1981

Energy Prices, Capital Formation, and Potential GNP

David F. Burgess

ISSN 0228-4235
ISBN 0-7714-0302-X

CENTRE FOR THE STUDY OF INTERNATIONAL ECONOMIC RELATIONS

WORKING PAPER NO. 8107C

ENERGY PRICES, CAPITAL FORMATION, AND POTENTIAL GNP

David F. Burgess

This paper contains preliminary findings from research work still in progress and should not be quoted without prior approval of the author.

DEPARTMENT OF ECONOMICS
UNIVERSITY OF WESTERN ONTARIO
LONDON, CANADA
N6A 5C2

20031

ENERGY PRICES, CAPITAL FORMATION, AND POTENTIAL GNP

by

David F. Burgess
Department of Economics
University of Western Ontario
London Canada

October 1981

ABSTRACT

The paper generalizes the standard EMF general equilibrium model of energy-economy interaction by specifying separate production functions for energy and non-energy goods. We show that even if capital and energy are AES complements at the level of the individual firm they may well be substitutes at the level of the aggregate economy. Using plausible estimates for a net energy importer like the United States we find that an increase in the world relative price of energy may well increase the competitive rate of return to capital, stimulate capital formation and as a consequence mitigate any initial real income loss.

1. Introduction

A common theme of the rapidly developing literature on energy-economy interaction is that higher energy prices--initiated by external events such as OPEC--will permanently reduce the growth potential of net energy importing economies even if full-employment conditions are maintained.[1] According to this literature, in the absence of government measures to encourage saving and investment any initial adverse effect on potential GNP resulting from the need to pay a higher real price for imported energy will be compounded by secondary effects operating to reduce the rate of capital formation; and this secondary or reverse feedback effect through capital may be the largest component of the overall impact on potential GNP.[2] The purpose of this paper is to examine critically the theoretical underpinnings behind this view. We find that the linkages between higher energy prices, capital formation, and potential GNP are very sensitive to one's choice of model specification. While the view that energy and capital are complementary inputs at the level of the aggregate economy seems compelling for economies that must import all their energy, it is considerably less convincing for economies that produce a substantial proportion of their total energy requirements using techniques that are typically more capital intensive than the rest of the economy. For a fully specified, competitive, two-sector model of energy economy interaction we find that--provided full-employment conditions are maintained--higher energy prices may well stimulate rather than deter capital formation. Thus, any initial reduction in potential GNP arising from the adverse shift in the terms of trade may be partially, if not wholly, offset by market-induced reverse feedback effects through capital formation. Using parameter values designed to provide a rough stylized description of the U.S. economy, we find no compelling case that an increase in the world relative price of energy will entail a secondary burden on potential GNP through its market-induced effect on capital formation. However, whether or not the original time path of potential GNP can be restored in the absence of government intervention, remains problematic.

The paper is organized as follows: Section 2 summarizes the essential features of the standard EMF model; section 3 develops an explicit two-sector specification of energy-economy interaction that is sufficiently general to permit different factor intensity and substitution parameters for energy and non-energy goods; section 4 derives expressions for the short run and long run effects of higher energy prices on potential GNP; section 5 provides a dual formulation of the model which has the advantage of yielding comparative statics results in terms of parameters about which economists have some empirical knowledge; sections 6, 7, and 8 derive expressions for the short-run and long-run effects of higher energy prices on factor rewards, outputs of energy and non-energy goods, capital formation, and potential GNP; section 9 attempts to quantify the rough order of impact of higher energy prices upon the U.S. economy; section 10 suggests some extensions, and offers some concluding remarks.

2. Background

The theoretical foundations for the interplay between energy, capital formation, and GNP have been developed over the past few years in research supported by the Energy Modeling Forum at Stanford. The idea has been to provide a simple yet intuitively reasonable general equilibrium framework that captures the essential two way linkages between energy and the rest of the economy while avoiding the complexity of complete and disaggregative treatments such as Hudson and Jorgenson (1974, 1978). The important initial work by Hogan and Manne (1977) has been refined and extended by Hogan (1977), Solow (1979), Sweeney (1979), and Solow and Peck (1980). The most general version of the model consists of an aggregate production function for gross final output $F(\cdot)$ with capital (K), labour (L), and energy (E) as inputs, a cost function for domestically produced energy $H(\cdot)$ which is increasing and convex in the amount of energy produced (E_d), and a specification of energy imports (E_m) available at a predetermined world relative price $\bar{p}_e$. The convexity of $H(\cdot)$ presumably reflects the existence of certain factors specific to the production of energy goods. The economy's GNP can then be written in the form:

$$GNP = F(K,L,E) - H(E_d) - \bar{p}_e E_m \quad (1)$$

In this formulation GNP is derived from gross final output by subtracting out the amount that must be exported on current account (or claimed by foreigners via inward foreign investment) to pay for energy imports, plus the amount that is used up in domestic energy production.

Under perfect competition and with no tax-tariff distortions an economy facing a given world relative price of energy and with fixed supplies of capital and labour will use energy up to the point where energy's marginal cost in terms of final output equals its world relative price. The first-order conditions for a competitive equilibrium are given by: $F_E(\bar{K},\bar{L},E) = H_E(E_d) = \bar{p}_e$. E and E_d are thereby determined as functions of $\bar{p}_E$, $\bar{K}$, and $\bar{L}$; E_m is then determined residually as $E - E_d$; and the competitive wage and rate of return to capital are given by $w = F_L(\bar{K},\bar{L},E)$ and $r = F_K(\bar{K},\bar{L},E)$ respectively.

According to the EMF model, an increase in the world relative price of energy will reduce, leave unchanged, or increase the competitive wage as $F_{LE} \gtreqless 0$. Since capital appears symmetrically with labour, the rate of return to capital will fall, remain unchanged, or increase as $F_{KE} \gtrless 0$. If the technology is weakly separable with respect to a partitioning between capital and labour on the one hand and energy on the other, then the wage and the rate of return to capital will both decline by the same percentage. However, if energy and labour are closer Hicks-Allen (hereafter AES) substitutes than energy and capital (i.e., $\sigma_{LE} > \sigma_{KE}$) then a smaller total GNP will be distributed from capital to labour.[3] The econometric evidence is virtually unanimous that $\sigma_{LE} > \sigma_{KE}$, although there remains considerable disagreement as to whether σ_{KE} is positive or negative. Cf. Berndt and Wood (1975, 1979) and Pindyck (1979). Consequently, within the framework of the EMF model there is a compelling case that an externally imposed increase in the relative price of energy will lower the competitive rate of return to capital; whether the competitive real wage rises or falls remains in doubt.

The long-run effects of higher energy prices depend upon the conditions of factor supply. If the supply of capital is an increasing function of the rate of return to capital and the supply of labour is perfectly inelastic, the reverse feedback effects on potential GNP through capital will exacerbate the initial adverse effect through the terms of trade. Therefore, according to the EMF model energy and capital should be viewed as aggregate complements, because an increase in energy prices--which leads to a reduction in energy use--will almost certainly lower the rate of return to capital and thereby the rate of capital formation.

3. A Revised Model

A crucial implicit assumption of the EMF model is that domestic energy production requires capital and labour in the same ratio as the rest of the economy at any set of factor prices. Expressed alternatively, the factor intensity and factor substitution parameters for energy and non-energy goods must be identical. If one believes that there are significant differences between the cost-minimizing capital-labour ratio and/or elasticity of substitution between capital and labour in the production of energy and non-energy goods, then a more general model is called for.

In this paper I propose to specify GNP explicitly in terms of production functions for final output and for energy. If $F(K_y,L_y,E)$ represents the production function for final output and $G(K_e,L_e,T)$ represents the production function for domestic energy in which capital, labour, and an energy-specific resource such as land enter as arguments, then GNP can be written:

$$GNP = F(K_y,L_y,E) + \bar{p}_e[G(K_e,L_e,T) - E]. \tag{2}$$

Since the expression in squared brackets $G(\cdot) - E$ represents net energy exports (or net imports if negative), then GNP is simply the amount of final output that remains after paying world prices for energy imports. Alternatively, GNP can be viewed as the sum across industries of the values added measured at world prices, namely $F(\cdot) - E + \bar{p}_e G(\cdot)$. Clearly, (1) and (2) are equivalent formulations only in the special case of a pure energy importing economy, in which case both $H(\cdot)$ and $G(\cdot)$ vanish. The major advantage of (2) is that it highlights the fact that even if the economy-wide supplies of capital and labour are fixed, they will nevertheless be shifted between the energy sector and the rest of the economy in response to changes in relative output prices, and this can have important consequences for their relative marginal productivities.

