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# Trade Policies and U.S. Economic Growth

Mun S. Ho & Dale W. Jorgenson

Harvard University

ABSTRACT

Traditional estimates of the welfare effects of trade policies were made within a static framework, whether using partial or general equilibrium models. Here we construct a dynamic g.e. model with full intertemporal equilibrium in order to assess the impact on *growth* as well as the usual static effects. We find that even a mild tariff rate of 3% will result in a consumption gain of 0.8% in the long run compared to the 0.16% static gain. When the effects of quotas are included the effects are even more dramatic. The GNP growth rate over the first 20 years rises form 2.34% to 2.38% due to the elimination of tariffs and some quotas. Unlike other g.e. models, ours allows for full substitution among inputs in the production and consumption functions. Furthermore, technical change is endogenous, i.e., it's affected by input prices.

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The numerical model used here was developed with Peter Wilcoxen, building on previous work by Ed Hudson and Dick Goettle B Fraumeni, D Park and D. Slesnick are the more prominent of the many associates whose data and estimates we use We are also grateful to Andrew Parks of the International Trade Commission for the trade data

## 1. Introduction

Two of the more striking features of the postwar U.S. macroeconomy are the sharp downturn in growth after the early 70s, and the slowdown of productivity growth. In parallel with this are the large sectoral shifts of output, the doubling of the trade share in GNP, and the changing nature of government microeconomic policies.[1] Among the latter we would include taxation, environmental regulation, energy policies and foreign trade regulation. The interaction between public policy and economic performance is obviously a complex web, given the expected increase in import penetration, here we shall focus only on U.S. trade policy.[2] We restrict our attention to two aspects of U.S. trade policy -- tariffs and quotas on imports, and examine the welfare and growth implications.

Over the recent decade U.S. commercial policy, and the world's in general, have turned from tariffs to quantitative restrictions. In 1980 U.S. tariff revenue was a mere 2.9% of the value of commodity imports. The coverage and severity of quotas and "voluntary export restrictions," however, has grown substantially. Hence, while the effects of tariffs are small, and will keep getting smaller with the continued international agreements, the effects of the new policies are bigger and may well increase.

Traditional analyses of trade barriers have been pursued along two lines. One is the detailed partial equilibrium estimates such as Hufbauer, Berliner and Elliot (1986), and the other uses large general equilibrium models such as the "Michigan Model" of Deardoff and Stern (1986).[3] While each of these approaches have many desirable features, they are both static in nature which ignores the dynamic effects on growth, capital accumulation

[1] Annual GNP growth declined from 3.7% (1948-73) to 2.3% (1973-85). The private sector productivity growth rate fell from 1.15% (1947-73) to -0.3% (1973-85) (see Jorgenson 1988). The agriculture and manufacturing sectors shar. of private GNP was 4.7% and 31.4% in 1960, by 1985 they were 2.6% and 22.8% respectively. Commodity imports (excluding factor payments) was 4.4% of GNP in 1960, 10.0% in 1985.

[2] Elsewhere, Jorgenson and colleagues have examined the effects of capital taxation and environmental regulation. See Jorgenson and Yun (1987), Jorgenson and Wilcoxen (1989).

[3] Another well known U.S. trade model is Whalley (1985). Srinivasan and Whalley (1986) contains reports of nine general equilibrium models.

and productivity change.

In parallel with the introduction of such computable models over the last fifteen years was the development of numerical dynamic general equilibrium models to analyse the effects of taxation on growth. Among these are Auerbach, Kotlikoff and Skinner (1983), Goulder and Summers (1989), Jorgenson and Yun (1986). These earlier dynamic models, however, are highly aggregated with just one or two sectors and are thus not useful for detailed analysis.

In this paper we tie these two strands of applied research by constructing a dynamic multi-sector model with full intertemporal equilibrium. By sacrificing country detail that the static models have, we put in the time dimension which allows us to capture the effects of policy shocks on savings, investment and productivity change. We of course still track shifts among our 35 domestic sectors.

We find that if world tariffs are eliminated beginning in 1980 consumption is 0.22% higher in the long run although leisure consumption *falls* initially. The consumption of goods rises by 0.16% in the first period and the welfare gain increases to 0.82% in the steady state. The GNP growth rate for the first 20 years rises from 2.34% per annum to 2.37% due to this elimination of a mere 2.9% U.S. tariff rate.

When some quotas are eliminated the welfare gains are even more substantial, the GNP growth rate (1980:2000) rises to 2.38% per annum. The steady state consumption is some 0.31% higher compared to the initial gain of 0.10%.

One can thus see the importance of including dynamic features to bring out this increase in the welfare effects. The only other multisector dynamic equilibrium models that we are aware of is Goulder and Eichengreen (1989) which utilizes a q-theoretic model with 10 sectors and 2 countries.[4] It, however, like most other numerical models including

[4] A smaller model is Go (1988), which is implemented on the World Bank's GAMS computer package.

the Michigan one, uses very simple functional forms for the producers and consumers, in particular there is no substitution among material inputs.

In our production functions not only is there a rich set of substitution possibilities, but also endogenous non-neutral technical change. Given the sharp swings in commodity prices and the parallel changes in input mix in the 70s and 80s, this flexibility is of great importance. Also, unique among such models, our consumption sector is represented by a non-homothetic function that incorporates demographics. We feel that these features are clearly demanded by the data. Even a cursory examination of the data will reveal the non-linearity of the Engel curves. A slightly more careful look will show the change in the input mix of the producers. Our model is estimated econometrically over a consistent set of post-War U.S. data which differentiate it from most numerical models that use parameter estimates from various sources.[5]

Our model thus complements much of the existing g.e. analyses of U.S. trade policies. While it does not yet have a fully endogenous rest-of-the-world structure, it does however, combine intertemporal equilibrium with the kind of multisectoral approach of the traditional models.

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Because of the limitations in GAMS it is a 3-sector model that runs for only 20 periods. Model implementation using such a high-level language is of course far more convenient.

[5] Our data covers the period 1947-85 and uses all official benchmark input-output tables. The Michigan Model and Whalley's model, in constrast, use pre-1973 I-O tables.

## 2 A Simplified Version of the Model

The degree of disaggregation of our model with its 35 industries and elaborate consumption and government sectors make it rather difficult to exposit in a straightforward manner. The important contrast between static and dynamic models, i.e. the role of capital accumulation, however, can be made with a bare-bones version of the model. It also provides us with phase diagrams that we shall use later.

Consider an infinitely-lived consumer who supplies labor inelastically, and is initially endowed with a capital stock $K_0$. He maximizes an intertemporal utility function,

$$\int e^{-\rho t} \log C_t \, dt \tag{2.1}$$

subject to $\dot{K} = I - \delta K$.

C and I are the rates of consumption and investment, ρ is the pure rate of time preference and δ the rate of depreciation of the capital stock. The dot above a variable denotes the time, t, derivative. Capital and labor are used to produce the consumer good and exportables, X:[6]

$$C = F(K, \bar{L}, X) \qquad F_k > 0, \quad F_L > 0 \quad F_x < 0 \tag{2.2}$$

For simplicity assume that capital goods are made wholly from imports and that there is balanced trade every period (wheat for steel, say). We therefore have:

$$P_m I = P_x X \tag{2.3}$$

where $P_m$ and $P_x$ are the prices of imports and exports respectively. The only role for the government here is that it has imposed "voluntary export restrictions" (VERs) on the trading partner, raising $P_m$ above the competitive world levels.

