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Henry Thompson

Economics Department, Auburn University, Auburn, Alabama, USA

**ABSTRACT**

This article examines a tariff on an imported factor of production in a small, open economy with two domestic factors. Suppose the imported factor is intensive in export production, and labor in import competing production. The factor tariff would reduce export production and trade, but raise the wage. The flexibility afforded by the three factors raises the possibility that import spending might fall more than the decrease in output. That is, the factor tariff could raise income. Inelastic demand for the imported factor and a high labor share of income favor increased income.

**KEYWORDS**

Factor tariffs; general equilibrium production; income

A tariff on an imported factor of production lowers the level of its import, leading to adjustments in outputs and domestic factor prices. The present article examines the effects of a factor tariff in a small, open economy producing two traded goods with the imported factor and two domestic factors of production. The small, open economy is a price taker in international markets for the two traded goods and for the imported factor.

The tariff shrinks the production frontier and lowers output valued at world prices. Domestic production and factor prices adjust to the higher domestic price of the imported factor. The tariff generates revenue, not explicitly considered in the related literature. The model applies to imported capital as well as energy and natural resource inputs.

Suppose the imported factor is intensive in the export, and labor in import competing production. The wage increases due to the tariff, more so if labor is an elastic substitute for the imported factor. Under some conditions, the decreased import spending can outweigh the decreased output. If so, the factor tariff raises income.

Section 1 reviews the literature on the factor proportions model with an imported factor in a small, open economy. Section 2 introduces the present three factor model, extending the literature by including tariff revenue in income. Section 3 analyzes comparative static adjustments to a factor tariff. Section 4 presents a simulation with a factor tariff raising income. Section 5 concludes.

**CONTACT** Henry Thompson thomph1@auburn.edu Economics Department, Auburn University, 139 Miller Hall, Auburn, AL 36849, USA.

## I. The factor proportions model with an international factor

The literature including an internationally mobile factor of production in general equilibrium production has a rich history, beginning with Mundell (1957) and including Kemp (1966), Jones (1967), Chipman (1971), Caves (1971), Jones and Ruffin (1975), Ferguson (1978), Srinivasan (1983), Thompson (1983), Svensson (1984), Ruffin (1984), Ethier and Svensson (1986), Neary (1995), Norman and Venables (1995), and Fachini and Willmann (2005). The literature focuses on adjustments to a change in the exogenous price of the international factor, typically capital combined with domestic labor producing two traded goods. The literature also considers adjustments in import of the international factor to changing prices of the traded goods and labor endowment.

The various assumptions in the literature include factor intensity and substitution, large economy price effects, and imperfect competition. An increase in the price of the imported factor lowers its import, with downward sloping demand allowing general equilibrium adjustments.

Ruffin (1969) develops the model of an imported intermediate good that enters production in fixed proportions. Panagariya (1992) finds that a tariff has an ambiguous effect on utility in this intermediate good model. The present model uncovers an analogous ambiguous effect of a factor tariff on income due to substitution with two domestic factors.

In the present model, substitution between the import and the two domestic factors is critical. Factor intensity and factor shares of income also influence adjustments in outputs and the two domestic factor prices.

Figure 1 illustrates adjustments to a factor tariff with the reduced production frontier. The economy begins at point x, given the exogenous terms of trade tt and world price $w_1$ of the imported factor. Export of Good 1 must cover import spending $w_1v_1$ where $v_1$ is the level of the imported factor. Consumers maximize utility subject to the terms of trade line tt that is reduced to cover spending on the imported factor. Real income in terms of Good 1 is determined at the intercept y on the $x_1$ axis.

A factor tariff shrinks factor import $v_1$, reducing the production frontier. Export production $x_1$ falls. Import competing output $x_2$ may increase as in Figure 1 or both outputs could fall. Increased income is illustrated as factor import spending $w_1v_1$ falls more than the value of output. Consumers maximize utility on a higher price line due to the factor tariff.

