambda_1 - \frac{\beta - \alpha}{\gamma - \alpha} \right) \quad (24)$$

The sign of $\partial p / \partial \tau$ is therefore, in general, ambiguous. Even if good 2 is more polluting than good 1 so that $\lambda_2 > \lambda_1$, p will not always rise with a higher tax. This point can be illustrated by the example where $\gamma = \beta$. This reduces Δ_2 to unity and (23) becomes

$$\frac{\partial p}{\partial \tau} = 1 + \lambda_2 > 0 \quad (25)$$

In other words, $\partial p / \partial \tau > 0$ when $\gamma = \beta$ regardless of whether $\lambda_1 \lesseqgtr \lambda_2$. This contrasts with results from previous models that predict a rise in the relative price of the more polluting good when the environmental tax is increased.

The ambiguity arises because tax τ causes two effects. First, it changes the relative burden of the tax between the two goods, depending on their relative pollution tendencies, λ_1 and λ_2 . Second, due to the expansion of the abatement sector, it changes relative factor returns. This affects the final goods prices, depending on their factor-intensities. Each effect is discussed in the following.

⁷Note that the revenue from pollution taxation is redistributed back to the consumer.

3.1 Channel 1: relative pollution tendencies of final goods

Effectively, each unit of good 1 faces a tax of $\tau\lambda_1$ while a corresponding unit of good 2 faces a tax of $\tau\lambda_2$. As in any standard analysis of taxation, a tax would increase the price of the good with the higher tax burden. Therefore, as long as $\lambda_1 \neq \lambda_2$ the tax would change the relative prices of the goods. If, for example, good 2 has a higher pollution coefficient, $\lambda_2 > \lambda_1$, this effect would tend to lead to a push p upwards.⁸

3.2 Channel 2: effect via changes in factor returns

The second effect of the pollution tax τ on goods prices is via the changes in factor prices ϖ . This effect can be seen by differentiating (25) with respect to τ . Rearrangement gives

$$\frac{\partial \varpi}{\partial \tau} = \frac{\Delta_1}{\gamma - \alpha} \left(\frac{\tau^{1-(\gamma-\alpha)}}{(1 - \tau\lambda_1)^{1+\gamma-\alpha}} \right)^{1/(\gamma-\alpha)} \quad (26)$$

(26) shows that the effect of the tax on factor returns depends on γ and α , i.e. $\partial \varpi / \partial \tau \geq 0$ if $\gamma \geq \alpha$, i.e. depending on whether abatement is relatively labour- or capital-intensive.

This effect can be explained by the Stolper-Samuelson theorem. The generalized Stolper-Samuelson theorem states that ‘the proportional change in the price of any produced commodity is a weighted average of the proportional changes in the two factor rewards ... any change in the relative prices of produced goods necessarily raises one factor reward in terms of all (still) produced goods and lowers the other factor reward in terms of all (still) produced goods, and the identification of the respective factor can be deduced from the relative factor intensities of any pair of produced goods whose relative price changes’ (Ethier, 1984).

The application of the Stolper-Samuelson theorem to this model is straightforward. An increase in τ is an increase in the price of abatement relative to the price of good 1, since good 1 is taken to be the numeraire. Hence, the effect on relative factor returns can be deduced from relative factor-intensities of producing good 1 and abatement. If abatement is relatively capital-intensive, a higher tax would lower ϖ and conversely if abatement was labour-intensive.

How does this impact on final goods’ price? Consider the case that ϖ falls with a higher τ . This means that, of the two final goods, the one that is capital-intensive

⁸This can be seen by differentiating (20) with respect to λ_1 and λ_2 in turn to obtain

$$\begin{aligned} \frac{\partial p}{\partial \lambda_1} &= -\Delta_3 \varpi^{\beta-\alpha} \tau < 0 \\ \frac{\partial p}{\partial \lambda_2} &= \tau > 0 \end{aligned}$$

For any give ratio of factor price ϖ and tax τ , we can say that the higher is λ_1 , the lower the relative price of good 2. Conversely, the higher is λ_2 , the higher the relative price of good 2.

will face higher costs due to lower ϖ and will, all else equal, see a price rise relative to the other good.

In other words, the expansion of abatement activity due to a rise in the pollution tax gives rise to a shift of resources away from final goods production. This shift depends on the factor-intensity of abatement relative to the final goods. Let \tilde{K} and \tilde{L} refer to the capital and labour available for final goods production, net of those in abatement, i.e. $\tilde{K} = \bar{K} - K_3$ and $\tilde{L} = \bar{L} - L_3$. An expansion of abatement activity reduces \tilde{K} and \tilde{L} . This effect is similar to that of directly unproductive profit-seeking (DUPS) activities, modeled by Bhagwati (1982), which reduce the resources available for the productive sectors.⁹ If abatement is capital-intensive relative to the numeraire good, then a higher pollution tax and the consequent expansion of the abatement sector would reduce the \tilde{K}/\tilde{L} ratio and ϖ . As far as the final goods industry is concerned, this is equivalent to a change in factor abundance. In a closed economy, the less abundant is capital, the higher the price of capital and the higher the price of the capital-intensive good. A reduction in the abundance of capital in this case would therefore raise the price of the final good which is relatively capital-intensive.