[6] This formulation is chosen merely to simplify the exposition. It's the production possibility frontier of $C = C(K_c, L_c)$, $X = X(K_x, L_x)$ and $K_c + K_x = K$, $L_c + L_x = L$.

The Hamiltonian for this dynamic problem is :

$$\begin{aligned} H &= e^{-\rho t}\log C_t + q_t\, e^{-\rho t}(I_t - \delta K_t) \\ &= e^{-\rho t}\log F(K_t, \bar{L}, X_t) + q_t\, e^{-\rho t}(P_z X_t / P_m - \delta K_t) \end{aligned} \tag{2.4}$$

The costate variable $q_t$ gives the marginal utility of an extra unit of capital.

Differentiating w.r.t. the control variable, $X_t$, we get the "within period" first-order condition:

$$\frac{F_z}{F_t} + q_t \frac{P_z}{P_m} = 0 \tag{2.5}$$

and the costate equation :

$$\dot{q} - \rho q = -\frac{F_k}{F} + q\delta$$

Rewriting the costate equation yields:

$$\dot{q} = (\rho+\delta)q - \frac{F_k(K, \bar{L}, X)}{F(K, \bar{L}, X)} \tag{2.6}$$

which has the usual interpretation that the marginal product of capital less depreciation plus capital gains is equal to the rate of interest, which in this equation is $\rho$ .

The state equation is:

$$\begin{aligned} \dot{K} &= I - \delta K \\ &= P_z X / P_m - \delta K \end{aligned} \tag{2.7}$$

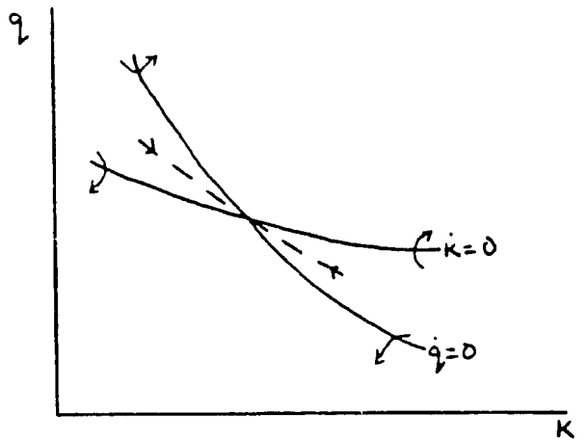
Imposing the transversality condition :

$$\lim_{t\to\infty} e^{-\rho t} q_t = 0 \tag{2.8}$$

For concreteness, take $F$ to be $C = F(..) = f(K,L) - \beta X$. From (2.7) and (2.5) we thus have :

$$\dot{K} = \frac{P_z}{P_m \beta}[f(K,L) - \frac{P_m \beta}{P_z q}] - \delta K \tag{2.9}$$

Putting the two dynamic equations (2.6) and (2.7) in a phase diagram one can see that this is a saddle path stable set of differential equations.




The dashed line represent the unique stable arm of the system where the transversality condition is met. The steady state capital stock is attained when $\dot{q} = 0$, i.e., when the marginal product of capital less depreciation is equal to the rate of time preference.

Another representation, of this economy using C and K, will be useful. Rewriting equation (2.5):

$$F_z = -\frac{P_z}{P_m} qC \tag{2.10}$$

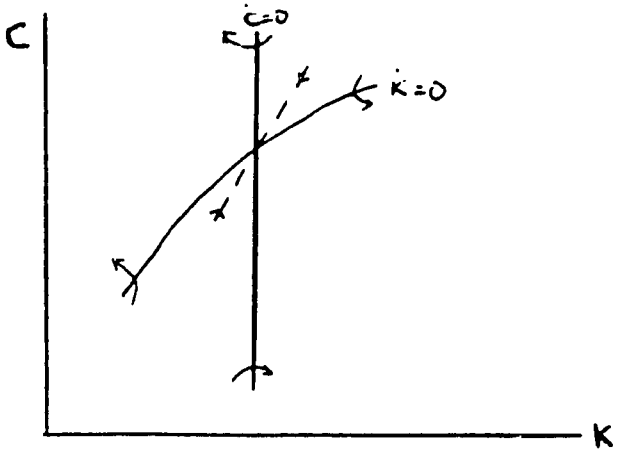
In the case of $F = f(K,L) - \beta X$, $F_z$ is a constant, and differentiating (2.10) w.r.t. time gives

$$0 = \dot{q}C + q\dot{C}$$

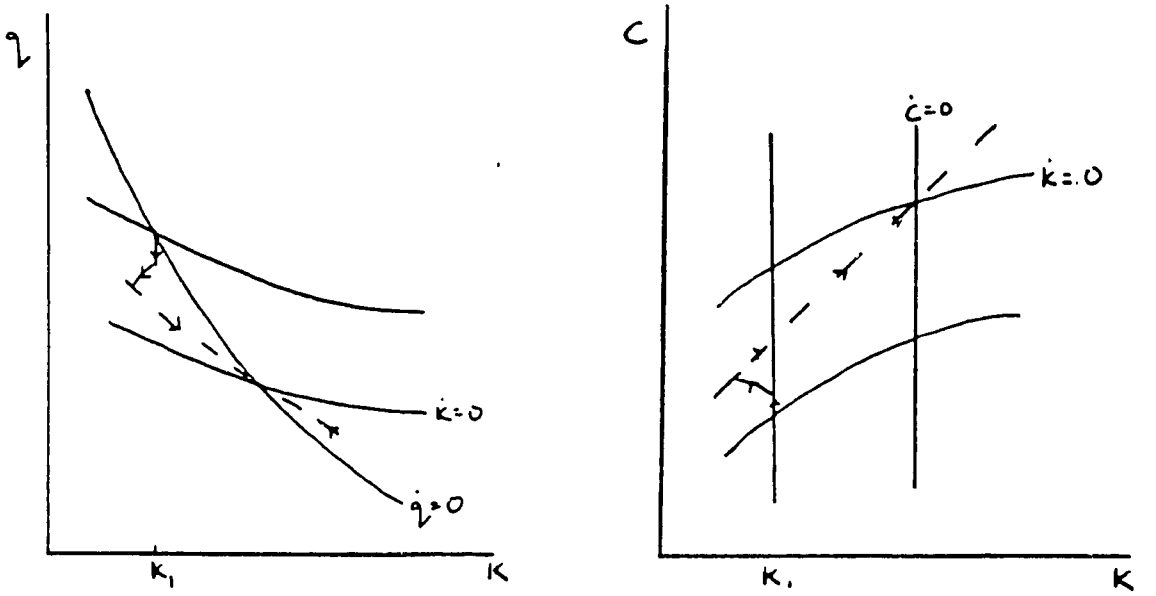
and substituting into (2.6) we get the alternative Euler equation:

$$\frac{\dot{C}}{C} = -(\rho + \delta) - \frac{F_k P_m}{F_z P_z} \tag{2.11}$$

Equations (2.7) and (2.11) can then be represented as,[7]




The effects of lifting the VER on the imported capital good can now be seen easily. Assume that the economy is initially in equilibrium at $K_1$, and consider an elimination of the VER announced in advance. This leads to an anticipated reduction in $P_m$ which will shift the $\dot{K}$ locus towards a lower price and higher consumption.




The price of capital goods will jump downwards immediately, and continue to fall

[7] This diagram is almost identical to the one derived from the dynamic models in Chamley (1981) and Jorgenson and Yun (1986)

until it reaches the new stable arm at the time of the price reduction. During this time, before the actual liberalization, the capital stock will decumulate. This is due to the consumer feeling richer and therefore raising his whole path of consumption. The rate of consumption jumps up and savings down, that is, less exportables are produced and traded for investment goods. When the import price is actually reduced the economy will move along the saddle path, and accumulate capital to a higher steady state stock, and to reach a higher rate of consumption.

