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Energy tariffs in a small open economy ☆

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ABSTRACT

Tariffs on imported energy alter production and redistribute income. The present paper examines a small open economy producing two traded goods with capital, labor, and imported energy. A tariff reduces import and domestic factor income but payment to one domestic factor rises. Energy intensive output falls but the other output may rise in the general equilibrium. Political opinions on the tariff would differ. Revenue is concave in the tariff suggesting that the government might set the tariff to maximize revenue. A simulation illustrates these general equilibrium properties across a range of tariffs.

1. Introduction

A tariff on imported energy lowers import, shrinking the production frontier and reducing domestic factor income. The present paper examines a small open economy producing two traded goods with capital, labor, and imported energy. The model extends the underlying theory by explicitly analyzing a tariff and tariff revenue. The paper addresses underlying issues in the debate over energy tariffs including energy intensive production and income distribution.

For reference, assume that export production is energy intensive and import competing production labor intensive. A tariff lowers export production and the capital return, but raises the wage and may raise production of the import competing good. Opposing interests to energy tariffs would be expected in practice.

Tariff revenue is shown to be concave in the tariff, extending this assumed property to general equilibrium. Energy tariffs offer a reliable source of government revenue when other taxes are more difficult to collect. Revenue maximization may be a typical if implicit policy goal suggesting the present model may predict energy tariffs in practice.

The literature on energy tariffs is motivated largely by issues of import dependence and emission control. Kline and Weyant (1982) make the point that energy tariffs reduce import dependence. Proost and Van Regemorter (1992) find tariffs on embodied carbon dioxide effectively attain emission targets. Dissou and Eyland (2011) similarly find that tariffs are effective but at higher cost than emission taxes, while Böhringer et al. (2012) find that tariffs compare favorably. Short of externalities, energy tariffs are expected to have negative economic impacts as documented by Hatibu and Semboja (1994). The present model offers a systematic framework to examine energy tariffs in the general equilibrium.

Section 2 introduces the general equilibrium model followed by a section developing the background of the model. Section 4 analyzes the comparative static effects of an energy tariff on production, domestic factor prices, and income. A final section simulates a Cobb–Douglas economy illustrating model properties including the revenue maximizing tariff.

2. The general equilibrium of energy tariffs

Internationally mobile factors of production are introduced to the theory of production and trade by Mundell (1957). The literature focusing on changes in the exogenous world price of the imported factor includes Kemp (1966), Jones (1967), Chipman (1971), Caves (1971), Jones and Ruffin (1975), Ferguson (1978), Srinivasan (1983), Svensson (1984), Ferguson (1978), Thompson (1983), and Ethier and

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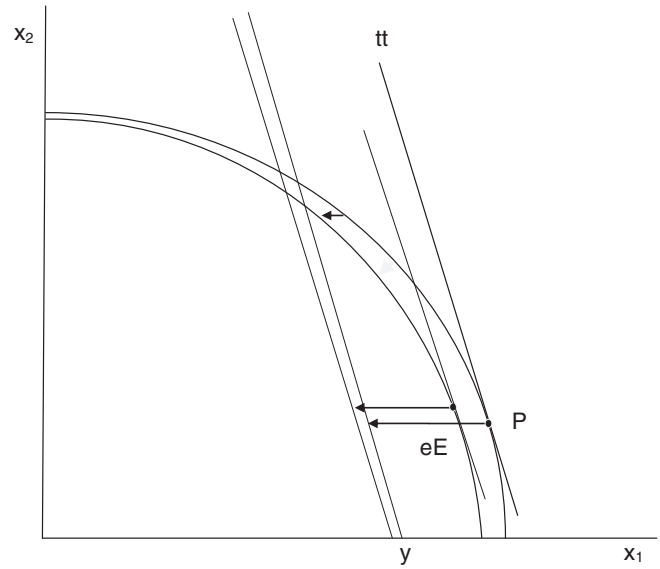

Fig. 1. A factor tariff and income.

Svensson (1986). The present paper extends this fundamental theory by analyzing a tariff and tariff revenue.

There is a related literature on imported intermediate goods entering production with fixed unit input coefficients. Ruffin (1969) develops the fundamental model analyzing the effects of a tariff. Panagariya (1992) finds a tariff that has an ambiguous utility effect. The present model focuses on production and allows input substitution when the tariff raises the domestic price of imported energy.