3.3 Summary: effect of environmental policy on patterns of comparative advantage

In sum, a higher τ affects final goods' prices via two channels. The first channel depends on the relative polluting tendencies across goods. The prices of the more polluting good will tend to rise with the imposition of a tax, *ceteris paribus*. The second channel depends on changes in factor returns and relative factor-intensities across goods. The good which is intensive in the factor whose returns have risen due to the tax will tend to face a price increase, *ceteris paribus*. The net effect of an increase in τ on p therefore depends on the direction and magnitude of both these effects. The effect of environmental policy on relative autarky goods prices is therefore, in general, ambiguous. There is no simple correlation between the changes in relative goods prices and rankings of their pollution tendencies.

The results above have implications on the predictions of the effect of tighter environmental policy on patterns of comparative advantage. Assume two countries that have identical factor endowments, preferences and technology. This assumption allows us to abstract from other sources of comparative advantage and focus on the interactions between environmental policy and trade. The home country has a pollution tax $\tau > 0$, while the other country does not. Since the pollution tax is the only difference across countries, the pattern of comparative advantage depends on how the tax affects autarky prices in the home country. If $\partial p/\partial \tau > 0$, then the home country would have a comparative advantage in and export good 1.

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⁹ While Bhagwati (1982) models DUP activities as a parallel inward shift of the production possibility frontier (PPF), the expansion of abatement activities in this model leads to a 'biased' inward shift of the PPF, depending on the factor-intensity of abatement.

Conversely, if $\partial p/\partial\tau < 0$, the home country would have a comparative advantage in good 2. Since the autarky price of the more polluting good does not always rise with a higher pollution tax, it is not always the case that the country with the tighter environmental policy (the North) will necessarily have a comparative advantage in the less polluting good.

As mentioned before, the model by Antweiler *et al.* (2001) is structurally similar to this model. In particular, they assume two final goods sectors (1 and 2) and one abatement sector. Production of good 2 generates pollution while the other does not. Producers have access to an abatement technology that uses only good 2 as an input. Their model is a special case of the model presented. Since $\lambda_2 > \lambda_1 = 0$, the tax burden is larger on good 2 than good 1. This tends to increase p . Further, since abatement technology uses only good 2 as an input, the expansion of abatement activity as a result of a higher τ leads to a relative scarcity of factors used intensively in the production of good 2. Consequently, ϖ is altered in a way that tends to increase p . In other words, both channels 1 and 2 described above work in the same direction to increase p . It is therefore unsurprising that Antweiler *et al.* (2001) find that the countries with stricter pollution policy will have a comparative advantage in the clean good (in this case, good 1).

4. Conclusion

Existing theory suggests that, with trade liberalization, countries with tighter environmental policy would have a comparative advantage in the less polluting good. However, this model shows that a higher pollution tax does not always lead to a rise in the relative autarky price of the more polluting good. Consequently, the country with the higher tax does not always have a comparative advantage in the less polluting good.

Acknowledgements

I am grateful to Simon Cowan, Will Cavendish, Dennis Anderson and two anonymous referees for their comments. All remaining errors are my own.

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Appendix

1. Derivations for ϖ and p

To solve for ϖ in terms of τ , we first equate (12) to (14). Using (18) and rearranging gives

$$\left(\frac{K_1}{L_1}\right) = \left[\left(\frac{\alpha(1-\gamma)}{\gamma(1-\alpha)}\right)^{1-\gamma} \frac{\gamma\tau}{\alpha(1-\tau\lambda_1)} \right]^{1/(\gamma-\alpha)} \quad (27)$$

Substituting (27) into (18) and rearranging, we get

$$\varpi = \Delta_1 \left(\frac{\tau}{1-\tau\lambda_1}\right)^{1/(\gamma-\alpha)} \quad (28)$$

where

$$\Delta_1 = \left(\frac{\gamma^\gamma(1-\gamma)^{1-\gamma}}{\alpha^\alpha(1-\alpha)^{1-\alpha}}\right)^{1/(\gamma-\alpha)} > 0$$

Equating (12) to (13), using (18) and rearranging gives:

$$\left(\frac{K_1}{L_1}\right) = \left(\left(\frac{\alpha(1-\beta)}{\beta(1-\alpha)}\right)^{1-\beta} \frac{\beta(p-\tau\lambda_2)}{\alpha(1-\tau\lambda_1)}\right)^{1/(\beta-\alpha)} \quad (29)$$

Equating (29) and (27) and rearranging, it can be shown that

$$p = \Delta_2 \tau^{(\beta-\alpha)/(\gamma-\alpha)} (1-\tau\lambda_1)^{(\gamma-\beta)/(\gamma-\alpha)} + \tau\lambda_2 \quad (30)$$

where

$$\Delta_2 = \left(\left(\frac{1-\gamma}{1-\alpha}\right)^{1-\gamma} \left(\frac{\gamma}{\alpha}\right)^\gamma\right)^{(\beta-\alpha)/(\gamma-\alpha)} \left(\frac{1-\alpha}{1-\beta}\right)^{1-\beta} \left(\frac{\alpha}{\beta}\right)^\beta > 0$$

A second expression for p in terms of ϖ can also be obtained. From (18) we know that

$$\frac{K_1}{L_1} = \frac{\alpha\varpi}{1-\alpha} \quad (31)$$

Substituting (31) into (29) and rearranging, we get

$$p = \Delta_3 \varpi^{\beta-\alpha} (1-\tau\lambda_1) + \tau\lambda_2 \quad (32)$$

where

$$\Delta_3 = \left(\frac{\alpha}{1-\alpha}\right)^{\beta-\alpha} \left(\frac{1-\alpha}{1-\beta}\right)^{1-\beta} \left(\frac{\alpha}{\beta}\right)^\beta > 0 \quad (33)$$