A major objective of this paper is to analyze the short-run and long-run effects of higher energy prices on factor rewards, capital formation, and potential GNP under competitive conditions and with full employment continuously maintained. In the short run the economy-wide supplies of capital, labour, and land will be held fixed but capital and labour will be free to shift between sectors to ensure that their returns are equalized. Thus, the short-run equilibrium is determined by maximizing (2) subject to (3):

$$L_y + L_e \le \bar{L};\ K_y + K_e \le \bar{K};\ T \le \bar{T} \tag{3}$$

In a longer-run perspective the supplies of capital, labour, and even land may be sensitive to their rates of return. In order to preserve the essential features of the standard EMF model, we shall assume that the supplies of labour and land are both perfectly inelastic, but the supply of capital is an increasing function of the rate of return to capital. There are certain tactical advantages in focussing on what might be interpreted as an extreme version of the economy's long-run equilibrium whereby the supply of capital is perfectly elastic and unaffected by changes in the relative price of energy.[4] For economies that are closed to international investment, a perfectly elastic domestic supply of capital emerges as a characterization of long-run equilibrium provided the citizenry maximizes an intertemporal preference function with a constant (possibly zero) pure discount rate on utility, and an isoelastic marginal utility of consumption at each date.[5] Of course, the transition from one long-run equilibrium to another will generally entail a gradual rather than an immediate accumulation or decumulation of capital. However, in this paper we abstract from the details of the dynamic adjustment process and focus only on a comparison of steady states. A long-run equilibrium in which the cost or supply price of capital remains fixed provides an extreme which can be compared to the short-run equilibrium in which the quantity of capital is held fixed. It yields a plausible upper bound for the secondary impact of higher energy prices on potential GNP operating through capital. The long-run equilibrium is then given by maximizing (2) subject to (4):

$$L_y + L_e \leq \bar{L}; \quad T \leq \bar{T}; \quad F_{K_y} = \bar{p}_e G_{K_e} = \bar{r}. \tag{4}$$

4. Short-Run and Long-Run Effects on Potential GNP

The short-run effect on potential GNP of a small increase in the relative price of energy is given by differentiating the first-order conditions corresponding to (2) and (3) with respect to $\bar{p}_e$. Letting a hat over a variable denote the percentage change in that variable, we obtain:

$$\widehat{SRGNP} = \{-\theta_{1E}(1-e/E)/[1-\theta_{1E}(1-e/E)\} \, \hat{p}_e \tag{5}$$

where θ_{1E} represents the share of energy in the cost of final output, and e/E represents the ratio of domestic energy production to energy demand. Clearly, potential GNP will fall whenever the economy is a net energy importer, and the percentage decline depends on both the share of energy costs in the production of final output and the fraction of energy demand met by imports. Thus, if energy constitutes 5 percent of the total cost of production for final output, a 10 percent increase in the relative price of energy will reduce potential GNP in the short run by approximately -.53 percent for a pure energy importer, but only by - .08 percent if the economy--like the United States--imports only 15 percent of its total energy requirements.[6]

In the long run, land and labour are exogenously determined while capital is free to adjust to preserve its rate of return. The long-run effect on potential GNP of a small increase in the relative price of energy is therefore given by differentiating the first-order conditions corresponding to (2) and (4) with respect to $\bar{p}_e$ to obtain:

$$\widehat{GNP} = \delta_K[\lambda_1\hat{K}_y + (1-\lambda_{1K})\hat{K}_e] - \{\theta_{1E}(1-e/E) / [1-\theta_{1E}(1-e/E)]\}\hat{p}_e \qquad (6)$$

Here δ_K represents the share of GNP accruing to capital, λ_{1K} represents the share of the capital stock employed in the production of final output, and $\hat{K}_y$ and $\hat{K}_e$ represent the percentage changes in the amount of capital that can be profitably employed in each sector at the long-run cost of capital $\bar{r}$.

Economic theory alone cannot determine the direction--let alone the magnitude--of change in capital formation that can take place in each sector at the predetermined long-run cost of capital. Nonetheless, there is a strong presumption--based upon both theoretical and empirical considerations--that $\hat{K}_y$ will be negative and $\hat{K}_e$ positive. Thus, consider the effect on factor rewards in each sector when neither factor is free to move. An increase in the relative price of energy confers windfall gains on factors as a whole in the energy sector, and windfall losses on factors as a whole in the rest of the economy. In the neutral case these gains and losses will be distributed equally among the factors within each sector, so one would expect the wage and rate of return to capital to rise in the energy sector and fall in the rest of the economy. The disparity in wage rates between sectors would then cause labour to shift from the production of final goods into the production of energy, and this process would normally cause the rate of return to rise further in the energy sector and fall further in the rest of the economy. But if capital must earn a rate of return of $\bar{r}$ in long-run equilibrium, the equilibrium capital stock must increase in the energy sector and decrease elsewhere.

While the foregoing argument is perfectly valid under 'normal' circumstances, it should be emphasized that it does not necessarily follow if one is willing to impose only the minimum well-behaved restrictions on the technology (i.e., monotonicity and convexity conditions). Even if one is prepared to accept the conditions necessary to ensure the 'normal' outcome, the critical determinant of whether the long-run effect through capital mitigates or exacerbates the short-run effect is the direction of change in the economy's overall capital stock. If 90 percent of the capital stock is used in the production of final output and only 10 percent is used in the production of energy, then $\hat{K}_e$ must be at least 9 times as great as $\hat{K}_y$ in absolute value to ensure a mitigating long-run (or reverse feedback) effect on potential GNP through capital. Finally, even if this seemingly stringent condition holds it does not ensure that the long-run reverse feedback effect through capital will offset the initial terms of trade loss. In the balance of this paper we attempt to show that, while the conditions for mitigating and offsetting reverse feedback effects through capital seem, at first blush, stringent indeed, they turn out to be not implausible conditions for a net importing economy like the United States.

5. Dual Formation

The short- and long-run competitive equilibria discussed in the previous two sections can be represented in an alternative way using the duality between production and cost functions. This dual formulation has the advantage of yielding comparative statics results in terms of factor intensity and factor substitution parameters about which there is some empirical evidence to guide our calculations. The short-run equilibrium is characterized by the minimization of total factor payments to the three indigenous factors subject to the constraints that all factor prices are positive and profits are zero or negative in all industries. Letting $C^i(\cdot)$ i=1,2 represent the dual unit cost functions for the final goods sector and energy sector respectively, and w, r, and s represent the competitive wage rate of return (or rental rate) to capital, and land rent respectively, we have the short-run equilibrium characterized by

$$\begin{aligned} &\text{minimize} \quad w\bar{L} + r\bar{K} + s\bar{T} \\ &\text{subject to} \quad C^1(w,r,\bar{p}_e) \geq 1;\ C^2(w,r,s) \geq \bar{p}_e;\ w,r,s \geq 0 \end{aligned} \tag{7}$$

The equilibrium conditions corresponding to this specification can be expressed as equations (8)-(12), where we have assumed that the economy produces positive amounts of both energy and non-energy goods, e and y respectively.

$$C^1(w,r,\bar{p}_e) = 1 \tag{8}$$

$$C^2(w,r,s) = \bar{p}_e \tag{9}$$

$$y \cdot C^1_w(w,r,\bar{p}_e) + e \cdot C^2_w(w,r,s) = \bar{L} \tag{10}$$

$$y \cdot C^1_r(w,r,\bar{p}_e) + e \cdot C^2_r(w,r,s) = \bar{K} \tag{11}$$

$$e \cdot C^2_s(w,r,s) = \bar{T} \tag{12}$$

The first two equations are zero profit conditions and the last three equations are market-clearing conditions for labour, capital, and land respectively. The first partial derivative of the unit cost function with respect to the price of a factor gives the cost minimizing per unit demand for that factor. Cf. Diewert (1974).

In the long run the supplies of land and labour remain fixed, but the supply of capital is determined endogenously by the condition that capital must earn a rate of return of $\bar{r}$ in both sectors. The long-run equilibrium is characterized by:

$$\begin{aligned} &\underset{\{w,s\}}{\text{minimize}} \quad w\bar{L} + s\bar{T} \\ &\text{subject to} \quad C^1(w,\bar{r},\bar{p}_e) \geq 1;\; C^2(w,\bar{r},s) = \bar{p}_e,\; w,s \geq 0 \end{aligned} \tag{13}$$

The equilibrium conditions for an interior minimum then consist of equations (8)-(10), and (12), with r constrained to equal $\bar{r}$. The short-run model is a fully simultaneous system. The tactical advantage of assuming that the rate of return to capital is an exogenous variable in long-run equilibrium is that it results in a recursive system that is considerably easier to solve.

6. Short-Run Effects on Factor Rewards

The percentage changes in factor rewards and sectoral outputs that occur in the short run with economy-wide factor supplies fixed and free inter-sectoral mobility are determined by totally differentiating the system of 5 equations (8)-(12) with respect to a small change in $\bar{p}_e$. The comparative statics results emerge as the solution to the following matrix equation:

$$\begin{bmatrix} \theta_{1L} & \theta_{1K} & 0 & 0 & 0 \\ \theta_{2L} & \theta_{2K} & \theta_{2T} & 0 & 0 \\ \delta_{LL} & \delta_{LK} & \delta_{LT} & \lambda_{1L} & \lambda_{2L} \\ \delta_{KL} & \delta_{KK} & \delta_{KT} & \lambda_{1K} & \lambda_{2K} \\ \delta_{TL} & \delta_{TK} & \delta_{TT} & 0 & 1 \end{bmatrix} \begin{bmatrix} \hat{w} \\ \hat{r} \\ \hat{s} \\ \hat{y} \\ \hat{e} \end{bmatrix} = \begin{bmatrix} -\theta_{1E} \\ 1 \\ -\delta_{LE} \\ -\delta_{KE} \\ 0 \end{bmatrix} \hat{p}_e \tag{14}$$

where the coefficients in (14) have the following interpretations: θ_{ij} represents the cost share of the j^{th} factor in the i^{th} sector; λ_{ij} represents the proportion of the j^{th} factor employed in the i^{th} sector; and $\delta_{ij} = \lambda_{1i}\theta_{1j}\sigma^1_{ij} + \lambda_{2i}\theta_{2j}\sigma^2_{ij}$ is an appropriate weighted average of the AES partial elasticities of substitution between factors i and j in the two sectors, namely σ^1_{ij} and σ^2_{ij}.[7]

Of particular interest in this paper are the percentage changes in the wage, rate of return to capital, and rent to the natural resource. These expressions evidently depend in a rather complex way upon the factor intensity and factor substitution parameters for each sector. Fortunately, certain restrictions hold on the values of the various parameters in the coefficient matrix of (14); the 2x3 sub-matrix θ and the 3x2 sub-matrix λ have non-negative elements with rows summing to unity; in addition, the 3x3 sub-matrix δ has non-positive diagonal elements, since the AES own partial elasticities of substitution are necessarily non-positive. However, despite these restrictions, it turns out that an increase in the relative price of energy may either raise or lower the wage, the rate of return to capital, and the rent accruing to the natural resource. The only theoretical restrictions on these distributive effects are: first, that if the wage increases then the rate of return to capital must fall, and vice versa; and second, that if the economy is a net energy importer prior to the increase in the relative price of energy then those groups that stand to gain from an increase in energy's relative price cannot compensate those who stand to lose without making themselves worse off.