The present model is illustrated by the production frontier in Fig. 1 determined by the two production functions, domestic endowments of capital and labor, and the level of imported energy. The small open economy produces at point P given the terms of trade $tt = -p_1 / p_2$ where p_j is the exogenous world price of good j. For reference, assume good 1 is the export and good 2 the import.

The small open economy is a price taker in the global energy market at price e. Export of energy intensive good 1 must cover import spending eE as well as imports of good 2 implying that trade in goods starts at that point on the lower tt line. Real income in terms of the export is its intercept y on the x_1 axis.

An energy tariff shrinks the production frontier with more of a reduction in energy intensive good 1. Output x_1 falls but x_2 may rise as in Fig. 1. Energy import spending eE decreases implying lower terms of trade line. The tariff changes outputs, redistributes income between domestic capital and labor, and generates tariff revenue.

Assuming that competitive constant returns production, Euler's theorem implies that the value of output is exhausted by payments to the three factors according to

$$\Sigma_j p_j x_j = wL + rK + (1+t)eE, \tag{1}$$

where p_j is the price of good j, L is the labor endowment, K is the capital endowment, w is the wage, r is the capital return, e is the world price of energy, E is energy import, and t is the tariff. Factors are paid marginal products in each sector. Income y equals domestic factor payment plus tariff revenue,

$$y \equiv rK + wL + teE, \tag{2}$$

equivalent to output less import spending $y = \Sigma_j p_j x_j - eE$.

Imported energy is utilized according to $E = \Sigma_j a_{Ej} x_j$ in the two sectors $j = 1, 2$ where a_{Ej} is the cost minimizing energy input per unit of good j. Unit inputs are functions of the three factor prices assuming homothetic production.

Energy imports change according to $dE = \Sigma_j(a_{Ej}dx_j + x_j da_{Ej})$. In elasticity terms

$$E' = \Sigma_j \lambda_{Ej}\left(a_{Ej}' + x_j'\right), \tag{3}$$

where the prime ′ denotes a percentage change and industry employment shares $\lambda_{Ej} \equiv a_{Ej}x_j / E$ sum to one. Constant returns imply that the unit energy inputs a_{Ej} are homogeneous in factor prices. Employment conditions for capital and labor are similar to Eq. (3).

The domestic energy price $e_D \equiv (1 + t)e$ changes with the tariff according to $de_D = edt$. For reference the percentage change in e_D simplifies to

$$\tau' \equiv dt/(1+t). \tag{4}$$

An energy tariff would lower capital demand if capital is a complement relative to the price of energy as found by Berndt and Wood (1975). If capital is a substitute for energy as in Griffin and Gregory (1976) the tariff would increase capital demand. Production functions differ between sectors raising the possibility that capital could be a complement with energy in one sector and a substitute in the other. Thompson (2006) reviews the literature on applied capital/energy input substitution.

Elasticities of input substitution capture how cost minimized factor mix terms adjust to changing factor prices. As an example the cross price substitution elasticity of capital relative to the domestic price of energy is the industry share weighted sum of those cross price elasticities, $\sigma_{KE} \equiv \Sigma_j \lambda_{Kj}(a_{Kj}' / \tau')$. Linear homogeneity implies elasticities sum to zero across factor prices, $\sigma_{iE} + \sigma_{iL} + \sigma_{iK} = 0$ where $i = K, L, E$. If capital is a complement with respect to the price of energy, σ_{KE} and σ_{EK} are negative. Own effects must outweigh cross effects in the condition $\sigma_{ii}\sigma_{kk} - \sigma_{ik}\sigma_{ki} > 0$ for $i, k = K, L, E$.

Unit energy inputs adjust according to $a_{Ej}' = \sigma_{EK}r' + \sigma_{EL}w' + \sigma_{EE}\tau'$ expanding the adjustment in energy imports in Eq. (3) to

$$E' = \sigma_{EK}r' + \sigma_{EL}w' + \sigma_{EE}\tau' + \Sigma_j \lambda_{Ej} x_j'. \tag{5}$$

Adjustments to changes in exogenous endowments of domestic capital K and labor L are similar.