One can thus see that all the welfare gains from liberalization in this economy come through the dynamics. In a static model with exogenous savings, this channel would not exist and there will be no change in the first period welfare. While there are no numerical models that are so simplistic, this is just a matter of degree. It should be pointed out that some 60% of U.S. merchandise imports are durable goods in the eighties and if these goods do not all enter the welfare function then the model will miss this channel.

## 3. The Structure of the Model

### 3.1 Key Features and Assumptions

The most notable feature of our growth model is the forward looking behavior. Expectations are realized in equilibrium, and since there is no uncertainty it reduces to a perfect foresight model. In this regard this is similar to the Jorgenson and Yun (1986), and Goulder and Summers (1986) models, and unlike Hudson and Jorgenson (1974) which have myopic expectations. However, like the latter it has a rich sectoral structure.

The "static" part of our model is quite standard, we have an aggregate household, a business sector, the government and rest-of-the-world. The business sector covers all of private GDP and is divided into 35 industries.[8] The production functions of the industries are assumed to be characterized by constant returns to scale with capital, labor and materials as inputs. There is an aggregate capital stock owned by the household which is freely mobile across the producers.

With constant returns to scale and mobile capital producers need not have foresight, output prices can be determined given current input prices. This makes the model far easier to solve, in a model with sector specific capital, like Goulder and Eichengreen for example, each firm must have its own costate variable that must be solved for dynamically. If there are scale economies one must specify some oligopoly model which, if at all realistic, must involve dynamics. The few general equilibrium models which have economies of scale are static in nature.[9]

The treatment of capital in g.e. models is a much debated issue and deserves further comment. Models with sector specific capital include the Michigan Model and those of

[8] Included in the business sector are government enterprises (mainly the Postal Service)

[9] The pioneer in this field is Richard Harris's (1983) model of Canada. Another model with scale economies is Devarajan and Rodrik (1989) Apart from the dynamics there are other difficulties with this approach. Firstly, the equilibrium is not unique, secondly, there are few reliable estimates of scale economies for most sectors.

Goulder & Co., while the Whalley and Harris models, like this one, has mobile capital. The "real" world is surely characterized by both. Nuclear power generators can only be used in the utilities industry, but on the other hand, automobiles and office buildings are easily transferred. We view our model as a long-run one whereby capital can reasonably be assumed to have accumulated and depreciated in the appropriate industries.[10] The two approaches should be regarded as complementary, with one or the other being preferred depending on the question asked.

A key assumption to allow such a flexible model to reach a steady state is that technical change is deterministic and forced to go to zero over time. If productivity growth is positive in the steady state then equal rates of growth must be imposed on all industries, otherwise the price of the output of the "smartest" industry will fall to zero and its quantity increase without bound.[11]

However, even if equal rates are imposed there is a further restriction that is required. If technical progress goes on forever, per capita incomes will rise indefinitely, and thus, to have a well defined steady state, the consumption function in the end must be homothetic. Otherwise the rising incomes will drive all but one demand to zero. In order to use the more realistic non-homothetic function we therefore impose zero long-run technical progress.[12]

On the household side, consumption and savings are determined endogenously in

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[10] It should be noted that dynamic models with sector specific capital requires some sort of adjustment/time-to-build function Such functions have not been very successfully estimated, in the q-theory models for example, the variation of q is simply too large More traditional investment adjustment forms does not have foresight

[11] At the same time, some quantity will be vanishingly small as a fraction of total output. While this may well approximate the economy a thousand years hence, this is not acceptable for the purposes of solving the model Our goal is to simulate the economy for the next 30 or so years, for computational reasons the "steady state" must be somewhat similar to the system then The realism of the model after this time frame is not the goal of this, or any other dynamic model

[12] An alternative solution would be to modify the consumption function so that is it progressively homothetic. We have not taken this approach given the difficulty of estimating all the production functions simultaneously and imposing a common rate of change. See discussion below.

this model. However, the allocation of savings between domestic capital formation, acquisition of foreign assets, and investment in government bonds is set exogenously. This means that the public deficit and current account are set exogenously.[13] Endogenizing portfolio choice would be more useful in a world model with endogenous trading partners. This however, must be left to future research, the estimation of a set of equations for the rest-of-the-world parallel to our domestic model is a quite formidable task, as will be obvious. Further, this is predicated on being able to specify and estimate portfolio choice models, otherwise one would be back in the world of approximately parameterized models.

In essence, this means means that, in the current form, this is a one-country model where there is no free capital movements across borders. World interest rates do not enter in a significant way, the "budget constraint" depends on domestice interest rates unlike open economy models.

The last major feature of this model is the treatment of imports. Commodity imports are divided into competitive and non-competitive types. Non-competitive imports enter directly as an input into the production functions and the final demand functions. Competitive imports are regarded as imperfect substitutes for domestically produced goods, i.e., the usual Armington assumption.[14] Total supply of each commodity therefore is the sum of domestic production and the competitive import.

Our model also distinguishes between industries and commodities. 35 industries are identifed, each producing a primary commodity (under which it is classified) and several

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[13] This is unlike the McKibbin & Sachs (1985), and Goulder & Eichengreen models which have an endogenous rest-ct-the-world sector This restriction simplifies the model tremendously by reducing the number of state and costate variables -- the major determinant of computational difficulty of the system. Given that our focus is not on international savings and investment flows, nor on monetary variables like exchange rates, but rather on productivity and structural change, this seems to be a workable simplication

[14] We shall not repeat the oft-cited arguments why this is the only workable assumption at the level of aggregation used here See Petri (1984) page 15, for example

secondary products. These are listed in Table 3.1. To preserve the dimensionality of the system there are also 35 distinct commodities, each corresponding to a primary product of the industries and may include the secondary products of other industries.[15] Each industry buys and uses these 35 intermediate commodities and the 3 non-produced inputs -- capital, labor and non-competitive imports. The supply of commodities is sold to intermediate and final demands, i.e., the 35 producers, and, household current consumption, government, investment and exports.

We shall explain the distinction between "current consumption" and investment below. In our model all household durables are considered to be part of the aggregate capital stock. For example, the household does not buy automobiles or housing directly but rents them from the "bank" which manages the capital stock. All users of capital -- the 35 producers and the household -- rents them from this "bank" that decides the investment demands.[16]

The input-output structure is given in Figure 3.1. The notation there are for quantities, there are of course corresponding matrices for values and prices. In the following sub-sections we shall describe the model briefly and give the details in the Appendix. The data is described in §A.6.