In order to facilitate the exposition, it is useful to focus on the special case where the production functions for each sector are members of the CES family. Then all three AES cross partial elasticities of substitution for each sector (σ_{ij}^k) are equal to the conventional two-factor elasticity of substitution (σ_k) and the own partial elasticities of substitution (σ_{ii}^k) are related to σ_k by $-\sigma_{ii}^k = (1-\theta_{ki})\sigma_k/\theta_{ki}$. Considerable simplification of (14) is then achieved, and we obtain the following expressions for the percentage changes in the wage rate and the rate of return to capital:

$$\hat{w} = \frac{1}{\Delta}\{[\theta_{1K} + \theta_{1E}\theta_{2K}(1 + \theta_{2T})]\lambda\sigma_2 + \theta_{1E}\theta_{2T}\lambda_{1L}(\lambda_{1K}\sigma_1 + (1 - \lambda_{1K})\sigma_2)\}\hat{p}_e \qquad (15)$$

$$\hat{r} = \frac{1}{\Delta}\{-[\theta_{1L} + \theta_{1E}\theta_{2L}(1 + \theta_{2T})]\lambda\sigma_2 + \theta_{1E}\theta_{2T}\lambda_{1K}(\lambda_{1L}\sigma_1 + (1 - \lambda_{1L})\sigma_2)\}\hat{p}_e \qquad (16)$$

In this formulation $\Delta = -\theta_{2T}(1-\theta_{1E})\lambda_{1K}\lambda_{1L}\sigma_1 - [\lambda\theta + \theta_{2T}(\theta_{1L}\lambda_{1L}\lambda_{2K} + \theta_{1K}\lambda_{1K}\lambda_{2L})]\sigma_2 < 0$, $\lambda = \lambda_{1L}\lambda_{2K} - \lambda_{1K}\lambda_{2L} = \lambda_{1L} - \lambda_{1K}$, and $\theta = \theta_{1L}\theta_{2K} - \theta_{1K}\theta_{2L}$.[8]

In the absence of factor market distortions λ and θ will have the same signs; each will be positive whenever the energy sector is more capital intensive than the rest of the economy, negative if the energy sector is less capital intensive, and zero if, as in the standard EMF model, energy and non-energy goods have the same factor intensities. Expressions (15) and (16) then clearly show the joint influence of factor intensity and factor substitution parameters. An increase in the world relative price of energy can drive up the real wage only if the energy sector is more labour intensive than the rest of the economy, and drive up the rate of return to capital only if the energy sector is more capital intensive than the rest of the economy. But neither of these conditions is sufficient when the economy's natural resource endowment constrains output in the energy sector; in addition to the degree of factor intensity disparity between sectors, the degree of inter-factor substitution within each sector plays a crucial role as well. Thus, even if factor intensities differ widely between sectors, neither the wage nor the rate of return to capital can increase as a consequence of an increase in the relative price of energy unless there is some scope for factor substitution in the energy sector, i.e., unless $\sigma_2 > 0$.

Expressions (15) and (16) become solutions to the standard EMF model of energy-economy interaction when $\lambda_{1K} = \lambda_{1L} = 1$ (implying that the economy is a pure energy importer), or when $0 < \lambda_{1K} = \lambda_{1L} < 1$ and $\sigma_1 = \sigma_2$ (implying that the factor intensity and substitution parameters are identical for the two sectors). In either case, it is apparent that the symmetric substitution possibilities exhibited by a CES technology for final output ensure that an increase in the relative price of energy reduces both the wage and the economy-wide rate of return to capital--and by the same percentage.

In the standard EMF model an increase in the world relative price of energy will distribute national income from capital to labour if and only if labour and energy are closer AES substitutes than capital and energy. In our more general two sector framework the income distribution criterion becomes:

$$\hat{w} - \hat{r} = \frac{1}{\Delta}\{\theta_{1K} + \theta_{1L} + \theta_{1E}(1 + \theta_{2T})(\theta_{2K} + \theta_{2L}) + \theta_{1E}\theta_{2T}\}\lambda\sigma_2\hat{p}_e \qquad (17)$$

Thus, the impact of an increase in the world relative price of energy on income distribution is governed solely by which sector is capital intensive, and the magnitude of the distributive impact varies directly with the size of the gap between factor intensities and the size of the elasticity of substitution in the energy sector.[9]

What is the effect of an increase in the relative price of energy on the competitive rent earned by the natural resource that is specific to the energy sector? We already have the information to answer this question since in our three factor model the GNP is simply the sum of the factor payments to capital, labour, and land. It follows that the percentage change in the return to the energy-specific natural resource is given by:

$$\hat{s} = (\widehat{GNP} - \delta_L\hat{w} - \delta_K\hat{r})/(1-\delta_L-\delta_K) \qquad (18)$$

where δ_L and δ_K represent the shares of GNP accruing to labour and capital.

Expression (18) determines $\hat{s}$ residually from $\hat{w}$ and $\hat{r}$, but it gives no indication whether $\hat{s}$ is positive or negative. If we proceed by solving the basic matrix equation (14) for $\hat{s}$ we obtain:

$$\hat{s} = -\frac{1}{\Delta}\{\lambda_{1L}(\theta_{1L}+\theta_{1E}\theta_{2L})(\lambda_{1K}\sigma_1+\lambda_{2K}\sigma_2)+\lambda_{1K}(\theta_{1K}+\theta_{1E}\theta_{2K})(\lambda_{1L}\sigma_1+\lambda_{2L}\sigma_2)\}\hat{p}_e \quad (19)$$

which clearly indicates that in the CES case the return to the energy specific resource must increase, and the magnitude of the increase varies directly with the elasticity of substitution in each sector but is independent of which sector is capital intensive.

7. Long-Run Effects on Capital Formation

If the competitive rate of return on the fixed supply of capital increases as a consequence of an increase in the world relative price of energy one might expect the flow of saving available to finance further capital formation to increase because of the higher reward for saving. However, this neglects the fact that for a net energy importing economy the total real income available for saving will have fallen and that the distribution of this income will be away from labour which--in a finite life cycle context--may have the highest propensity to save. These considerations are ignored in this paper by postulating that the individual consumer-saver effectively has an infinite time horizon with the well-being of his heirs as an argument. Bequests as well as retirement consumption constitute the motive for saving. Then under plausible conditions the immediate response to an increase in world energy prices which raises the reward for saving but lowers the current income available for saving is to induce individuals to undertake additional saving until the return for saving is driven down to an exogenously determined value that reflects pure time preference.

If the cost of capital remains unchanged in the long run, the economy's competitive wage rate depends only on the technology of the final goods sector and the exogenously determined cost of energy; the competitive wage rate is independent of the economy-wide supplies of labour and land provided both energy and non-energy goods are produced. From (10) a (small) increase in the relative price of energy with the cost of capital held fixed will reduce the real wage by:

$$\hat{w} = -(\theta_{1E}/\theta_{1L})\hat{p}_e \quad . \tag{20}$$

The unit cost of final output cannot change, because the price of final output is held fixed as the price of energy increases, i.e., we are examining the effects of an increase in the relative price of energy. Labour costs must therefore fall whenever energy costs rise; and if labour costs bulk large in total cost while energy costs are minor, the percentage reduction in the wage is a mere fraction of the percentage increase in the price of energy. The fact that only factor intensity (share) parameters and not factor substitution parameters matter in (20) is a reflection of the second-order importance of induced factor substitution effects for small changes.

The long-run impact on the competitive rent to the energy specific natural resource is given by totally differentiating (11) with respect to $\bar{p}_e$ holding r fixed, and substituting $\hat{w}$ from above to obtain:

$$\hat{s} = \frac{1}{\theta_{2T}} \{1 + \frac{\theta_{1E}\theta_{2T}}{\theta_{1L}}\}\hat{p}_e \tag{21}$$

The overall impact on the return to the natural resource is the sum of two components: the first component measures the response of an increase in the price of energy with no change in either labour or capital costs; the second component takes into account that labour costs actually fall because the competitive wage is set in the final goods sector. Notice the magnification effect of higher energy prices on the competitive rent to the natural resource;

all of the benefits of an energy price increase (and more) accrue to the energy-specific resource in the long run, and the percentage increase in the rent is a multiple of any energy price increase because only a fraction of the unit cost of energy goods is made up of energy-specific resource rents.

In the special case of a CES technology the percentage changes in the outputs of energy and non-energy goods are determined by differentiating equations (10) and (12) totally with respect to a change in $\bar{p}_e$ holding r fixed and substituting for $\hat{w}$ and $\hat{s}$:

$$\hat{e} = \{\theta_{2L}[\theta_{1L} + \theta_{1E}(\theta_{2L} + \theta_{2T})]\sigma_2/\theta_{1L}\theta_{2T}\}\hat{p}_e \qquad (22)$$

$$\hat{y} = \{-\frac{\theta_{1E}}{\theta_{1L}}\sigma_1 - \frac{1-\lambda_{1L}}{\lambda_{1L}}[\theta_{1E}(\theta_{2L} + \theta_{2T}) + \frac{\theta_{1L}}{\theta_{2T}}]\theta_{1L}\sigma_2\}\hat{p}_e \qquad (23)$$

The elasticity of substitution is a crucial determinant of the response in supply of each output; for a CES technology domestic energy production will expand unless $\sigma_2 = 0$, and the production of final goods will contract unless $\sigma_1 = \sigma_2 = 0$.

The expression in braces in (22) measures the general equilibrium elasticity of supply of domestic energy; it differs from the partial equilibrium elasticity given by $\eta_s=(1-\theta_{2T})\sigma_2/\theta_{2T}$, because in the general equilibrium framework an increase in the price of energy is accompanied by a reduction in the wage rate, and this serves to further stimulate domestic energy production.

The percentage reduction in the output of final goods as shown in (23) is greater than it would be if the economy were a pure energy importer. Higher energy prices cause firms producing final output to economize on energy use.

If the supply of labour were fixed and the cost of capital were given to these firms the response would be given by the first term in (23). But we have seen that there will be a tendency for some labour to shift from final goods production to energy production and this loss of labour will further reduce the output of final goods, an effect that is captured by the second term in (23).