Revenue in each sector is exhausted by factor payments, $p_j x_j = wL_j + rK_j + (1+t)eE_j$ for $j = 1, 2$. Dividing by output leads to the competitive pricing conditions $p_j = e_D a_{Ej} + wa_{Lj} + ra_{Kj}$. Differentiate to find $dp_j = ea_{Ej}dt + a_{Lj}dw + a_{Kj}dr + [e_D da_{Ej} + wda_{Lj} + rda_{Kj}]$. The bracketed expression disappears due to the cost minimizing envelope property, leading to

$$p_j' = \theta_{Ej}\tau' + \theta_{Kj}r' + \theta_{Lj}w', \tag{6}$$

where the θ_{ij} are factor shares of revenue that sum to 1.

Income $y = rK + wL + teE$ in Eq. (2) changes according to $dy = rdK + wdL + Kdr + Ldw + tedE + eEdt$. In elasticity form

$$y' = \varphi_K(K' + r') + \varphi_L(L' + w') + \varphi_R(E' + T\tau'), \tag{7}$$

where $T \equiv (1 + t) / t$. The three income shares $\varphi_K \equiv rK / y$, $\varphi_L \equiv wL / y$, and $\varphi_R \equiv teE / y$ sum to 1.

Combine energy imports in Eq.(5), similar employment conditions for capital and labor, competitive pricing in Eq. (6), and income in Eq. (7) into the comparative static system,

$$\begin{pmatrix} -1 & \sigma_{EK} & \sigma_{EL} & \lambda_{E1} & \lambda_{E2} & 0 \\ 0 & \sigma_{KK} & \sigma_{KL} & \lambda_{K1} & \lambda_{K2} & 0 \\ 0 & \sigma_{LK} & \sigma_{LL} & \lambda_{L1} & \lambda_{L2} & 0 \\ 0 & \theta_{K1} & \theta_{L1} & 0 & 0 & 0 \\ 0 & \theta_{K2} & \theta_{L2} & 0 & 0 & 0 \\ -\phi_R & -\phi_K & -\phi_L & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} E' \\ r' \\ w' \\ x_1' \\ x_2' \\ y' \end{pmatrix} = \begin{pmatrix} -\sigma_{EE}\tau' \\ K'\text{-}\sigma_{KE}\tau' \\ L'\text{-}\sigma_{LE}\tau' \\ p_1'-\theta_{E1}\tau' \\ p_2'-\theta_{E2}\tau' \\ \phi_K K' + \phi_L L' + \phi_R T\tau' \end{pmatrix}. \tag{8}$$

This general specification of the model is open to application with any estimates of substitution as in Thompson (2006). The effects of changes K′, L′, p_1', p_2', and τ′ are derived with Cramer's rule. Adjustments occur in the endogenous vector for energy imports E′, domestic factor prices r′ and w′, outputs x_1' and x_2', and income y′.

3. Comparative static properties of the model

Comparative static properties hinge largely on factor intensity described by factor shares θ_{ij} and industry shares λ_{ij}. The model solution assumes no factor intensity reversal. Assume that energy is the intensive factor for good 1 and labor for good 2,

$$\theta_{E1}/\theta_{E2} > \theta_{K1}/\theta_{K2} > \theta_{L1}/\theta_{L2}, \tag{9}$$

implying the identical ranking of industry shares. Between energy and capital, good 1 is energy intensive relative to capital in the terms $\theta_{EK} \equiv \theta_{E1}\theta_{K2} - \theta_{E2}\theta_{K1} > 0$ and $\lambda_{EK} \equiv \lambda_{E1}\lambda_{K2} - \lambda_{E2}\lambda_{K1} > 0$. Good 1 is capital intensive relative to labor with similarly positive terms θ_{KL} and λ_{KL}. Good 1 is also energy intensive relative to labor, $\theta_{EL} > 0$ and $\lambda_{EL} > 0$. Further, note that $\theta_{EL} > \theta_{EK}$ and $\lambda_{EL} > \lambda_{EK}$. The determinant Δ of the system (Eq. (8)) is negative, $\Delta = -\theta_{KL}\lambda_{KL} < 0$.

There are six possible factor intensities leading to qualitatively different comparative static properties. The present analysis assumes that there is no factor intensity reversal in the adjustment process. The critical alternative assumption to Eq. (9) with energy as the middle factor $\theta_{K1}/\theta_{K2} > \theta_{E1}/\theta_{E2} > \theta_{L1}/\theta_{L2}$ is discussed in the results.

Domestic factor endowments affect energy imports in Eq. (8) according to $E'/K' = \lambda_{EL}/\lambda_{KL} > 0$ and $E'/L' = -\lambda_{EK}/\lambda_{KL} < 0$. Increased capital raises energy imports while increased endowment of labor, intensive in the other sector, reduces imports. Projecting these results to compare two otherwise identical countries, the capital abundant country would import more energy.