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[15] For example, most of the output of "Textile Industry" is allocated to the "Textile Commodity" but a fraction is also allocated to "Apparel Commodity" and "Misc Manuf Commodity" Conversely, the "Textile Commodity" consists of output from the "Textile Industry" and the "Apparel Industry." This distinction is made according to the official input-output tables

[16] Such a treatment of household capital differentiates this from most other c.g.e. models where all goods, durables and non-durables, enter symmetrically into the consumption functions We regard this as a rather important refinement, consumer durables purchases was some 17% of all non-housing Consumption expenditures in 1985

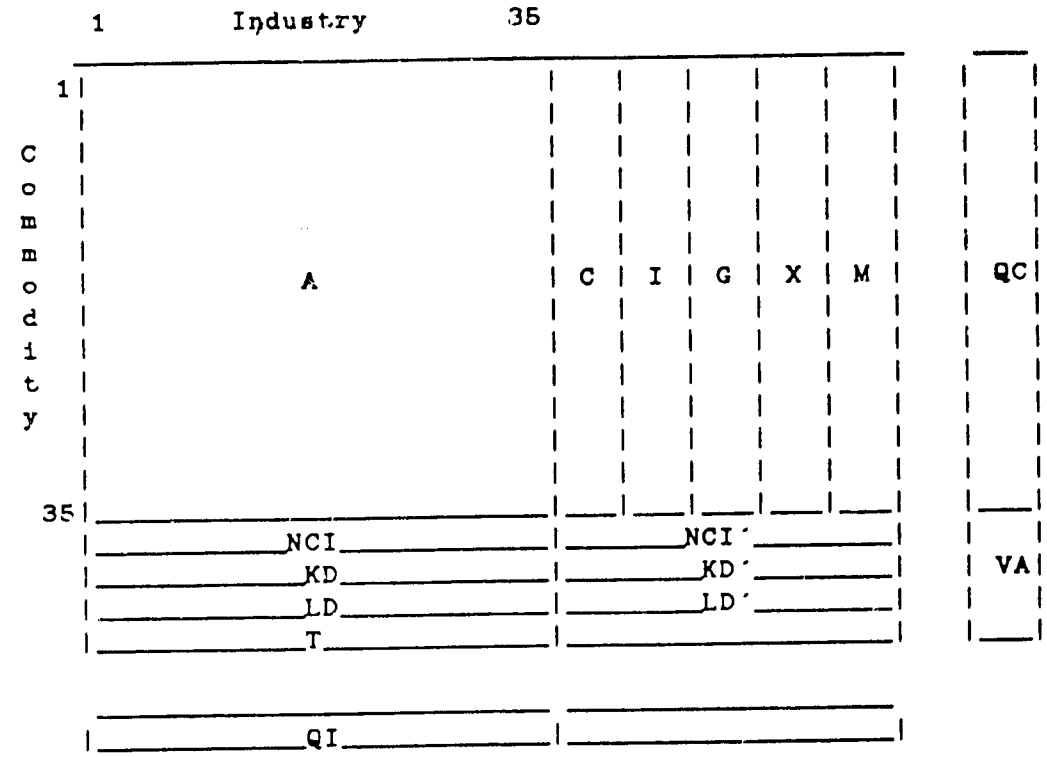
Table 3.1 Industries identified in the model.

| NO. | Industry | Value added 1985 $ bil. |
|---|---|---|
| 1 | Agriculture | 90.1 |
| 2 | Metal mining | 3.5 |
| 3 | Coal mining | 15.0 |
| 4 | Oil & gas extraction | 87.4 |
| 5 | Non-metal mining | 5.9 |
| 6 | Construction | 243.7 |
| 7 | Food & kindred products | 68.4 |
| 8 | Tobacco | 7.5 |
| 9 | Textile mill | 14.1 |
| 10 | Apparel | 26.1 |
| 11 | Lumber & wood | 22.1 |
| 12 | Furniture | 13.7 |
| 13 | Paper & allied products | 34.4 |
| 14 | Printing & publishing | 50.7 |
| 15 | Chemicals | 54.1 |
| 16 | Petroleum refining | 23.4 |
| 17 | Rubber & plastic | 36.3 |
| 18 | Leather | 3.5 |
| 19 | Stone Clay & Glass | 24.9 |
| 20 | Primary metal | 41.7 |
| 21 | Fabricated metal | 63.5 |
| 22 | Machinery | 97.4 |
| 23 | Electrical machinery | 88.1 |
| 24 | Motor vehicles | 51.5 |
| 25 | Transportation equipment | 57.1 |
| 26 | Instruments | 31.2 |
| 27 | Miscellaneous manufacturing | 12.1 |
| 28 | Transportation | 133.1 |
| 29 | Communications | 89.2 |
| 30 | Electric Utilities | 81.0 |
| 31 | Gas Utilities | 25.4 |
| 32 | Trade | 503.5 |
| 33 | Finance, Insurance & Real Estate | 382.6 |
| 34 | Services | 645.6 |
| 35 | Government Enterprises | 57.8 |

Note: Industry 33, "Real estate" excludes owner-occupied housing. This is allocated directly to households.

Figure 3.1 Intersectoral flows.

Use Table

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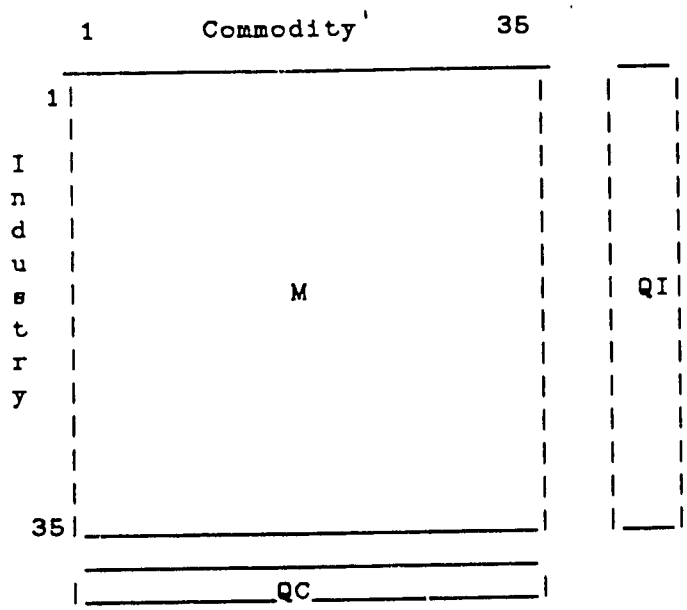

Figure 3.1 Continued.

| | |
|---|---|
| A | Use matrix: commodities used by industries |
| M | Make matrix: Industries contribution to commoditiy supply. |
| C | Household consumption of nondurables and services only. Service flow from durables enter in the capital row of that column. |
| I | Investment in the domestic capital stock. |
| G | Government purchases of goods and services. |
| X | Exports of commodities (interest receipts are accounted separately) |
| M | Competitive imports (entered as a negative column) |
| NCI | Non-competitive imports |
| KD | Capital demanded by producers |
| LD | Labor demanded by producers |
| T | Sales tax on industry output |
| | NCI',KD',LD' are factor inputs allocated directly to final demand |
| QI | Industry output |
| QC | Commodity output of domestic producers |
| QS | = QC+M = Total commodity supply |
| VA | Total value added = GDP |

### 3.2 The Household Sector

The economy is essentially driven by the optimizing behavior of the household sector. We assume the existence of an infinitely lived aggregate household who consumes goods and leisure, and owns all government debt and all private foreign assets, and a "bank" (which owns the capital stock). The consumer has an endowment of time (for work and leisure) equal to an index of the actual and projected U.S. population.[17]

Given the difficulty in estimating a function that simulataneously decides commodity consumption, labor supply and savings, we have chosen to represent household behavior by a 3-tier choice model. At the first stage, the aggregate consumer maximizes an intertemporal utility function to allocate income between "full-consumption" and savings. At the next stage, full-consumption is allocated between leisure and a commodity basket. The final choice distributes this basket over the various commodities.