Perhaps of greater interest for this paper is the general equilibrium response in the domestic demand for energy. Using Shephard's lemma, we can express domestic energy demand as the product of the level of final output and the cost minimizing per unit demand for energy in the production of final output: $E = y \cdot C^1_{p_e}(w,r,p_e)$. It follows that the general equilibrium elasticity of demand for energy is given by the expression in braces in (24):

$$\hat{E} = \{-\left(\frac{\theta_{1E}+\theta_{1L}}{\theta_{1L}}\right)\sigma_1 - \frac{1-\lambda_{1L}}{\lambda_{1L}}\left[\theta_{1E}(\theta_{2L}+\theta_{2T})+\frac{\theta_{1L}}{\theta_{2T}}\right]\theta_{1L}\sigma_2\}\hat{p}_e \quad (24)$$

The elasticity of demand for energy is greater for a net energy importer than for a pure energy importer because we have already noted in (23) that the output of final goods declines by a greater percentage in the former case than the latter; this effect is captured by the second term in (24).[10]

The impact of an increase in the relative price of energy on total capital formation in long-run equilibrium depends on the impact on each sector. Equation (25) expresses the economy's long-run demand for capital as the sum of sectoral demands:

$$K^d = K_y + K_e = y\, C^1_r(w,\bar{r},\bar{p}_e) + e\, C^2_r(w,\bar{r},s) \quad (25)$$

The percentage change in capital formation in the energy sector is given by differentiating totally the second term in (25) with respect to $\bar{p}_e$ and substituting for $\hat{w}$, $\hat{s}$, and $\hat{e}$. In the special case of a CES technology for energy goods we obtain:

$$\hat{K}_e = (1 + \theta_{1E}\theta_{2L}/\theta_{2T})\sigma_2\ \hat{p}_e \quad (26)$$

Thus, in the CES case the percentage increase in capital formation in the energy sector is proportional to the elasticity of substitution σ_2, where the factor of proportionality is always greater than one.

The percentage change in capital formation in the rest of the economy is given by totally differentiating the first term in (25) with respect to $\bar{p}_e$ and substituting for $\hat{w}$, $\hat{s}$, $\hat{y}$, and $\hat{e}$. For the special case of a CES technology we obtain:

$$\hat{K}_y = \{-\frac{\theta_{1E}}{\theta_{1L}}\sigma_1 - \frac{1-\lambda_{1L}}{\lambda_{1L}}[\frac{\theta_{1E}}{\theta_{1L}}(\theta_{2L}+\theta_{2T})+1]\frac{\sigma_2}{\theta_{2T}}\}\hat{p}_e \qquad (27)$$

where λ_{1L} represents the share of the labour force employed in the production of final output. For a pure energy importer $\lambda_{1L} = 1$ and the second term in (27) vanishes. Higher energy prices will then lead to a decrease in capital formation, and to an extent that is proportional to σ_1. However, if the economy has a viable energy sector, there will be a further reduction in capital formation in the final goods sector because some labour will be shifted into energy production.

It should be emphasized that under more general technological conditions an increase in the world relative price of energy may actually lead to a reduction in capital formation in the energy sector and an increase in capital formation in the rest of the economy. An intuitive explanation for this somewhat anomalous result is as follows. An increase in the relative price of energy ultimately causes a reduction in the economy's competitive wage while the long-run cost of capital remains unchanged. Firms throughout the economy are therefore encouraged to use less capital intensive methods than before in producing any level of output and to an extent that depends upon the elasticity of substitution between capital and labour. This pure substitution effect serves to reduce the capital requirements for energy and non-energy goods alike. On the other hand, a higher relative price of energy makes it privately and socially profitable to expand the domestic production of energy; this output expansion effect is accomplished in our model by devoting more capital and labour to the given natural resource base, and to an extent that depends on the elasticity of substitution between capital and labour on the one hand and the energy-specific resource on the other. In the CES case the two relevant elasticities of substitution are equal, and this guarantees a positive overall impact on capital formation in the energy sector. However, the CES specification could bias the actual outcome upward or downward in particular circumstances.

For example, if it is relatively easy to substitute capital for labour in the energy sector but very difficult to substitute either of these inputs for the fixed supply of the energy-specific natural resource, then capital formation in the energy sector will fall. Moreover, if labour and capital are strong complements in the rest of the economy and capital and energy are closer substitutes than labour and energy, then it is conceivable that higher relative energy prices cause labour to shift from the energy sector to the rest of the economy, and this could result in more capital formation in this sector rather than less.

The percentage change in total capital formation for the economy as a whole is a weighted average of the percentage changes in each sector, where the weights reflect the initial shares of capital employed in each sector. In the CES case we have found that capital formation increases in the energy sector and decreases in the rest of the economy. Nonetheless, even within this relatively simple framework the direction and magnitude of change in economy-wide capital formation is an issue that can only be resolved empirically.

8. Implications of AES Capital-Energy Complementarity

The foregoing section illustrates that even within the simplified framework provided by a CES technology the interplay between higher energy prices, the rate of return to capital, capital formation, and potential GNP is a complex empirical issue. However, while the CES specification is both rich and tractable as a vehicle of analysis, there is at least one potentially important feature of the economy that it fails to capture. Recent empirical work by Berndt and Wood (1975,79) and others has indicated that capital and energy may be AES complements rather than substitutes--at least for the industrial sectors. An increase in the relative price of energy may therefore induce cost minimizing firms facing given prices for labour and capital to reduce their per unit demands for both energy and capital, and to increase their per unit demand for labour.

The CES specification used in the derivations above rules out AES complementarity between any pair of factors, so some generalization is required if we are to trace through the implications of this feature. A full generalization of the technology for $F(\cdot)$ would place no a priori restrictions on the signs or magnitudes of the three AES cross-partial elasticities of substitution--except for the fact that at most one of them can be negative. But this degree of generality would come at the cost of computational simplicity and require reliable empirical knowledge of three parameters rather than one. Fortunately, as noted by Berndt and Wood (1979) there is a weakly separable specification of the production function for final output that cannot be rejected on statistical grounds and yet is consistent with (but does not necessarily imply) AES capital energy complementarity. Suppose $F(K,L,E)$ can be written in the nested form $H(R(K,E),L)$, where $H(\cdot)$ is linear homogeneous in labour and the composite factor (R, interpreted as 'utilized' capital), and R(·) is linear homogeneous in physical capital (K) and energy. Then the cost minimizing mix of physical capital and energy depends only on the relative price of capital to energy, while the cost minimizing mix of the composite factor and labour depends on the relative price of the composite factor to labour. The price of the composite factor is a linear homogeneous function of the prices of physical capital and energy. A one percent increase in the price of energy holding all other factor prices fixed will cause the ratio of physical capital to energy to rise by σ_R percent if the quantity of utilized capital is held constant, where σ_R is the elasticity of substitution between E and K in R(·). But if the price of energy increases by one percent, the price of the composite factor (utilized capital) of which energy is a component must rise by a percentage equal to the proportion of energy costs in the cost of the composite factor, namely $\theta_{1E}/(\theta_{1E} + \theta_{1K})$. Consequently, the ratio of utilized capital to labour in the production of final output will fall by $\sigma_H \cdot (\theta_{1E} + \theta_{1K})$ percent, where σ_H measures the elasticity of substitution between R and L in H(·). Whether more or less physical capital is used in the production of a unit of final output when the price of energy increases with labour and physical capital costs unchanged depends on the relative strength of these two effects. Capital and energy will be AES complements in F(·) whenever $\sigma_R < \theta_{1L}\sigma_H$.[11]

An important advantage of the weakly separable specification is that it reduces from 3 to 2 the number of AES cross-partial elasticities of substitution that are free to vary independently. If σ^1_{KE} represents the AES partial elasticity of substitution between capital and energy in F(·), the above restrictions imply that σ^1_{KE} is free to vary from negative to positive while the other two AES cross-partial elasticities are necessarily non-negative and equal to each other ($\sigma^1_{KL} = \sigma^1_{LE} \equiv \sigma^1_{RL}$). Some additional generality over the CES framework is therefore achieved because we now require information about both σ^1_{KE} and σ^1_{RL} rather than just σ_1.

It will suffice for our purposes in this section to derive an expression for the percentage change in the rate of return to capital in this somewhat more general framework. Detailed calculations for the other variables of interest will be deferred to the next section. Returning to the basic matrix equation (14) and imposing the weakly separable restrictions outlined above, we obtain the following expression for $\hat{r}$:

$$\hat{r} = \frac{1}{\Delta^1}\{-[\theta_{1L} + \theta_{1E}\theta_{2L}(1+\theta_{2T})]\ \lambda\ \sigma_2 + \theta_{1E}\theta_{2T}\lambda_{1K}[\lambda_{1L}((1+\theta_{1L})\sigma^1_{RL} - \sigma^1_{KE}) + (1-\lambda_{1L})\sigma_2]\}\hat{p}_e \qquad (28)$$

where $\Delta^1 < 0$.[12] In the 3 factor case at most one pair of factors can be AES complements so that $\sigma^1_{RL} > 0$ whenever $\sigma^1_{KE} < 0$. Inspection of (28) then reveals that if the capital-labour ratios are identical for energy and non-energy goods (i.e., $\lambda = 0$) then AES capital energy complementarity is a sufficient condition for an increase in the relative price of energy to reduce the competitive rate of return to capital. On the other hand, whenever the energy sector is more capital intensive than the rest of the economy (i.e., $\lambda > 0$) and there is some scope for factor substitution in the production of energy goods ($\sigma_2 > 0$), then AES capital energy complementarity in $F(\cdot)$ is no longer sufficient to ensure that higher energy prices reduce the rate of return to capital.

If the competitive rate of return to capital in the economy can increase when the supply of capital is held fixed, even though capital and energy are AES complements in the production of final output, it follows that economy wide capital formation can increase in the long run when the supply price of capital is restored to its initial level.

9. Toward an Empirical Assessment

What is the likely response in factor rewards, capital formation, and potential GNP to a small increase in the world relative price of energy for the U.S. economy under perfectly competitive conditions and full employment? Since the appropriate values for several key parameters that enter as determinants remain a matter of considerable debate, we have made calculations for a range of the main contentious parameters, and assigned precise values for others. Our choice of parameter values requires some justification.