Introducing notation for the model,

$p_j$ = exogenous price of Good j

$x_j$ = output of Good j

t = factor tariff rate

$w_i$ = international price of the imported factor

$v_1$ = level of factor import

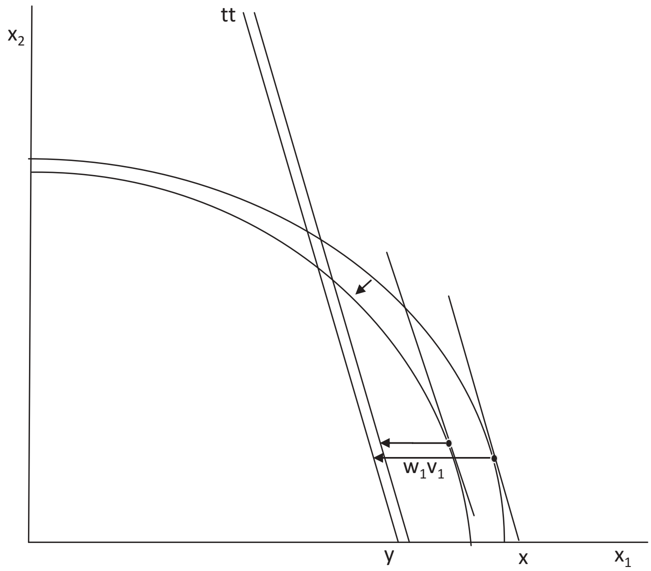


**Figure 1.** A factor tariff, output, and income.

$v_2$, $v_3$ = domestic factor endowments
$w_2$, $w_3$ = domestic factor prices.

Constant returns and Euler's theorem imply that factor payments exhaust output x:

$$x \equiv \sum_j p_j x_j = (1+t)w_1v_1 + w_2v_2 + w_3v_3 \tag{1}$$

Constant world prices of the two goods imply output x in real terms. Output x must cover factor payment $w_1v_1$ as well as tariff revenue $tw_1v_1$ included in income. Income y is the value of output less factor import spending, or domestic factor payments plus tariff revenue:

$$y = x - w_1v_1 = tw_1v_1 + w_2v_2 + w_3v_3 \tag{2}$$

Changes in domestic factor prices and tariff revenue reflect real income, given world prices of the goods. In the comparative static adjustments, the factor tariff t lowers its import $v_1$, leading to adjustments in domestic factor prices $w_2$ and $w_3$. Under some conditions, t increases y.

## II. A factor import in the 3 × 2 model

Turning to the algebra, the imported factor is utilized, producing the two goods according to $v_1 = \Sigma_j a_{1j}x_j$ where $a_{1j}$ are cost-minimizing unit inputs for j = 1,2. The import adjusts according to $dv_1 = \Sigma_j(a_{1j}dx_j + x_j da_{1j})$. Letting the prime denote percentage change, import of the factor adjusts according to

$$v_1' = \sum_j \lambda_{1j}\left(a_{1j}' \tau' + x_j'\right), \tag{3}$$

where $\lambda_{1j} \equiv a_{1j}x_j/v_1$ is the industry share of the factor import utilized in sector j. Industry shares sum to one, $\Sigma_j\lambda_{ij} = 1$. Constant returns imply that the flexible unit inputs $a_{1j}$ are functions of factor prices only.

Denote the domestic price of the imported factor as $\omega \equiv (1 + t)w_1$. The tariff changes $\omega$ according to $d\omega = w_1dt$ assuming $dw_1 = 0$ for the small economy. The percentage change in the domestic price is

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

Cross price elasticities summarize substitution due to changing factor prices. The cross price elasticity of the import relative to price of the domestic factor i is $\sigma_{1i} \equiv \Sigma_j\lambda_{1j}(a_{1j}'/w_i')$ as the industry share weighted cross price elasticity. The three own price elasticities $\sigma_{11}$, $\sigma_{22}$, $\sigma_{33}$ are negative due to Shephard's lemma and concavity of cost functions. Linear homogeneity implies elasticities for each input k sum to zero across factor price changes, $\Sigma_i\sigma_{ki} = 0$.

Positive cross price elasticities between two factors indicate substitutes. With three factors, one pair may be complemented with an increase in the price of one lowering the cost-minimizing input of the other. Concavity of the cost function requires positive principle minors in the matrix of price elasticities with own effects outweighing cross effects, $\sigma_{ii}\sigma_{kk} - \sigma_{ik}\sigma_{ki} > 0$ for i, k = 1,2,3.