*Stage 1.* We write the objective function in the utilitarian form which multiplies the utility per household by the number of households :

$$\max \quad \sum_{t=1}^{\infty} \frac{N_t}{(1+\rho)^t} (F_t/N_t)^{1-\frac{1}{\sigma}} \tag{3.1}$$

subject to the lifetime budget constraint:

$$WF \equiv W_0 + \sum_{t=1}^{\infty} \frac{\bar{w}_t LH_t + misc_t}{\prod_{s=1}^{t} 1+r_s} \geq \sum_{t=1}^{\infty} \frac{PF_t F_t}{\prod_{s=1}^{t} 1+r_s}$$

F is full consumption and PF its price. $N_t$ is an index of the number of households.[18] WF is full-wealth, the sum of tangible assets and human capital. $W_0$ is the initial tangible

[17] The construction of this population index is described in detail in Ho (1989) Appendix C. Essentially the population is divided by sex, age and educational attainment, and an economy wide index is then constructed by Divisia aggregation over these demographic groups using wages as weights

[18] This is computed using the "household equivalent measure" in Jorgenson & Slesnick (1987) which adjusts the simple total number of households by a price-weighted composition index. See Ho (1989) Appendix B

wealth, the sum of capital, government debt and foreign assets (all in net terms). $\bar{w}$ is the after-tax wage and $LH$ the aggregate household's time endowment. *misc* are miscellaneous exogenous items like government transfers.[19] $r$ denotes the after-tax nominal rate of return on capital.

As shown in the Appendix, we can derive the Euler equation, and hence consumption and savings, from maximising (3.1). The Euler equation is forward looking, current consumption incorporates expectations about future prices and interest rates.

*Stage 2.* Full consumption is allocated to leisure and the commodity basket via an aggregate indirect utility function:

$$VV(PCC, w, MF; t) = \max F(CC, LEIS) \quad s.t. \; MF \leq PCC.CC + w.LEIS \tag{3.2}$$

where $CC$ is the quantity of commodities, $LEIS$ is leisure, and $PCC$, $w$ are their prices. $MF = PF.F$ is "full expenditures."

Given prices, we can solve for consumption, CC, and labor supply, LS (see Appendix):

$$LS_t = LH_t - LEIS_t$$

*Stage 3.* At the final step the commodity basket is allocated to the 35 commodities and 3 non-produced inputs (non-competitive imports,[20] capital and labor). Unlike other numerical models our consumption function is a richly specified one that allows for non-homotheticity, a high degree of substitution among the components, and incorporates demographic characteristics. Given that we are concerned with policies that affect the prices of consumption goods directly this is an important feature of the model.[21]

At this stage households are treated as consuming units and allowed to have their

[19] These are included in order to have a consistent set of accounts that matches the official data. They play no significant role in the simulations

[20] Mostly foreign tourism and military related expenditures abroad.

[21] Most other c.g.e. models specify Cobb-Douglas or Leontief demand systems, and are not estimated

own utility function. For each household j we have the indirect utility function:

$$V^j(p, Y_j) = \max U^j(C^j) \qquad s.t. \;\; Y_j \leq p.C^j \tag{3.3}$$

where $Y_j$ is the total expenditures of j, $p$ and $C^j$ are the price and quantity vectors of the 38 inputs. $C^j = (C_1^j, \ldots C_{35}^j, C_{NCI}^j, C_K^j, C_L^j)'$. Given the large number of goods demanded, this function is assumed to be separable into a tier structure.[22] At the top tier $Y_j$ is allocated to five commodity groups, and in the subsequent tiers these aggregates are further broken down until we reach the 35 basic commodities. We write the top tier function of $V$ in the translog form,[23]

$$\ln V^j = \ln(\frac{p}{Y_j})'\alpha + \tfrac{1}{2}\ln(\frac{p}{Y_j})' B \ln(\frac{p}{Y_j}) + \ln(\frac{p}{Y_j})' B_{pA} A_j$$

where

$\ln(p/Y_j) = (\ln(p_1/Y_j), \ln(p_2/Y_j), \ldots \ln(p_5/Y_j))'$ vector of logarithms of prices.

$Y_j = \sum_{n=1}^{5} p_n C_n^{gj}$ total expenditures of j.

$p_n$ price of commodity group n.

$C_{gj}$ quantity of commodity group n demanded by j.

$A_j$ vector of attributes of household j.[24]

The vector $\alpha$ and the matrices $B$ and $B_{pA}$ are estimated coefficients.

From this individual household function we can derive aggregate consumer demand by exact aggregation. This is shown in the Appendix. The resulting aggregate expenditure share equations are:

$$shr^C = \begin{bmatrix} p_1 C_1^g / PCC.CC \\ .. \\ p_5 C_5^g / PCC.CC \end{bmatrix} = \frac{\alpha + B \ln p - B\iota\, \xi^d + B_{pA}\, \xi^L}{-1 + \iota' B \ln p} \tag{3.5}$$

[22] Two-stage allocation in the context of consumer behavior is discussed in more detail by Jorgenson, Slesnick and Stoker (1988)

[23] The econometric model and estimates we use are from Jorgenson and Slesnick (1987).

[24] The elements of vector Aj are one-zero dummies that classify households by the following

where $\xi^d$ is a measure of expenditure ("income") distribution ($\sum Y_j \ln Y_j / \sum Y_j$ ) and $\xi^L$ is a vector summarizing the demographic characteristics of the aggregate household. Aggregate expenditures is given by $PCC.CC = \sum_j Y_j$. Note that the function is not homothetic, this is very important given the huge increase in income in the post-War period. The neccesity of imposing zero long-run productivity growth can be seen clearly in (3.5). As income rises, $\xi^d$ rises and thus some share will turn negative if this is allowed to go on long enough. This is obviously not admissable.

Equation (3.5) gives the consumption demand for the commodity groups given prices. These demands are then broken down via a tier structure with an indirect utility function at each node of the tier.[25] At the tiers below the top we impose homotheticity and ignore the demographic characteristics. From these aggregate demand functions we derive total consumption by commodities, $C = (C_1, \ldots C_{35}, C_{NCI}, C_K, C_L)'$, corresponding to the C column in the use table in Fig. 3.1.

As mentioned, the household sector does not buy durable goods directly. These are rented from the aggregate capital stock (the demand for household capital is denoted $C_K$). That is, the "consumption" of durables is an imputed flow of capital services and not depreciated 100% within the period as in most other models.

### 3.3 The Producer sectors

An ideal production function would allow substitution among all inputs, however, given the large number of inputs the typical approach have been to specify output as a function of value added and a material aggregate. The material aggregate is almost always a Leontief function of its components. In our model we have specified a relatively

demographic characteristics: family size, age, region, race and urban/rural. With this classification system we distinguish a total of 672 household types.

[25] The details of the tier structure and the estimates of the demand functions are reported in Ho (1989)

rich system of input demand functions allowing substitution among capital, labor, energy and materials. That is, if the price of oil is raised by an oil import fee for example, then our functional form allows, firstly, for the substitution of coal for oil among the energy aggregate, and secondly, substitution of capital for energy. In almost no other models is there such a degree of flexibility.

Each of the 35 industries consist of one column of the "use table" in Fig. 3.1. That is, the $j$th industry output $QI_j$, is made from the 35 commodities ($A_{ij}$ $i=1,..35$), as well as, non-competitive imports,[26] capital and labor:

$$QI_j = QI^j(A_{1j},...A_{35j}, NCI_j, KD_j, LD_j) \tag{3.6}$$

As in the consumption function, to have an implementable producer model, we assume that (3.) is separable into a nested structure,[27] where at the top tier we have 4 aggregate inputs -- capital, labor, energy, and materials. At the next tier the energy aggregate is composed of all 5 "energy commodities" (coal, crude, oil, electricity, gas), while the material aggregate is gradually broken down to the remaining 30 commodities and $NCI$.