First, we assume that under initial free trade conditions, and with domestic consumer and producer prices for energy goods equal to world prices, the U.S. would import 15 percent of its domestic energy requirements. This is somewhat less than the 20 percent figure assumed by Schelling (1979) to be the contribution of imported energy to the U.S. in 1977-78 when domestic energy prices were substantially below world prices, and it coincides with the 15 percent assumption made by Solow and Peck (1980).

Second, in modelling the technology of final output we have assumed that the production function is weakly separable between labour on the one hand and capital and energy on the other. As noted, this restriction has the advantage of leaving open the issue as to whether capital and energy are AES substitutes or complements, while reducing from 3 to 2 the number of free parameters that summarize substitution possibilities for this sector; it also reduces to the CES technology as a special case. But rather than permit both σ^1_{KE} and σ^1_{RL} to vary, we have constrained σ^1_{RL} to equal 0.5--a value that is broadly consistent with a wide range of econometric evidence.

Third, two alternative sets of parameter values have been assumed to represent the cost shares of labour, capital, and energy in the production of final output: in the first case the cost shares are $\theta_{1L} = .7$, $\theta_{1K} = .25$, and $\theta_{1E} = .05$ respectively; in the second case the cost shares are $\theta_{1L} = .65$, $\theta_{1K} = .30$, and $\theta_{1E} = .05$ respectively. These cost shares would correspond to a division of GNP between returns to labour and property (capital plus land) ranging from .735 to .684 and from .265 to .316 respectively, if the economy were a pure energy importer, or if the economy were a net energy importer with identical capital labour rates for energy and non-energy goods.[13] Even if the capital-labour ratio were significantly higher for the energy sector than for the rest of the economy the implied division of GNP into labour and property incomes would deviate only slightly from this range; labour's share of GNP would be shifted downward somewhat, and capital's share would be shifted upward by a corresponding amount. National income data for the U.S. are broadly consistent with this range of values.

Fourth, in modelling the technology of the energy sector we have assumed that the production function is weakly separable between capital and labour on the one hand and the energy specific natural resource on the other. As already noted, this offers somewhat more flexibility in summarizing substitution possibilities than the CES specification, since there are then two freely independent AES parameters. However, the weakly separable specification, like the simpler CES specification, is imposed at some risk; one of its implications is that the cost-minimizing capital-labour ratio for incremental energy projects that become viable as the relative price of energy increases is the same as that for existing projects. It may well be the case that new energy projects are more capital intensive than existing ones--not just in the sense of requiring a higher capital-output ratio, but also in the sense of requiring a richer mixture of capital to labour. If true, our simplification will bias downward the short-run impact of higher energy prices on the rate of return and the long-run impact of higher energy prices on capital formation.

The weakly separable specification for the energy sector leaves both the AES cross-partial elasticity of substitution between capital and labour (σ^2_{KL}) and the AES cross-partial elasticity of substitution between either capital or labour and the natural resource (σ^2_{VT}) free to vary. To reduce further the number of degrees of freedom we have assumed that the direct elasticity of substitution between capital and labour holding the natural resource fixed is 0.5--again a number with some econometric support. Consequently, the above two AES parameters are constrained by the condition that $(\theta_{2K}+\theta_{2L})\sigma^2_{KL} + \theta_{2T}\sigma^2_{VT} = 0.5$, so that choosing values for one necessarily implies values for the other.[14]

The range of values we have chosen for σ^2_{VT} reflects different perceptions about the partial equilibrium elasticity of supply of domestic energy η_S, which is related to σ^2_{VT} by: $\eta_S = (1-\theta_{2T})\sigma^2_{VT}/\theta_{2T}$. If $\theta_{2T} = .5$, then σ^2_{VT} and η_S are identical, whereas if $\theta_{2T} = .33$ then η_S is twice σ^2_{VT}. Peck and Solow (1980) think of η_S as being in the neighbourhood of 0.25, whereas Solow (1974) would place the value of σ^2_{VT} somewhat in excess of 1.0, and Nordhaus and Tobin (1972) regard it as of the order of 1.5. We have chosen the values of 0.25 and 1.5 as upper and lower bounds for σ^2_{VT}.

Finally, the appropriate cost shares for the energy sector in an aggregative model of this type is a matter of considerable debate. However, the implicit maintained hypothesis of the EMF model--that the energy sector is no more or less capital intensive than the rest of the economy--is strongly contradicted by evidence presented by Hudson and Jorgenson (1974,78) and Vacarra (1975).[15] Moreover, as long as the share of rents earned in the energy sector (θ_{2T}) exceeds the share of energy costs in final output (θ_{1E}), the EMF model implies a higher capital-output ratio in the production of final output than in the production of energy, and we find this implication at odds with the growing evidence that the capital requirements necessary to reduce the nation's dependence on imported oil are massive. Accordingly we have made two sets of assumptions about the division of the revenue generated by domestic energy production: in the first case we assume that the revenue is distributed equally between capital, labour, and land so that $\theta_{2K} = \theta_{2L} = \theta_{2T} = .33$; in the second case we assume that $\theta_{2L} = .5$, $\theta_{2K} = .3$, and $\theta_{2T} = .2$, thereby making the energy sector somewhat less capital intensive than in the first case but still significantly more capital intensive than the rest of the economy.

Table 1 presents, for the first set of cost share parameters, distributive effects of a 10 percent increase in the relative price of energy for various pairings of σ^1_{KE} and σ^2_{VT} when the economy wide supplies of all factors are held fixed. There are 16 sets of implied estimates corresponding to 4 alternative values of σ^1_{KE} (shown in the 4 rows) and 4 values of σ^2_{VT} (shown in the 4 columns). The entries in the first two rows of the table are consistent with AES capital-energy complementarity in the production of final output; the third and fourth rows reflect situations where capital and energy are independent factors and substitutes respectively. The entries in the first two columns of the table correspond to a pessimistic view of the elasticity of domestic energy supply; the elasticity of domestic energy supply approaches zero as the price of energy rises, so the fixed supply of the energy specific resource places an upper bound on domestic energy production. By contrast, the third and fourth columns reflect an optimistic view about domestic energy supply: in column 3 the elasticity of domestic energy supply is constant everywhere along the supply curve; in column 4 the elasticity of domestic energy supply is actually increasing as the price of energy rises, as would be consistent with the existence of a backstop technology in which the energy-specific resource was non-essential.

It is evident from Table 1 that the competitive wage falls and the competitive rent to the natural resource rises for all combinations of σ^1_{KE} and σ^2_{VT}. The percentage decline in the competitive wage, while small in

TABLE 1

Impact on Wage, Rate of Return, and Natural Resource Rent of 10 Percent Increase in Relative Price of Energy with Factor Supplies Fixed*

σ^1_{KE} \ σ^2_{VT}		.25	.5	1.0	1.5
$\hat{w}$		- .25	- .41	- .72	-1.01
$\hat{r}$	-1.0	-1.31	- .86	.01	.84
$\hat{s}$		31.49	31.20	30.64	30.12
$\hat{w}$		- .40	- .55	- .85	-1.13
$\hat{r}$	- .5	- .89	- .46	.37	1.16
$\hat{s}$		31.22	30.94	30.41	29.91
$\hat{w}$		- .54	- .69	- .97	-1.24
$\hat{r}$	0	- .49	- .08	.71	1.46
$\hat{s}$		30.97	30.70	30.20	29.71
$\hat{w}$		- .67	- .81	-1.08	-1.34
$\hat{r}$	.5	- .12	.27	1.02	1.75
$\hat{s}$		30.73	30.48	30.00	29.53

*Short-run impact on potential GNP is $\widehat{SRGNP} = -.076$. Distributive shares of national income accruing to capital, labour, and land are .266, .720, and .014 respectively.

TABLE 2

Impact on Capital Formation and Potential GNP of 10 Percent Increase in Relative Price of Energy with Capital Supply Perfectly Elastic*

σ^1_{KE}	σ^2_{VT}	.25	.5	1.0	1.5
$\hat{K}_e$		7.60	15.37	30.92	46.47
$\hat{K}_y$	-1.0	-1.27	-1.43	-1.74	-2.05
$\hat{K}$		- .79	- .53	.01	.55
$\widehat{GNP}$		(-.29)	(-.22)	(-.07)	(.06)
$\hat{K}_e$		7.60	15.37	30.92	46.47
$\hat{K}_y$		-1.02	-1.18	-1.49	-1.80
$\hat{K}$	- .5	- .56	- .29	.25	.78
$\widehat{GNP}$		(-.22)	(-.15)	(-.01)	(.13)
$\hat{K}_e$		7.60	15.37	30.92	46.47
$\hat{K}_y$		- .77	- .93	-1.24	-1.55
$\hat{K}$	0	- .32	- .05	.48	1.02
$\widehat{GNP}$		(-.16)	(-.09)	(.05)	(.20)
$\hat{K}_e$		7.60	15.37	30.92	46.47
$\hat{K}_y$		- .52	- .68	- .99	-1.30
$\hat{K}$	.5	- .08	.18	.72	1.26
$\widehat{GNP}$		(-.10)	(-.03)	(.12)	(.26)

*Long-run impacts on wage and natural resource rent are $\hat{w} = -.71$ and $\hat{s} = 30.74$.

magnitude, is nevertheless highly sensitive to the values of the two AES parameters, and varies directly with them. By contrast, the percentage increase in the competitive natural resource rent is on the order of three times the percentage increase in the price of energy, and highly stable across pairings of the AES parameters.

The most important feature of the table pertains to the percentage change in the rate of return to capital. Here we find that both the direction and magnitude of change in the rate of return is sensitive to the relative values of the two AES parameters. While the percentage change in the rate of return is an increasing function of both σ^1_{KE} and σ^2_{VT}, it is apparent that the rate of return to capital can increase even if σ^1_{KE} is negative, and even if σ^2_{VT} is less than one. Finally, the percentage reduction in potential GNP is -.076 for all pairings of the AES parameters. This is an appropriate weighted average of the percentage changes in the three factor prices using the distributive shares as weights. The fact that it is independent of substitution terms reflects the second-order importance of induced substitution effects when price changes are small. However it should be noted that it is an upper bound estimate that is strictly accurate only if there are no induced substitution effects, i.e., only if σ^1_{KE} and σ^2_{VT} are both zero.