Cost-minimizing input of the import adjusts according to $a_{1j}' = \sigma_{12}w_2' + \sigma_{13}w_3' + \sigma_{11}\tau'$, expanding (3) to

$$v_1' = \sigma_{12}w_2' + \sigma_{13}w_3' + \sigma_{11}\tau' + \sum_j \lambda_{1j}x_j'. \tag{5}$$

This import adjustment is included in the comparative static system (8) with similar conditions for adjustments to changing endowments $v_2$ and $v_3$ of domestic factors.

Competitive pricing in (1) implies that revenue in each sector is paid to the factors according to $p_jx_j = (1 + t)w_1v_{1j} + w_2v_{2j} + w_3v_{3j}$. Divide by $x_j$ to find the condition linking prices of goods and factors, $p_j = (1 + t)w_1a_{1j} + w_2a_{2j} + w_3a_{3j}$ with price equal to cost. Differentiate to find $dp_j = w_1a_{1j}dt + a_{2j}dw_2 + a_{3j}dw_3 + [(1 + t)w_1da_{1j} + w_2da_{2j} + w_3da_{3j}]$. The bracketed expression disappears due to the cost-minimizing envelope property, leading to

$$p_j' = \theta_{1j}\tau' + \theta_{2j}w_2' + \theta_{3j}w_3', \tag{6}$$

where $\theta_{ij} \equiv a_{ij}w_i/p_j$ is the factor share of i in the revenue of j. Factor shares sum to one, $\Sigma_i\theta_{ij} = 1$. The percentage change of price in (6) is a weighted average of percentage changes in factor prices.

The last condition entering the comparative static system (8) is for income y in (2). Income changes according to

$$y\prime = \varphi_1(v_1'+T\tau')+\varphi_2(v_2'+w_2')+\varphi_3(v_3'+w_3'), \tag{7}$$

where $T \equiv (1 + t)/t$, $\varphi_1 \equiv tw_1v_1/y$, and $\varphi_k \equiv w_kv_k/y$. Income shares are $\varphi_1$ for tariff revenue and $\varphi_k$ for the domestic factors k = 2,3. The three income shares sum to one $\Sigma_i\varphi_i = 1$, implying that the percentage change in income is a weighted sum of percentage changes in factor payments.

Combine the conditions for changes in import utilization (5), domestic factor employment (5), competitive pricing (6), and income (7) into the comparative static system (8) with exogenous variables on the right-hand side:

$$\begin{pmatrix} 1 & \sigma_{12} & \sigma_{13} & \lambda_{11} & \lambda_{12} & 0 \\ 0 & \sigma_{22} & \sigma_{23} & \lambda_{21} & \lambda_{22} & 0 \\ 0 & \sigma_{32} & \sigma_{33} & \lambda_{31} & \lambda_{32} & 0 \\ 0 & \theta_{21} & \theta_{31} & 0 & 0 & 0 \\ 0 & \theta_{22} & \theta_{32} & 0 & 0 & 0 \\ -\varphi_1 & -\varphi_2 & -\varphi_3 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} v_1' \\ w_2' \\ w_3' \\ x_1' \\ x_2' \\ y' \end{pmatrix} = \begin{pmatrix} -\sigma_{11}\tau' \\ v_2' - \sigma_{21}\tau' \\ v_3' - \sigma_{31}\tau' \\ p_1' - \theta_{11}\tau' \\ p_2' - \theta_{12}\tau' \\ \varphi_2 v_2'+\varphi_3 v_3'+\varphi_1 T\tau' \end{pmatrix} \tag{8}$$

The present focus is on the effects of changes in the tariff $\tau'$ given constant factor endowments and prices, $v_2' = v_3' = p_1' = p_2' = 0$. The model solves for adjustments to changes in exogenous variables with Cramer's rule.

Assume the imported factor is most intensive or extreme in Good 1 with domestic $v_3$ extreme in Good 2:

$$\theta_{11}/\theta_{12} > \theta_{21}/\theta_{22} > \theta_{31}/\theta_{32} \tag{9}$$

Summary intensity terms are $\theta^{12} \equiv \theta_{11}\theta_{22} - \theta_{12}\theta_{21} > 0$ between factors 1 and 2, with similar positive intensity terms $\theta^{23}$ and $\theta^{13}$. Industry shares have similar positive intensity terms $\lambda^{12}$, $\lambda^{13}$, and $\lambda^{23}$. The negative determinant of the system matrix in (8) is $\Delta = -\theta^{23}\lambda^{23} < 0$.