Prices of domestic factors are not affected by endowment changes, $r'/K' = w'/L' = r'/L' = w'/K' = 0$ due to the factor price equalization property. Adjustments in factor demands exactly offset supplies. Trade between two such economies based on different domestic factor endowments would lead to equal factor prices.

Outputs adjust to endowments according to factor intensity. Each output has a positive link to the endowment of its intensive domestic factor and a negative link to the other domestic factor. Two such countries would trade in the Heckscher–Ohlin pattern as developed by Ruffin (1977).

The effects of factor endowments on income depend on income shares and factor intensity,

$$y'/K' = \phi_K + \phi_R\lambda_{EL}/\lambda_{KL} > 0 \tag{10}$$

$$y'/L' = \phi_L - \phi_R\lambda_{EK}/\lambda_{KL}.$$

Capital raises income by its return, attracting energy imports and generating tariff revenue. The total adjustment y′/K′ is the income weighted average of those two effects. For labor the net effect is ambiguous due to declining tariff revenue. For larger tariff revenue shares of income, labor growth would lower income as the lost tariff revenue more than offsets the labor payment.

The effects of prices on energy imports depend on elasticities of input substitution as well. For the price of good 1,

$$E'/p_1' = (\theta_{K2}\sigma_1 - \theta_{L2}\sigma_2)/\Delta, \tag{11}$$

where $\sigma_1 \equiv (\lambda_{KL} - \lambda_{EK})\sigma_{EL} - (\lambda_{EL} + \lambda_{EK})\sigma_{KL}$ and $\sigma_2 \equiv (\lambda_{KL} + \lambda_{EL})\sigma_{EK} + (\lambda_{EK} + \lambda_{EL})\sigma_{LK}$. A presumed negative σ_1 and positive σ_3 imply increased energy imports with increased output of energy intensive good 1. Energy imports would decrease, however, if energy is a complement with capital. Analysis of a change in p_2 is similar. Thompson (1983) shows that energy imports increase in at least one of the two prices.

Standard Stolper–Samuelson adjustments of domestic factor prices r′ and w′ to changing prices p_1' and p_2' depend only on factor intensity. A higher p_1 raises its intensive factor price r and lowers w. Results are opposite for p_2. The production frontier is also convex in prices with each output increasing in its own price and decreasing in the other price.

Income adjusts to p_1 according to

$$y'/p_1' = [(\phi_K\theta_{L2} - \phi_L\theta_{K2})/\theta_{KL}] + \phi_R(E'/p_1'). \tag{12}$$

The expression in brackets is positive due to the spanning condition necessary for production of both goods, $K_1/L_1 > K/L > K_2/L_2$. This positive expression captures the net positive effect of an increase in p_1 on domestic factor payments. With increasing energy imports p_1 raises income. The effect of an increase in p_2 is ambiguous due to falling energy imports.

4. An energy tariff in the general equilibrium

An energy tariff lowers imports in Eq. (8) according to

$$E'/\tau' = -\Delta_{32}/\Delta < 0, \tag{13}$$

where Δ_{32} is the negative determinant of the model with three domestic factors. Concavity implies $\Delta_{32} < 0$ as discussed by Chang (1979) and Thompson (1985). The *mutatis mutandis* demand for energy in Eq. (12) is downward sloping, not apparent given the flexibility of decreased labor intensive production. There is elastic import demand $E'/\tau' < -1$ implying that the tariff reduces import spending inclusive of the tariff if $\Delta_{32} > \Delta$. The determinant Δ_{32} increases in absolute value with the degree of input substitution. That is, a higher degree of input substitution favors elastic import demand. As the degree of input substitution approaches zero so does Δ_{32} implying inelastic import demand.

Effects of the energy tariff on domestic factor prices are independent of input substitution, depending only on factor intensity,

$$\begin{aligned} r'/\tau' &= -\theta_{EL}/\theta_{KL} < 0 \\ w'/\tau' &= \theta_{EK}/\theta_{KL} > 0. \end{aligned} \tag{14}$$

The two domestic factors of production have opposite interests in a tariff. Labor, intensive in import competing production, benefits from the tariff while the middle factor capital loses. Output prices are constant at world levels implying that Eq. (14) captures changes in real incomes. If energy were the middle factor, the negative θ_{EK} would imply that both domestic factor prices fall with the tariff.