Whenever the competitive rate of return to capital increases in the short run when the economy-wide supplies of productive factors are fixed, the rate of capital formation will increase in the long run, thereby at least partially offsetting the initial reduction in potential GNP. This is confirmed in Table 2,which presents the implied effects on sectoral and total capital formation and, in brackets, the percentage change in potential GNP. Focussing on the first two rows of the table, we find that even if capital and energy are AES complements, an increase in energy prices can lead to an increase in capital formation which at least partially offsets the initial reduction in potential GNP. In fact, for the parameter values we have chosen, the reverse feedback effects through capital can fully offset the initial adverse terms of trade effect, leaving the economy with a higher sustainable real income than before the energy price increase; this can happen despite AES capital-energy complementarity whenever σ^2_{VT} is somewhat greater than one. In general, the reverse feedback effect through capital will mitigate and possibly fully offset the initial terms of trade effect when σ^1_{KE} and σ^2_{VT} tend to be large. Table 2 dramatizes the fact that the direction of the reverse feedback effect through capital is fundamentally an empirical issue that cannot be resolved by simple characterizations of the production process for final output (such as that it is CES, or such that capital and energy are AES complements). Finally, it should also be noted that whenever the reverse feedback effect through capital serves to offset the initial terms of trade effect, it tends to drive up both the competitive wage and natural resource rent. Nevertheless, in long-run equilibrium the competitive wage is necessarily lower than prior to the energy price increase--lower by .71 percent whenever the relative price of energy rises by 10 percent for the parameter values used in this paper.[16]

How sensitive are our results to the above cost share assumptions? To answer this question we consider briefly the alternative case in which the cost shares of capital, labour, and energy in the production of final output are $\theta_{1K}= .30$, $\theta_{1L}= .65$, and $\theta_{1E}= .05$ respectively, so that the 'rest of the economy' is slightly more capital intensive than before. In addition, we assume that the cost shares of capital, labour, and the natural resource in the energy sector are $\theta_{2K}= .30$, $\theta_{2L}= .50$, and $\theta_{2T}= .20$ respectively, so that energy goods are slightly less capital intensive than before. The energy sector remains more capital intensive than the rest of the economy, but the gap between factor intensities narrows.

Table 3 indicates that the percentage reduction in the real wage is somewhat smaller than in the previous case, and the percentage increase in the rent to the natural resource is somewhat larger. The direction and magnitude of change in the rate of return to capital remains highly sensitive to the pairing of the two AES parameters as before; however, in this case an increase in the world relative price of energy results in an increase in the rate of return only when $\sigma^1_{KE} \geq 0$ and $\sigma^2_{VT} \geq 1$. Thus, as illustrated in Table 4, the secondary reverse feedback effect on potential GNP through capital is the largest component of the overall negative effect of higher world real energy prices whenever $\sigma^1_{KE} \leq 0$ and $\sigma^2_{VT} \leq 1$. Only if $\sigma^1_{KE} = 0.5$ and $\sigma^2_{VT} = 1.5$ will the secondary reverse feedback effect through capital actually more than offset the initial terms of trade effect, thereby leaving the economy with a higher sustainable real GNP after the full adjustment to higher energy prices is complete.[17]

TABLE 3

Impact on Wage, Rate of Return, and Natural Resource Rent of 10 Percent Increase in Relative Price of Energy with Factor Supplies Fixed*

	σ^1_{KE} \ σ^2_{VT}	.25	.5	1.0	1.5
$\hat{w}$		-.08	-.17	-.34	-.52
$\hat{r}$	-1.0	-1.49	-1.30	-.92	-.55
$\hat{s}$		52.44	52.37	52.24	52.11
$\hat{w}$		-.27	-.35	-.52	-.69
$\hat{r}$	-.5	-1.09	-.90	-.54	-.18
$\hat{s}$		52.30	52.24	52.11	51.99
$\hat{w}$		-.44	-.52	-.68	-.84
$\hat{r}$	0	-.71	-.53	-.18	.16
$\hat{s}$		52.17	52.11	51.99	51.87
$\hat{w}$		-.60	-.68	-.84	-.99
$\hat{r}$	.5	-.36	-.19	.15	.49
$\hat{s}$		52.05	51.99	51.87	51.76

*Short-run impact on potential GNP is $\widehat{SRGNP} = -.076$. Distributive shares of national income accruing to capital, labour, and land are .315, .676, .009 respectively.

TABLE 4

Impact on Capital Formation and Potential GNP of 10 Percent Increase in Relative Price of Energy with Perfectly Elastic Supply of Capital*

σ^1_{KE} \ σ^2_{VT}		.25	.5	1.0	1.5
$\hat{K}_e$		12.87	25.96	52.16	78.37
$\hat{K}_y$	-1.0	-1.57	-2.00	-2.85	-3.71
$\hat{K}$		-.98	-.86	-.61	-.36
$\widehat{GNP}$		(-.38)	(-.35)	(-.27)	(-.19)
$\hat{K}_e$		12.87	25.96	52.16	78.37
$\hat{K}_y$	-.5	-1.32	-1.75	-2.60	-3.46
$\hat{K}$		-.74	-.62	-.37	-.12
$\widehat{GNP}$		(-.31)	(-.27)	(-.19)	(-.11)
$\hat{K}_e$		12.87	25.96	52.16	78.37
$\hat{K}_y$	0	-1.07	-1.50	-2.35	-3.21
$\hat{K}$		-.50	-.38	-.13	.12
$\widehat{GNP}$		(-.23)	(-.19)	(-.11)	(-.04)
$\hat{K}_e$		12.87	25.96	52.16	78.37
$\hat{K}_y$	.5	-.82	-1.25	-2.10	-2.96
$\hat{K}$		-.26	-.14	.11	.36
$\widehat{GNP}$		(-.16)	(-.12)	(-.04)	(.04)

*Long-run impacts on wage and natural resource rent are $\hat{w} = -.77$ and $\hat{s} = 51.92$.

10. Conclusion

An increase in the world relative price of energy confers an immediate real income loss upon a net energy importing economy whose magnitude under full employment conditions depends on both the proportion of its energy requirements met from imports and the share of energy costs in the production of final output. The reduction in real income coincides with a reduction in potential real GNP properly adjusted for terms of trade effects; it reflects a transfer of real income from domestically owned primary factors (capital and labour) to foreign suppliers of energy.

In a pure energy importing economy--or in an economy in which the capital-labour intensity and substitution parameters are identical for energy and non-energy goods--the distribution of the domestic real income loss under competitive conditions depends upon the relative magnitude of the AES partial elasticities of substitution between energy and capital and energy and labour; capital will suffer a greater percentage real income loss than labour whenever labour and energy are closer AES substitutes than capital and energy. Since econometric evidence is broadly supportive of this ordering--at least for the industrial sectors--there is a reasonably strong presumption that an increase in the world relative price of energy will reduce the competitive rate of return to capital. If the domestic supply of capital is an increasing function of the rate of return to capital while the supply of labour is perfectly inelastic, the feedback effects through capital will lead to a further reduction in the potential GNP and sustainable real income of the economy.

We have shown in this paper that if energy production is significantly more capital intensive than the rest of the economy an increase in the world relative price of energy may distribute real income from labour to capital and actually drive up the competitive rate of return to capital despite the fact that capital and energy appear as AES complements to individual energy using forms throughout the economy. Thus, for a modest net energy importing economy like the U.S. that relies on foreign sources for 15 to 20 percent of its domestic energy requirements any initial adverse effect on potential GNP and real income arising from the need to pay a higher real price for imported energy may be partially, if not wholly, offset by reverse feedback effects through capital. Consequently, even if higher real energy prices reduce the incentive to invest in sectors which contribute 95 percent or more to the economy's GNP, it may be seriously misleading to ignore the substantial positive stimulus to capital formation in the other 5 percent of the economy producing energy goods. The standard EMF model of energy-economy interaction thus carries a very real danger of reversing rather than replicating the full general equilibrium result of an increase in world energy prices for net energy importing economies.

The results of this paper appear at first blush to contradict flatly simulation results presented by Hudson and Jorgenson (1978) based upon an elaborate and impressive dynamic general equilibrium model of the U.S. economy. They find that U.S. real potential GNP fell by 3.2 percent as a consequence of the increase in world energy prices that took place between 1972 and 1976. In their own words "higher energy prices have had a dramatic impact on the U.S. economy over the period 1972-76. This impact is not limited to a reduction in the growth of energy consumption, but it has also resulted in a slowdown in economic growth, a weak recovery of capital spending, a substantial increase in employment and a decline in the growth of productivity" (1978, p. 877). However, a closer examination of the H-J analysis reveals that subtle but crucially different questions are being asked in the two cases. Whereas we assume that higher energy prices are externally imposed, and therefore stimulate domestic energy production as well as deterring domestic energy demand, H-J assume implicitly that higher energy prices are a reflection of a perceived need to reduce domestic energy demand, and that domestic energy supply is adjusted downward to satisfy the lower domestic demand requirements that will be forthcoming at the higher prices. Despite the obvious reliance of the U.S. on imported energy, the H-J analysis treats energy as a sort of non-traded intermediate good whose domestic supply is adjusted to meet domestic demand requirements, or some fraction thereof. This can be the only plausible interpretation of their simulation results which indicate that despite the 1972-76 increase in world energy prices "the importance of the energy sector is reduced substantially, from 5.9 percent to 5.0 percent of total output" (1978, p. 883).