Comparative static properties of this 3 × 2 model are developed by Thompson (1983). The production frontier is concave, given neoclassical production. If the imported factor is extreme in export production, its import is positively related to the price of the export and negatively related to the price of the import competing good. An increase in the export price raises demand for the imported factor. An increase in the endowment $v_3$ lowers export production and the factor import, while an increase in the endowment of the middle factor $v_2$ has the opposite effect. Factor intensity determines the directions of these adjustments with substitution contributing to the magnitudes. An increase in the price of the imported factor lowers its import and export production, raising $w_3$ as the economy shifts toward import competing production. The other domestic factor price $w_2$ falls. The following section extends this model to include tariff revenue in income.

## III. Adjustments to a factor tariff in the 3 × 2 model

A change in the factor tariff affects its import in the system (8) according to

$$v_1'/\tau' = -\Delta_{32}/\Delta < 0, \tag{10}$$

where $\Delta_{32}$ is the negative determinant of the model with three domestic factors. Concavity and cost minimization imply $\Delta_{32} < 0$, as developed by Chang (1979) and Thompson (1985). Factor import demand slopes downward, allowing full adjustments in outputs and factor prices.

The effects of a tariff on domestic factor prices depend only on factor intensity:

$$\begin{aligned} w_2'/\tau' &= -\theta^{13}/\theta^{23} < 0 \\ w_3'/\tau' &= \theta^{12}/\theta^{23} > 0. \end{aligned} \tag{11}$$

The wage $w_3$ rises with capital released from export production. The marginal product of labor increases as import competing production expands. The capital return $w_2$ falls in absolute size more than the increase in the wage, implying a net decrease in the income of domestic factors.

If imported energy were the middle factor, the tariff would lower both domestic factor prices in (11). Substitution has no effect due to the dimensions of the model with one more factor than good. More generally, substitution plays a role in income redistribution among domestic factors due to the tariff.

Output adjustments on the shrinking production frontier depend on factor intensity and substitution:

$$\begin{aligned} x_1'/\tau' &= (\lambda_{12}\sigma_3 - \lambda_{22}\sigma_4)/\Delta \\ x_2'/\tau' &= (\lambda_{21}\sigma_4 - \lambda_{11}\sigma_3)/\Delta, \end{aligned} \tag{12}$$

where $\sigma_3 \equiv (\theta^{13} + \theta^{23})\sigma_{21} + \theta\sigma_{23}$, $\sigma_4 \equiv (\theta^{12} - \theta^{23})\sigma_{31} + \theta\sigma_{32}$, and $\theta \equiv (\theta^{12} + \theta^{13})$. Thompson (1983) shows that at least one of these effects must be negative.

Although net payment to domestic factors falls in (11), the offsetting tariff revenue is included in the income adjustment:

$$y'/\tau' = \varphi_1(T + v_1'/\tau') + \varphi_2(w_2'/\tau') + \varphi_3(w_3'/\tau'). \tag{13}$$

The first term reflects the ambiguous change in tariff revenue $tw_1v_1$ due to the import elasticity. The second and third terms are weighted effects of domestic factor price changes in (11). The elasticity of income is the weighted average of the three payments.

An increase in income $y'/\tau' > 0$ is favored by a number of properties, including larger income shares $\phi_3$ and $\phi_1$ for labor and tariff revenue. A low tariff level indicated by a high T in (13) also favors an increase in income.

Weak substitution relative to the price of the imported factor would imply inelastic import demand with the negative $v_1'/\tau'$ in (13) close to zero. A smaller decrease in the imported factor favors increased income due to the larger increase in tariff revenue and smaller changes in domestic factor prices.

The comparative static effect of the tariff on income in (13) would be zero at the optimal tariff. The optimal factor tariff depends on the production functions.