The energy tariff shrinks the production frontier as outputs adjust according to

$$x_1'/\tau' = (\lambda_{K2}\sigma_3 + \lambda_{L2}\sigma_4)/\Delta \tag{15}$$

$$x_2'/\tau' = -(\lambda_{K1}\sigma_3 + \lambda_{L1}\sigma_4)/\Delta,$$

where $\sigma_3 \equiv \theta_{EL}\sigma_{LK} - (\theta_{KL} + \theta_{EK})\sigma_{EL} - \theta_{EK}\sigma_{KL}$ and $\sigma_4 \equiv (\theta_{KL} + \theta_{EL})\sigma_{EK} + \theta_{KL}\sigma_{LK} - \theta_{EK}\sigma_{KL}$. Factor intensity and substitution both play roles in output adjustments. The tariff must lower at least one of the two outputs as shown by Thompson (1983). The presumption that $\sigma_3 < 0$ and $\sigma_4 > 0$ leads to decreased energy intensive output x_1. Import competing production then increases as the economy moves away from the energy intensive production. Increased labor intensive x_2 as pictured in Fig. 1 is consistent with the rising wage w in Eq. (14).

If energy and capital were complements, the negative σ_{LK} and σ_{KL} would favor less of a decrease in x_1. The tariff would then reduce capital demand with strong substitution toward labor leading to a smaller decrease in x_1. A smaller share of capital employed in sector 1 reflected by a larger λ_{K2} also favors less of a decrease in x_1.

Income adjusts to the tariff according to

$$y'/\tau' = [\phi_L\theta_{EK} - \phi_K\theta_{EL}]/\theta_{KL} + \phi_E(R'/\tau'), \tag{16}$$

where R is tariff revenue teE and $R'/\tau' = T + E'/\tau'$. The term in brackets is negative due to the property $\phi_L\theta_{EK} < \phi_K\theta_{EL}$ reflecting the rising w and falling r in Eq. (14). A larger labor share ϕ_L favors less of a decrease in domestic factor income with more weight on the rising wage. A larger θ_{EK} and smaller θ_{EL} with energy closer to labor in factor intensity also favor less of a decrease in domestic factor income.

The term $\phi_R(T + E'/\tau')$ in Eq. (16) captures tariff revenue. The tariff lowers $T = (1 + t) / t$ offsetting the decreased import. At a zero tariff, the term T is infinitely large implying that R must increase with a marginal tariff. The implication is that at low tariffs tariff revenue R increases with rising tariff revenue more than offsetting diminished import. At high tariffs, the term T approaches 1 implying a more negative E'/τ' as the tariff lowers R. Elasticities of input substitution also become stronger at higher tariffs implying a more elastic E'/τ'. It follows that R is concave in t. A revenue maximizing tariff is illustrated in the following simulation.

5. A simulated energy tariff

Consider adjustments to an energy tariff ranging from 0 to 1 with the Cobb–Douglas production functions $x_1 = K_1^{0.5}L_1^{0.2}E_1^{0.3}$ for energy intensive good 1 and $x_2 = K_2^{0.4}L_2^{0.5}L_2^{0.1}$ for labor intensive good 2. In the simulation, the tariff rate rises by increments of 0.01. The factor intensity ranking in Eq. (9) holds throughout the range of tariffs. Cobb–Douglas is a familiar but restrictive functional form implying constant factor shares. Constant elasticity of substitution CES production functions leads to similar results. Domestic factor endowments are $K = 100$ and $L = 10$. The price e of imported energy and product prices p_1 and p_2 are set equal to 1. The following adjustment paths are sensitive to the Cobb–Douglas production coefficients but not to other parameters.

Factors are paid marginal products in each sector. The solution is found with nonlinear optimization of income $y = wL + rK + tE$. Euler's theorem implies an identical outcome with nonlinear optimization of $y = p_1x_1 + p_2x_2 - E$.

In Fig. 2 energy import E declines from 8.3 to 1.4. Energy intensive output x_1 declines from 26.6 to 3.4 as labor intensive x_2 increases from 3.4 to 17.4. Total output $x_1 + x_2$ declines from 30.0 to 20.8. Stronger CES substitution results in a declining energy share, a smaller decrease in imports, and smaller output adjustments.

Income y declines from 21.7 to 19.4. Income becomes more sensitive to the tariff as the income elasticity y'/τ' in Eq. (15) falls from −0.004 to −0.242. At low tariff levels, reduced import spending nearly offsets decreased domestic factor income. The effect of the tariff on income is smaller with stronger CES substitution.