It is a major thrust of this paper that domestic energy conservation initiatives should be viewed as a rational response to higher world energy prices originating from events external to the U.S. and other industrialized nations. An increase in world energy prices--unaccompanied by offsetting measures to restrict or curtail domestic energy supply--will stimulate domestic energy production as well as deterring domestic energy demand. Failure to take into account the substantial positive stimulus to capital formation in the domestic energy sector has led analysts to draw erroneous conclusions about the impact of higher world energy prices on capital formation and potential GNP.[18]

Two final points are worth making before concluding the paper. First, we have made no mention of the effect of higher world energy prices on domestic welfare, but it should be apparent that unless there are pre-existing domestic tax distortions any net energy importing economy must be made worse off by an increase in world energy prices whether or not sustainable real GNP and real income rises or falls as a consequence of the energy price increase. However, if as many would argue, the predominant domestic distortion arises from the tax treatment of income from capital, there will be a welfare gain whenever higher world energy prices stimulate capital formation because the discounted sum of future consumption gains will exceed the immediate consumption loss. Second, while we have considered an increase in world energy prices matched by a domestic energy price increase, it is worth noting that if the U.S. were to impose a tariff on energy imports at unchanged world energy prices and rebate the tariff revenue in a lumpsum fashion this would have precisely the same qualitative effects on capital formation and potential GNP without any accompanying terms of trade loss; however, it would still result in a reduction in domestic welfare in the absence of pre-existing market distortions.

Footnotes

[1]It should be noted that there are at least three quite distinct sources of domestic energy price increases which have been analyzed--but not always carefully distinguished--in the literature: First, domestic energy price increases designed to reduce domestic energy use at unchanged world energy prices c.f. Wright (1980); second, increases in world energy prices with concomitant increases in domestic energy costs c.f. Pindyck (1979); and third increases in world energy prices with domestic cost conditions unchanged c.f. Sweeney (1979). We focus on the latter source of domestic energy price increases throughout this paper primarily because of a belief that recent energy conservation initiatives should be viewed as a rational response to higher energy prices resulting from events external to the industrialized nations--the 1973 Arab oil embargo and the subsequent pricing policy of OPEC.

[2]Hudson and Jorgenson (1978) estimate that U.S. potential real GNP fell by 3.2 percent between 1972 and 1976 as a consequence of the increase in world energy prices that occurred over that period. Sweeney (1979) provides a simple conceptual framework within which the Hudson-Jorgenson results can be rationalized. He and Hogan (1977) argue that, if energy and capital are complementary inputs, an increase in energy prices will reduce potential real GNP not only because of a reduction in energy use but also because of an induced reduction in capital formation. Hogan and Manne (1977) show that if the aggregate production function for final output is CES with the elasticity of substitution equal to 0.3 then a 50 percent increase in energy prices will reduce real potential GNP by 4 percent if the capital stock is held fixed, but by 11 percent if the supply of capital is adjusted (downward) to preserve the rate of return to capital.

[3]If $\sigma_{KE} = \sigma_{LE}$ then the aggregate production $F(\cdot)$ is weakly separable between energy on the one hand and primary factors (capital and labour) on the other. The isoquant for a unit of real value added then shifts outward in a neutral manner when the price of energy increases. With fixed economy-wide supplies of capital and labour the competitive wage and rental rate to capital decline by equal percentages. Algebraically $d(w/r)/dpe = d(F_L/F_K)/dpe = (F_K F_{LE} - F_L F_{KE})/F_K^2$. But $\sigma_{KE} = F|F_{KE}|/K \cdot E \cdot |F|$, and $\sigma_{LE} = F|F_{LE}|/L \cdot E \cdot |F|$. It follows after some manipulation that $\text{sign}(\sigma_{KE} - \sigma_{KE}) = \text{sign}(F_K F_{LE} - F_L F_{KE})$.

[4]For small open economies integrated into the world capital market a perfectly elastic supply price of capital seems like a reasonable first approximation. However, unless all capital formation were financed by internally generated savings the economy's GNP would deviate from its GDP.

[5]From (2) the economy's GNP can be expressed in terms of a variable profit function $\pi(\bar{p}_e, K, \bar{L}, \bar{T})$. If we postulate that the citizenry behaves as if it maximizes $\int_0^\infty U(C)e^{-\rho t}dt$, where $U(C) = C^\gamma$, subject to: $\dot{K} = \pi(\bar{p}_e, K, \bar{L}, \bar{T}) - \delta K - C$, and $K(0) = K_o$, it follows that in long-run equilibrium $\pi_K = \delta + \rho$, independent of the relative price of energy $\bar{p}_e$. This specification of the determinants of aggregate savings (whereby individuals act as if they have infinite time horizons) follows if finite lived agents have the utility of future generations as an argument in their intertemporal preference functions.

[6] Real GNP is typically defined using prices prevailing in some base period. Thus, according to this practice an increase in the world relative price of energy will leave real GNP at full employment unchanged unless the economy uses less energy, and for a net energy importer real GNP as conventionally measured will fall by less than real income because the terms of trade effect is ignored. In this paper we identify the economy's real GNP with its real income. The estimates derived here will be biased upward because they ignore induced factor substitution effects which occur whenever the elasticity of substitution between energy and other factors is greater than zero. But they will be accurate first approximations provided the change in the relative price of energy is small.

[7] In arriving at (14) we have made use of the fact that the AES own and cross partial elasticities of substitution can be expressed in terms of the first and second partial derivatives of the unit cost function, namely $\sigma_{ij} = CC_{ij}/C_iC_j$. See Diewert (1974) for proof.

[8] λ_{1L} represents the proportion of the labour force employed in the first sector, namely $y \cdot C_w^1/L$, and similarly $\lambda_{1K} = y \cdot C_r^1/K$. Therefore $\lambda_{1L} - \lambda_{1K} > 0$ whenever $C_w^1/L - C_r^1/K > 0$, i.e. whenever $C_w^1/C_r^1 > L/K$, or that the first sector uses a higher L/K ratio than the economy as a whole. θ_{1L} represents the share of labour costs in the production of final output, and θ_{1K} represents the share of capital costs. Thus $\theta_{1L}/\theta_{1K} = wL_1/rK_1 = wC_w^1/rC_r^1$ by Shephard's Lemma. In the absence of factor market distortions the costs of labour and capital are the same for the two sectors so that $\theta_{1L}/\theta_{1K} > \theta_{2L}/\theta_{2K}$ whenever $L_1/K_1 > L_2/K_2$, i.e. whenever the first sector is more labour intensive than the second.

[9]An interesting feature of (17) is the fact that a wider gap between the capital-labour ratios in the two sectors serves to strengthen the distributive impact. This is in stark contrast to the knife-edge property of the conventional two factor-two good model of non-joint production where the distributive impact is greatest when the factor intensities differ but are close together.

[10]The own price elasticity of demand for energy holding the level of final output fixed is given by $\eta_d = -(\theta_{1K} + \theta_{1L})\sigma_1$ for a CES technology. This is, of course, just a local response in energy demand since unless $\sigma_1 = 1$ the distributive shares accruing to the non-energy inputs (capital and labour) will vary. The general equilibrium elasticity differs because the level of output and the competitive wage fall when the price of energy is increased.

[11]If the production function F(K,L,E) can be written in the nested form H(R(K,E),L) then the following relationship holds between the conventional two factor elasticities of substitution (σ_K and σ_H) and the AES partial elasticity of substitution σ^1_{KE}: $\sigma^1_{KE} = \sigma_R/S_R + (1 - 1/S_R)\sigma_H$, where S_R is the share of capital and energy costs in the production of final output, namely $\theta_{1E} + \theta_{1K}$. Capital and energy will be AES complements whenever $\sigma^1_{KE} < 0$, i.e., whenever $\sigma_R < (1 - S_R)\sigma_H$, where $1 - S_R = \theta_{1L}$, the share of labour costs in the production of final output.

[12]The expression for Δ obtained as the determinant of the coefficient matrix in (14) can be written in the general form: $\Delta = -(1+\theta_{2T})(\lambda_{1L} - \lambda_{1K})(\theta_{1L}\theta_{2K} - \theta_{1K}\theta_{2L})\sigma_2 - \theta_{2T}[\theta_{1L}(\lambda_{1K}\delta_{wr} - \lambda_{1L}\delta_{rr}) + \theta_{1K}(\lambda_{1L}\delta_{rw} - \lambda_{1K}\delta_{ww})]$. To get the particular value of Δ when the production function for final output $F(\cdot)$ can be written in the nested form H(R(K,E),L) and when the production function for energy is CES we must substitute the following values for the δ_{ij} into the

expression for Δ to obtain Δ'.

$$\delta_{ww} = -[\lambda_{1L}(1-\theta_{1L})\sigma^1_{RL} + \lambda_{2L}(1-\theta_{2L})\sigma^2]; \quad \delta_{rr} = -[\lambda_{1K}(\theta_{1L}\sigma^1_{RL} + \theta_{1E}\sigma^1_{KE}) + \lambda_{2K}(1-\theta_{2K})\sigma_2]$$

$$\delta_{wr} = \lambda_{1L}\theta_{1K}\sigma^1_{RL} + \lambda_{2L}\theta_{2K}\sigma_2; \quad \delta_{rw} = \lambda_{1K}\theta_{1L}\sigma^1_{RL} + \lambda_{2K}\theta_{2L}\sigma_2.$$

[13]If δ_L represents the share of labour income in GNP, then we can write $\delta_L = WL/GNP = (WL_1/Y)(Y/GNP)/(L_1/L)$. But $Y/GNP = Y/(Y + P_e(e - E)) = 1/(1 + \theta_{1E}(e/E - 1))$. Hence $\delta_L = \theta_{1L}/[\lambda_{1L}(1 + \theta_{1E}(e/E - 1))]$. Similarly, the share of capital income in GNP can be written: $\delta_K = \theta_{1K}/[\lambda_{1K}(1 + \theta_{1E}(e/E - 1))]$.

[14]This relationship between direct and AES partial elasticities of substitution follows by an argument perfectly analogous to that presented in footnote 11 above.

[15]Table 1 of Hudson and Jorgenson (1974) indicates that the ratio of capital's share to labour's share is higher in all energy producing sectors (except coal mining) than in any energy consuming sector. Even for coal mining, future expansion of the industry will involve open pit rather than underground techniques, and the former is substantially more capital intensive than the latter.