Substitution at all levels of the nested structure of input demands are estimated econometrically as opposed to the usual calibration procedure.[28] The production functions for each industry are estimated over an annual time series of input-output matrices running from 1947-85.[29] Such a procedure allows us to track the historical experience of the U.S. economy far better than the calibrated models

A important feature of our model is that productivity is allowed to change over

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[26] Mostly raw materials like coffee, rubber and various metallic ores

[27] See Jorgenson (1986) for a discussion of the restrictions required for two-stage allocation in the context of producer behavior

[28] The calibration method is described in Mansur and Whalley (1984) Essentially parameters are determined by making the functions fit a single year's input-output matrix In practice this has meant taking some estimate of capital-labor substitution elasticity and imposing fixed coefficients for everything else This precludes substitution among materials and between materials and, capital and labor

[29] The details of the data are given in Wilcoxen (1988) while the estimation results are in Ho (1989)

time *and* in response to changes in input prices. Again, this allows us to track the large changes that have occurred in the input structure of U.S. industry over the past four decades.

*Top tier* The top node of industry j's production function is therefore written as $QI_j = QI^j(KD_j, LD_j, E_j M_j, t)$. As explained in Jorgenson (1986) we use the cost dual instead of the primal function. $PO_j = PO^j(PKD_j, PLD_j, PE_j, PM_j)$. $PO_j$ is the price of output,[30] $PKD$, $PLD$, $PE$, $PM$ are the prices of the input aggregates. The price function is written in the translog form:

$$\ln PO_j = \alpha_0^j + \ln P^{j\prime}\alpha_p^j + \tfrac{1}{2}\ln P^{j\prime} B^j \ln P^j + \ln P^{j\prime} B_{pt}^j g^j(t) + \alpha_t g(t) + \tfrac{1}{2}\beta_{tt}^j g^j(t)^2 \quad (3.7)$$

where the input price vector $P^j = (PKD_j, PLD_j, PE_j, PM_j)'$. The scalars $\alpha_0, \alpha_t, \beta_{tt}$, the vectors $\alpha_p, B_{pt}$, and the matrix $B$ are estimated parameters. $g(t)$ is an index for the level of technology.

Differentiating, we obtain the share equations for input demands:

$$shr^j = \alpha_p^{j\prime} + B^j \ln P^j + B_{pt}^j g^j(t) \quad (3.8)$$

where $shr^j = \left( \frac{PKD_j KD_j}{PO_j QI_j}, \frac{PLD_j LD_j}{PO_j QI_j}, \frac{PE_j E_j}{PO_j QI_j}, \frac{PM_j M_j}{PO_j QI_j} \right)'$.

Differentiating w.r.t. time we get the (negative of) rate of productivity growth:

$$-v_t^j = [\alpha_t^j + B_{pt}^j \ln P_j + \beta_{tt}^j g(t)]\, \dot{g}^j(t) \quad (3.9)$$

As discussed in §3.1, in a dynamic model such as ours, there must be restrictions placed on the productivity term in order to have a sensible steady state. The restriction that we impose is that there is no technical change in the long run. To achieve this in a smooth manner we chose to write $g(t)$ in the logistic form:

[30] The notation PO is meant for the price of output received by producers, while PI denotes the "industry price," which is the purchase price inclusive of sales tax, PI=(1+T)PO

$$g^j(t) = \frac{1}{1 + e^{-\mu_j(t-\tau_j)}}.$$

Notice that $\dot{g}(\infty) = 0$, i.e., technical progress (or regress) disappears. Note also that technical change $\tau_j$ is a function of input prices. Appendix A.2 gives a fuller discussion of the restrictions on, and interpretation of, the parameters.

*Bottom tiers* Demands for the energy and material aggregates are decomposed into demands for commodity inputs by regarding them as "output" of a "production function" with the components of the aggregates as inputs. Thus for each node $m$ of the tier structure below the top we have a price and share equations parallel to eqns. (3.7) and (3.8), except that the time terms are ignored. See Appendix A.2.

*Industry and commodity output* Each industry sells a primary product which goes to the commodity with the same name, and secondary products which belong to other commodity classes. Instead of modelling this multiple output explicitly in the production function, we take a simpler approach and regard the industry products in a given commodity class as imperfect substitutes. Again one can regard the supply of a commodity as the output of a production function that takes the industry products as inputs, $QC_i = QC^i(M_{1i},\ldots,M_{35i})$. $M_{ji}$ are the elements of the "make matrix" in Fig. 3.1.

### 3.4 Capital supply and investment demand

We have described the model so far in terms of the dynamic behavior of the aggregate household with regard to consumption and savings. Optimal savings is optimal investment in this one-consumer one-capital economy. Strictly speaking the consumer problem (eq. 3.1) should have been written as maximising the discounted static utility subject to the technology embodied in the production functions of §3.3, the demands and supplies of the rest-of-the-world, the initial capital stock and the capital accumulation

equation:

$$K_t = (1-\delta)K_{t-1} + I_t \tag{3.10}$$

To complete the description of the economy we need to append to (3.1) the behavior of an optimizing investor -- the "bank." The bank maximizes the present value of the capital stock by choosing an optimal path of investment given the price of investment goods and interest rates. This is described in Appendix A.3. Essentially there must be an arbitrage equation between investing in bonds that pay the interest rate $r$, or in investment goods that can be rented out to the producers at a rental rate $PKD$. Ignoring taxes, this condition is given by:

$$(1+r_t)PII_{t-1} = PKD_t + (1-\delta)PII_t \tag{3.11}$$

where $PII$ is the price of the capital goods. This just says that the interest foregone is equal to the gross rental receipts, less depreciation plus capital gains.

The next step of the "bank" is to allocate the aggregate investment $I_t$ to the individual commodities (mostly construction and the manufactured durables). This is done in a way parallel to the allocation of consumption demands, i.e., splitting $I = I(I_1,...,I_{35},I_{NCI})$ via a nested structure of translog price frontiers.

Conceptually we treat it like another industry whose "output" is this aggregate investment good $I_t$, and the "inputs" are bought from the other industries in a way similar to the demand for material inputs in the producer model above. There are of course no capital and labor inputs. This "production function" is described in §A.3.

### 3.5 The Government

The public sector, as in all numerical G.E. models, is treated in a simple, exogenous fashion here. The government deficit is set exogenously since there is no equation (e.g. a portfolio choice model) to determine it in the steady state. That leaves us with two

possible closures for the model, either endogenizing government purchases given fixed tax rates, or, fixing public spending and adjusting tax rates/lump sum taxes. Both methods are used depending on the simulation.

On the revenue side the government imposes taxes -- sales tax, import tariffs, capital income tax, labor income tax, property tax and wealth (estate) tax; and collects fees -- "non-tax revenues" and surpluses of government enterprises.

Government spending falls into 4 major categories -- purchases of goods, transfers (to household sector and foreign aid), interest payments on debt (to domestic and foreign bondholders), and subsidies to producers. The first three are set to actual data in the sample period (1947-87) while subsidies are regarded as negative sales taxes. Transfers and interest payments are projected outside the sample period.[31]

The value of goverment total purchases, VGG, are distributed over the 35 commodities, and imports and labor, via an exogenous share function:

$$VG_{it} = \alpha_{it}^{G} VGG_t \tag{3.12}$$

The shares $\alpha_{it}$ are set to the actual data in the sample period and and kept fixed thereafter. The government does not rent from the aggregate capital stock. All purchases are regarded as current consumption.[32] $VG_i$ corresponds to the elements of the G column in the use matrix in Fig. 3.1

Given our closure assumptions the government expenditures must satisfy:

$$VGG = Exog.\ Deficit + tax\ revenue - interest - transfers \tag{3.13}$$

[31] The seemingly more natural approach would be to link interest rates to the rate of return on real capital. This however is not practical, the holy grail of explaining risk premia is still eluding empirical researchers. Since the focus of the model is on the real economy, exogenizing the debt and interest payments seem to be the most straight-forward simplification

[32] We are well aware that public capital affects welfare directly, and indirectly through enhancing private sector productivity. Unfortunately there is as yet no implementable model of demand and supply of public capital.