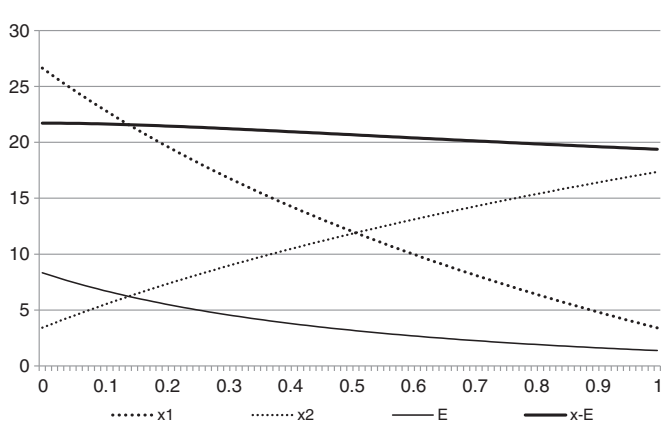

Fig. 2. Outputs, import E, and income x-E.

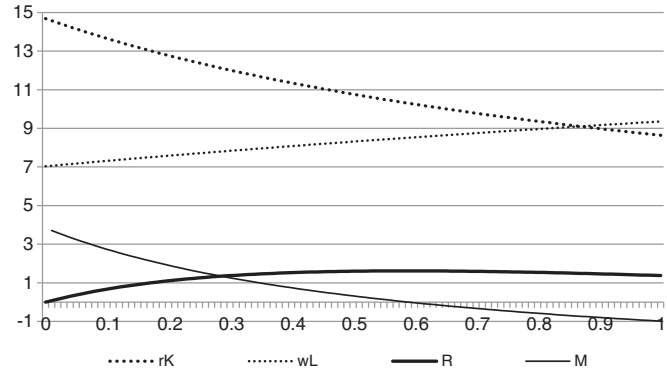

Fig. 3. Factor payments, tariff revenue R, and its effect M on income.

Fig. 3 shows adjustments in domestic factor payments. The capital payment rK declines from 14.7 to 8.6 as the labor payment wL increases from 7.0 to 9.4. An increase in the energy tariff would be favored by labor even though total domestic factor payments decline from 21.7 to 18.0.

Tariff revenue R rises from 0 to its maximum 1.62 at $t^R = 0.59$. The tariff revenue share ϕ_R of income has a similar path maximized at $t^\phi = 0.64$ that is less than t^R due to the negative effect on domestic factor payments. Stronger CES substitution implies revenue that is maximized at a higher tariff.

The elastic effect on energy imports E'/τ' becomes stronger at higher tariff levels, falling from −2.16 to −3.33 over the range of tariffs. Stronger CES substitution implies less elastic imports.

The effect on the domestic energy price diminishes as the tariff increases with τ' falling from 0.010 to 0.005. The gross effect of tariff revenue on income $M \equiv \phi_E(R'/\tau')$ in Eq. (16) declines and becomes negative in Fig. 3 at the revenue maximizing tariff t^R.

To illustrate potential application of the model, assume the government tax factor income at 10%. Government revenue g rises from $g = 2.2$ at $t = 0$ to its maximum $g^* = 3.5$ at $t^g = 0.52$. The negative effect of the tariff on domestic factor payments implies that $t^g < t^*$. A similar property holds for taxes on outputs.

6. Conclusion

In a small open economy producing two goods with imported energy and two domestic factors of production, a tariff lowers energy intensive output but the other output may rise. The tariff has opposite effects on domestic factor prices. There is a revenue maximizing tariff in the competitive general equilibrium. Political opinions on energy tariffs should be expected to differ. The effects of a tariff generally depend on production functions and the state of the economy.

The present model can be extended to relate directly to issues in the energy tariff literature including import dependence and emission control. The model can also be extended to large economies with market power in the international energy market. Weitzel et al. (2012) stress the terms of trade effects of oil tariffs. The Metzler (1949) paradox with a lower domestic energy price inclusive of the tariff would be possible as suggested by Thompson (2007). As another extension, domestic import competing energy supply would lead to the potential of increased income with a tariff as documented for US oil tariffs by Jones (1990). Finally, the model can be extended to analyze the potential of energy tariffs to obviate subsidies for alternative energy.

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