[16]It is worth noting that for the parameter values chosen for this case the general equilibrium elasticity of demand for energy ranges from a low of -.18 (when $\sigma^1_{KE} = -1.0$ and $\sigma^2_{VT} = .25$) to a high of -.63 (when $\sigma^1_{KE} = 0.5$ and $\sigma^2_{VT} = 1.5$). The general equilibrium elasticity of domestic supply of energy ranges from a low of .5 to a high of 3.0 as σ^2_{VT} varies from .25 to 1.5.

[17]For the parameter values chosen for this case the general equilibrium elasticity of demand for energy ranges from -.13 to -.79, while the general equilibrium elasticity of domestic energy supply ranges from 1.0 to 6.0.

[18]Thus, Pindyck (1979, p. 271), argues that while the initial adverse economic impact of higher world energy prices may be ameliorated by a re-investment of the windfalls accruing to domestic energy producers, this effect is likely to be minor so that with reasonable approximation one can view an increase in world energy prices as an increase in the resource cost of domestic energy.

REFERENCES

[1] Allen, R. D. G., Mathematical Analysis for Economists, Macmillan, London, 1938.

[2] Berndt, E. R. and D. O. Wood, "Technology, Prices and the Derived Demand for Energy," Review of Economics and Statistics, vol. 56, August 1975, pp. 259-268.

[3] Berndt, E. R. and D. O. Wood, "Engineering and Econometric Interpretations of Energy-Capital Complementarity," American Economic Review, vol. 69, June 1979, pp. 342-354.

[4] Diewert, W. E., "Applications of Duality Theory" in M. D. Intriligator and D. A. Kendrick (eds.), Frontiers of Quantitative Economics, vol. 2, Amsterdam, North-Holland, 1974.

[5] Hogan, W. W., "Capital-Energy Complementarity in Aggregative Energy-Economic Analysis" in Energy and the Economy, Volume 2, Energy Modeling Forum Report EMF 1.10 (Stanford University, Institute for Energy Studies, Stanford, CA), September, 1977.

[6] Hogan, W. W., and A. S. Manne, "Energy-Economy Interactions: The Fable of the Elephant and the Rabbit?" in Energy and the Economy, Volume 2, Energy Modeling Forum Report EMF 1.3 (Stanford University, Institute for Energy Studies, Stanford, CA), September, 1977; also published in C. Hitch (ed.), Modeling Energy-Economy Interactions: Five Approaches, Resources for the Future, Washington, D.C., 1977.

[7] Hudson, E. A. and D. W. Jorgenson, "U.S. Energy Policy and Economic Growth 1975-2000," Bell Journal of Economics, vol. 5, Fall 1974, pp. 461-514.

[8] Hudson, E. A. and D. W. Jorgenson, "Energy Prices and the U.S. Economy 1972-76," Natural Resources Journal, vol. 18, October, 1978, pp. 877-897.

[9] Hudson, E. A. and D. W. Jorgenson, "The Economic Impact of Policies to Reduce U.S. Energy Growth," Resources and Energy, vol. 1, November, 1978, pp. 205-229.

[10] Nordhaus, W. D. and J. Tobin, "Is Growth Obsolete?" in Economic Growth, Fiftieth Anniversary Colloquium, vol. 5, N.B.E.R., New York, 1972.

[11] Peck, S. C. and J. L. Solow, "Domestic Energy and Taxes: Forgotten Factors in Energy-Economy Interactions," Electric Power Research Institute and Stanford University, mimeo, 1980.

[12] Pindyck, R. S., The Structure of World Energy Demand, MIT Press, Cambridge, Mass., 1979.

[13] Reister, D. B. and J. A. Edmonds, "A General Equilibrium Two Sector Energy Demand Model" in C. Hitch (ed.), Modeling Energy-Economy Interactions: Five Approaches, Resources for the Future, Washington, D.C., 1977.

[14] Schelling, T. C., Thinking Through the Energy Problem, Committee for Economic Development, Washington, 1979.

[15] Solow, J. L., "A General Equilibrium Approach to Aggregate Capital-Energy Complementarity," Journal of Economics Letters, vol. 2, 1979, pp. 91-94.

[16] Solow, R. M., "Intergenerational Equity and Exhaustible Resources," Review of Economic Studies, Symposium Issue, 1974.

[17] Sweeney, J. L., "Energy and Economic Growth: A Conceptual Framework," Energy Modeling Forum, Occasional Paper, EMF OP 3.0, 1979, also in B. Kursunoglu and A. Perlmutter (eds.), Directions in Energy Policy: A Comprehensive Approach to Energy Resource Decision Making, Cambridge, Ballinger, 1979, pp. 115-140.

[18] Uzawa, H., "Production Functions with Constant Elasticities of Substitution," Review of Economic Studies, vol. 29, June, 1962, pp. 291-299.

[19] Vaccara, B. N., A Study of Fixed Capital Requirements of the U.S. Business Economy 1971-1980, Washington: U.S. Department of Commerce, Bureau of Economic Analysis, December, 1975.

[20] Wright, B. D., "The Cost of Tax Induced Energy Conservation," Bell Journal of Economics, vol. 11, No. 1, pp. 84-107.

CENTRE FOR THE STUDY OF INTERNATIONAL ECONOMIC RELATIONS

University of Western Ontario

Working Papers

8001. Robson, Arthur J. OPEC VERSUS THE WEST: A ROBUST DUOPOLY SITUATION

8002. McMillan, John and Ewen McCann. WELFARE EFFECTS IN CUSTOMS UNIONS

8003. Leith, J. Clark. MONEY, THE BALANCE OF PAYMENTS, AND GOVERNMENT DEBT IN A SMALL OPEN LDC: HAITI

8004. Mansur, Ashan and John Whalley. A DECOMPOSITION ALGORITHM FOR GENERAL EQUILIBRIUM COMPUTATION WITH APPLICATION TO INTERNATIONAL TRADE MODELS

8005. Schmid, Michael. OIL, EMPLOYMENT AND THE PRICE LEVEL: A MONETARY APPROACH TO THE MACROECONOMICS OF IMPORTED INTERMEDIATE GOODS UNDER FIXED AND FLEXIBLE RATES

8006. Markusen, James R. THE DISTRIBUTION OF GAINS FROM BILATERAL TARIFF REDUCTION

8007. Markusen, James R. TRADE AND THE GAINS FROM TRADE WITH IMPERFECT COMPETITION

8008. Markusen, James R. and James R. Melvin. TRADE, FACTOR PRICES, AND THE GAINS FROM TRADE WITH INCREASING RETURNS TO SCALE

8009. Whalley, John. AN EVALUATION OF THE RECENT TOKYO ROUND TRADE AGREEMENT THROUGH A GENERAL EQUILIBRIUM MODEL OF TRADE INVOLVING MAJOR TRADING AREAS.

8010. Laidler, David. MONETARISM: AN INTERPRETATION AND AN ASSESSMENT.

8011. Wonnacott. Paul and Ronald J. Wonnacott. FREE TRADE BETWEEN THE UNITED STATES AND CAN ADA: FIFTEEN YEARS LATER

8012. Hamilton, Bob and John Whalley. OPTIMAL TARIFF CALCULATIONS IN ALTERNATIVE TRADE MODELS AND SOME POSSIBLE IMPLICATIONS FOR CURRENT WORLD TRADING ARRANGEMENTS.

8013. Wonnacott, Paul and Ronald J. Wonnacott. THE TARIFF-FOREIGN OWNERSHIP-TECHNOLOGY NEXUS: TOWARDS A LESS TRUNCATED THEORY OF CANADIAN INDUSTRIAL TRUNCATION

8014. Laidler, David. INFLATION AND UNEMPLOYMENT IN AN OPEN ECONOMY - A MONETARIST VIEW.

8015. Leith, J. Clark. AN ESSAY ON COMMERCIAL POLICY IN THE POST-IMPORT SUBSTITUTION ERA.

8016. Schmid, Michael. DEVALUATION: KEYNESIAN TRADE MODELS AND THE MONETARY APPROACH -THE ROLE OF NOMINAL AND REAL WAGE RIGIDITY-

8017. Whalley, John. INTERNATIONAL TRADE NEUTRALITY PROPOSITIONS FOR MOVEMENTS BETWEEN 'ORIGIN/SPLIT-RATE' AND'DESTINATION/CREDIT' TAX BASES.

8018 Whalley, John and Bernard Yeung. EXTERNAL SECTOR 'CLOSING' RULES IN APPLIED GENERAL EQUILIBRIUM MODELS.

8019. Boyer, Russell S. and Geoffrey H. Kingston. Currency Substitution: A Perfect Foresight Optimizing Analysis.

8020. Markusen, James R. MULTINATIONALS AND THE GAINS FROM TRADE: A THEORETICAL ANALYSIS BASED ON ECONOMIES OF MULTI-PLANT OPERATION.

8021. Conlon, R.M. TRANSPORT COST AND TARIFF PROTECTION OF AUSTRALIAN AND CANADIAN MANUFACTURING: A COMPARATIVE STUDY.

8022. Markusen, James R. THE WELFARE AND ALLÒCATIVE EFFECTS OF EXPORT TAXES VERSUS MARKETING BOARDS.

1981

8101C. Markusen, James R. Factor Movements and Commodity Trade as Compliments: A Survey of Some Cases.

8102C. Conlon, R.M. Comparison of Australian and Canadian Manufacturing Industries: Some Empirical Evidence.

8103C. Conlon, R.M. The Incidence of Transport Cost and Tariff Protection: Some Australian Evidence.

8104C Laidler, David. On the Case for Gradualism.

8105C. Wirick, Ronald G. Rational Expectations and Rational Stabilization Policy in an Open Economy.

8106C Mansur, Ahsan and John Whalley. NUMERICAL SPECIFICATION OF APPLIED GENERAL EQUILIBRIUM MODELS: ESTIMATION, CALIBRATION, AND DATA

8107C Burgess, David F., ENERGY PRICES, CAPITAL FORMATION, AND POTENTIAL GNP