The stock-flow relation of government debt is given in the Appendix.

### 3.6 Commodity Supply, Imports and the Rest-of-the-world.

*Supply and imports* Total supply of commodities in the economy comes from the output of domestic producers and "competitive imports." The purchasers of these commodities regard them as imperfect substitutes, i.e. the Armington assumption. We model the demand for the domestic commodities ($QC_i$) and imports ($M_i$) using a translog price dual:

$$\ln PS_{it} = \ln p^{i\prime}\alpha_t^i + \tfrac{1}{2}\ln p^{i\prime}B^i\ln p^i \tag{3.14}$$

where $PS$ denotes the price of the composite good $QS = QS(QC,M)$ that is supplied to the market. $p$ is the vector of prices of domestic commodity i and the competitive import, $(PC_i, PM_i)'$. The matrix $B$ gives the elasticity of substitution between the two goods, while $\alpha_t$ is the base share vector. The corresponding share equations are:

$$shr^i = \begin{bmatrix} PC_i QC_i / PS_i QS_i \\ PM_i M_i / PS_i QS_i \end{bmatrix} = \alpha_t^i + B^i \ln p^i \tag{3.15}$$

Unique among numerical models we have subscripted $\alpha$ with the time index. The reasons for this are given in detail in Ho (1989). Basically price movements cannot explain the large secular increase in import penetration that the U.S. experienced in the post-War period without untenable substitution elasticities. This "unexplained imports" has been noted earlier by Petri (1986).[33]

A common approach to estimating import demands has been to put income as an explanatory variable. We however, like Petri, have not chosen to do so, but put in time

[33] Petri in Srinivasan and Whalley page 227, "...important historical changes in trade shares are plainly inconsistent with conventional price elasticities and observed relative price changes. Between 1960 and 1980, for example, Japan's share of the US steel market grew so fast that the Armington elasticity would have had to be 32 (against the Michigan assumption of 1.4).... Something is not right, and we need more micro level data work and historical validation to identify the source of the problems."

on the right hand side instead.[34] We find that this not only simplifies the model but fitted the data quite well too. Appendix A.4 give the details of (3.15).

*Prices of imports* The domestic price of imports is the foreign price multiplied by the "exchange rate" plus the tariffs:

$$PM_{it} = (1+tr_{it})e_t PM_{it}^* \qquad (3.16)$$
$$PNCI_i = (1+tr_i^n)e_t PNCI_i$$

In the construction of the data the terms of trade $e_t$ is normalized to one. In the model it is endogenous as explained below.

*Exports* Without an explicit endogenous model of the rest-of-the-world we assume a simple form for the demand for U.S. exports. Commodity exports $X_i$ is a function of world income $Y^*$ and the price of U.S. goods $PC_i$:

$$X_i = EX_{i0}(Y^*)[(1+tr_i^*)PC_i/e]^{\eta_i} \qquad (3.17)$$

$EX_{i0}(Y^*)$ are the actual exports in the historical data and projected out of sample. The "exchange rate" $e$ corresponding to this is similarly normalized to one in the data. We do not have the world import data to estimate the price elasticity $\eta_i$, and hence took it as the average of import price elasticities of the major trading partners of the U.S. found in the literature.

*Non-commodity flows* To complete the income accounts we include factor income and payments to foreigners. These are interest and dividends on U.S. private net claims on the ROW, $BF_t$, and U.S. official net liabilities, $BG^*$. This net factor income, $e_t i_t^* BF_{t-1}$ and $-iBG_{t-1}^*$, is set exogenously to the historical data in the current version of the

[34] Petri (1984), "high income elasticities is probably spurious, and is explained by the rapid growth and rising market shares of developing countries ...Unfortunately these extraneous trends are highly correlated with income, and their effects cannot be estimated separately."

model.

*"e" and the current account balance* Adding over the foreign trade and income flows we get the current account surplus:

$$CA = \sum PC_i X_i - \sum PM_i M_i - \sum PNCI_i NCI_i + ei^* BF - iBG^* - transfers \tag{3.18}$$

This current account balance is set exogenously in the current model in a way identical to the other trade models (e.g. the Michigan Model). From above we see that $X_i$ and $M_i$ is a function of the "exchange rate" $e_t$. This is an endogenous variable in the model which adjusts commodity flows so that the exogenous current account is met.[35] The non-commodity components of (3.18) are set exogenously.

### 3.7 Equilibrium Conditions and Solution of Model.

In our model with constant returns to scale and perfect competition all markets clear at zero profits in every period. There are four types of markets and one definitional "market". The first category are the markets for the 35 commoditites:

$$PS_i QS_i = \sum_j PS_i A_{ij}' + PS_i(C_i + I_i + G_i) + PC_i X_i \qquad i = 1,..35 \tag{3.19}$$

Total supply is allocated to intermediate demands of j=1,..35 industries and the final demands of the consumer, investor, government and exports. These markets are cleared by the prices of domestically produced commodities $PC_i$.

The next two markets are the factor markets for capital and labor:

$$PKD_t K_{t-1} = \sum_j PKD_{tj} KD_{tj} \tag{3.20}$$

$$w_t LS_t = (1 - tl^m) \sum_j PLD_{tj} LD_{tj}$$

[35] See Whalley and Yeung (1984) for a discussion of the implications and pitfalls of using such a method of closing the model.

As described in eq. 3.2, $w$ is the price of leisure. $tl^m$ is the marginal tax rate. There is only one aggregate capital and one aggregate labor supply in our model. However, the historical factor inputs have varied a great deal across the industries in terms of their compositions (e.g. more or less equipment vs. structures, or highly educated vs. less educated workers). This means that the time series for $PKD_j$, $PLD_j$ over our sample period have evolved differently among the 35 industries. We reconcile the data with our model assumptions in a simple way using adjustment coefficients:

$$\begin{aligned} PKD_{tj} &= \psi^K_{tj} PKD_t \\ PLD_{tj} &= \psi^L_{tj} w_t/(1-tl^m_t) \end{aligned} \tag{3.21}$$

The $\psi$ coefficients are determined from the data by reversing the above equalities. The aggregate factor prices $PKD_t$ and $w_t$ are of course the ones that clear these markets.

The last market is the foreign one where the "exchange rate" $e_t$, moves to hit the current account balance as given in (3.18) above.

The final equality for savings and investment is not a market as such in our model as discussed in §3.4:

$$PII_t I_t = S_t - (BG_t - BG_{t-1}) - (BF_t - BF_{t-1}) \tag{3.22}$$

Optimal savings determined from the intertemporal equation is allocated to the exogenous government deficit (domestic portion only), the exogenous current account surplus, and investment in physical capital.[36]

*Solving the Model* To recall from the simplified version of the model in §2, the economy moves along the saddle path from a given initial capital stock to a steady state defined by $\dot{j}=0$ and $\dot{K}=0$. Within any period $t$, consumption, exports, factor demands, etc.,

[36] The interest rate r is determined from the cost of capital equation (3 11), it is not a variable that clears this "market".

can be calculated given the costate and state variables, $q$ and $K$.