## IV. A simulated factor tariff

To illustrate the adjustments to a factor tariff, consider an economy facing unit exogenous world prices $w_1 = p_1 = p_2 = 1$. For reference, consider energy input imported at price $e = w_1$. Domestic endowments of capital and labor are $K = L = 1$. The implied static equilibrium includes endogenous outputs $x_1 = 2.50$ and $x_2 = 0.83$, energy import $E = v_1 = 1.33$, domestic capital return $r \equiv w_2 = 0.77$, and wage $w \equiv w_3 = 1.10$.

Tariff rate $t = 0.10$ implies tariff revenue $teE = 0.13$. Output $x = 3.33$ in (1) less import spending equals income $y = 2.00$ in (2). Income shares are $\varphi_E = 0.07$ for tariff revenue, $\varphi_K = 0.38$, and $\varphi_L = 0.55$.

Factor and industry shares are consistent with the factor intensity condition (9). The factor shares equal cost-minimizing inputs $a_{ij}$ due to the unit prices.

$$\begin{pmatrix} \Theta_{E1} & \theta_{E2} \\ \Theta_{K1} & \theta_{K2} \\ \Theta_{L1} & \theta_{L2} \end{pmatrix} = \begin{pmatrix} 0.55 & 0.11 \\ 0.23 & 0.23 \\ 0.22 & 0.66 \end{pmatrix} \quad \begin{pmatrix} \lambda_{E1} & \lambda_{E2} \\ \lambda_{K1} & \lambda_{K2} \\ \lambda_{L1} & \lambda_{L2} \end{pmatrix} = \begin{pmatrix} 0.94 & 0.06 \\ 0.75 & 0.25 \\ 0.50 & 0.50 \end{pmatrix} \tag{15}$$

Assume the factor substitution elasticities

$$\begin{pmatrix} \sigma_{Ee} & \sigma_{Er} & \sigma_{Ew} \\ \sigma_{Ke} & \sigma_{Kr} & \sigma_{Lr} \\ \sigma_{Le} & \sigma_{Lr} & \sigma_{Lw} \end{pmatrix} = \begin{pmatrix} -0.9 & -0.6 & 1.5 \\ -0.2 & -0.3 & 0.5 \\ 0.2 & 0.2 & -0.4 \end{pmatrix} \tag{16}$$

Imported energy is a complement with capital with the negative $\sigma_{Er}$ and $\sigma_{Ke}$, and an elastic substitute relative to the wage in $\sigma_{Ew}$. These factor price elasticities satisfy concavity conditions and are consistent with the static equilibrium. They can be derived from the quadratic cost functions $c_1 = -e^2 - r^2 - w^2 + 0.86er + 1.72ew + 0.89wr$ and $c_2 = -e^2 - r^2 - w^2 + 0.29er + 1.72ew + 1.41rw$, and are consistent with any number of production or cost functions.

Solving the resulting comparative static model (8) for the effects of a factor tariff, import adjusts according to $v_1'/\tau' = -0.33$. This inelastic effect implies a small reduction in import. In contrast, domestic factor price adjustments are $r'/\tau' = -3.35$ and $w'/\tau' = 1.00$ with the tariff inducing strong substitution toward labor. Output adjustments are elastic, $x_1'/\tau' = -3.48$ and $x_2'/\tau' = 5.22$, with export production falling as the economy strongly shifts toward import competing production.

Income increases with the factor tariff according to $y'/\tau' = 0.05$ due to the inelastic decrease in the factor import, the rising wage, and the high income share of labor. This positive $y'/\tau'$ is not robust to changes in parameters, but is possible under various conditions. Conditions favoring increased income due to a factor tariff can be traced in models with more factors of production and more goods.

## V. Conclusion

Other arguments in favor of factor tariffs should be mentioned to better isolate the present result. For a large country, a factor tariff lowers the international price, raising the possibility of a Metzler (1949) paradox with a falling domestic price including the tariff. An analogous effect occurs when importing from an international monopoly, as the tariff transforms some of the foreign monopoly profit into tariff revenue. In an economy with import competing domestic supply of the factor import, Thompson (2016) shows that a tariff might raise income by increasing the domestic quantity supplied. Externalities associated with the import would diminish with a Pigouvian tariff, not the best solution but a feasible policy option. Factor tariffs may also be efficient relative to other taxes.

The present argument for factor tariffs is much different. The potential increase in income arises in a competitive neoclassical economy when there are two or more domestic factors of production. Technical conditions may favor increased income due to a factor tariff.

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