The actual model is similar with only one pair of state and costate dynamic equations. We find that the most convenient formulation of the model is to have full consumption as the costate variable. (Any other endogenous variable could of course have been used.) In the numerical implementation of the model of the model we obviously use the discrete form of these inter-period equations, eqns. (A.2) and (3.10):

$$\left[\frac{F_t/N_t}{F_{t-1}/N_{t-1}}\right]^{\frac{1}{\sigma}} = \frac{1+r_t}{1+\rho}\frac{PF_{t-1}}{PF_t} \tag{3.23}$$

$$K_t = (1-\delta)K_{t-1} + I_t$$

In the steady state (SS), which is stationary since there is neither long-run technical progress nor population growth, we therefore have:

$$\begin{aligned} r_{SS} &= \rho \\ I_{SS} &= \delta K_{SS} \end{aligned} \tag{3.24}$$

These two equations and the equilibrium conditions above are sufficient to determine all variables in the steady state.

The dynamic path of the economy is solved next by iterating on a guess of the whole path of the costate variable $\{PF_t F_t^{1/\sigma} t=1,..T\}$.[37] At any year t, given $PF_t F_t^{1/\sigma}$ and $K_{t-1}$ we can solve the intraperiod equilibrium using the market clearing equations above. (See Appendix A.5) That is, all endogenous prices and quantities, including consumption and investment. The capital stock is given by cumulating investment from the initial period where $K_0$ is taken from the data. The interest rate from $t-1$ to $t$ is calculated from (3.11) using the intraperiod solution of those periods.

[37] We found that setting T=2100 was sufficiently far out that the difference between the equilibrium at T and the separately calculated steady state was zero at FORTRAN single precision.

The guesses of the costate variable are revised by using the Euler equation (3.23) backwards from the steady state. The $k+1$th guess is given by the interest rate from the $k$th guess (if $\sigma = 1$);

$$PFF_{t-1}^{(k+1)} = PFF_t^{(k)} \frac{(1+\rho)(1+\dot{N})}{(1+r_t)} \qquad t = T,\ldots,2,1 \tag{3.25}$$

with $r_T = r_{SS}$ and $PFF_T^{(k)} = PFF_{SS}$.[38] The iterations are repeated until convergence. The algorithm used is Wilcoxen's (1988) algorithm whcih combines the best features of the Fair-Taylor (1983) and "multiple shooting" methods.

*Comment*

The size of the SS economy is effectively determined by the stationary time endowment. The rate of return $r_{SS}$ is independent of government policies, the capital stock is determined by the cost-of-capital equation linking the marginal product of capital and tax policies with $r_t$. In this sense the supply of capital is perfectly elastic in the long run. This should be compared with the Cass-Koopmans neoclassical growth model with the same independence of $r_{SS}$. In our model policies affecting sectoral allocation (e.g. rates of tariffs and quotas) will result in different levels of capital intensity -- all corresponding to the same rate of return. This is impossible in the one-sector Cass-Koopmans model.

In the short run the supply of aggregate capital is fixed, however, under our mobility assumptions the sectoral allocation of factors may be affected by government policies within the period. This will result in different prices of the goods, in particular the price of investment. The transition path is thus affected directly, and indirectly through the price of capital goods.

[38] In the actual implementation, the k+1 th guess is a weighted sum of the expression in (3.25) and the k th guess.

The dynamic path depends also on the other exogenous variables. If the initial stock of capital (per household) is lower than the steady state's then $r_t < r_{SS}$ and the household will postpone consumption and $\dot{K} > 0$. This is the situation depicted in Fig. 2.2. Conversely if $K_0 > K_{SS}$ the economy will move down and to the left along the saddle path.

## 4 Effects of Trade Barriers

In this section we shall examine the effects of U.S. trade policies on economic growth and welfare. Specifically, we shall consider a multilateral reduction in tariffs, a unilateral reduction, and quotas.

The methodology of the analysis here is the typical approach taken by applied general equilibrium models. A base case is first computed using historical policies and actual data for the exogenous variables, and then the model is solved for again but with the counterfactual parameters. The results of the two simulations are then compared.

Trade restrictions have long been in effect, to illustrate the use of our model to track the time path of tariff shocks we shall focus on the Tokyo Round Negotiations, which is the latest cycle of tariff cuts within the General Agreement on Tariffs and Trade (GATT) framework. We choosen this in part because of the large number of empirical studies of it that we can compare our results to.

### 4.1 The Tokyo Round Negotiations.

The seventh round of multilateral negotiations completed in Tokyo in 1979 was unusual in that it included agreements on nontariff barriers. Tariff rates were already quite low in 1979 after the repeated reductions of the previous Kennedy Round. In this section however, we shall concentrate only on the tariffs.

In Table 4.1[39] we present the tariffs that were in place in 1980. Most of the rates were quite low, the highest taxed sectors were Textiles, Apparel, Leather (mostly footwear), Glass, and Primary Metal (mostly iron and steel). As an aggregate, total custom duties collected on U.S. imports were $7.2 bil. compared with some $251 bil. of commodity imports (2.9%) and a GNP of $2732 bil.[40]

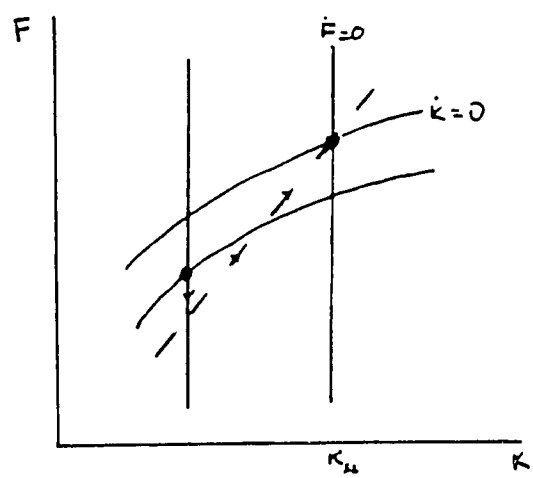
[39] Tables are presented at the end of each sub-section.

[40] These rates are calculated from data provided by the U.S. International Trade Commision (see Appendix H of Ho 1989) The rest-of-the-world rates are taken from Deardoff and Stern (1986). Our

In this counterfactual experiment we eliminate all domestic and foreign tariffs as listed in the first two columns of Table 4.1 beginning in 1980. This is almost, but not quite free trade, the quotas and other quantitative restrictions are still in place. In our procedures, this experiment consist of setting the capital stock and all other state variables at the start of 1980 equal to the actual data. Both the base, and counterfactual simulations, are then run from 1980 to T=2100.

In the base case the government deficit and tax rates are exogenous with government spending on commodities endogenous.[41] In the "zero-tariffs" case we set government expenditures, $VGG$, exogenous and equal to the values from the base simulation. The lump sum tax variable is then changed to be an endogenous one.

The results of comparing the two simulations are summarized diagrammatically in Figures 4.1 and 4.2. The vertical axis of the graphs in Fig. 4.1 is the percentage change of "zero tariffs" from the base. The impact effect of this tariff cut is to raise consumption of goods by 0.16% and reduce the consumption of leisure by 0.09%. The aggregate full-consumption, F, *falls* by 0.02%. This can be understood by using the phase diagrams of §2 :




classifications do not exactly match with theirs but is very close, both models work at the "2-digit level".

[41] Other items like government transfers and interest payments remain exogenous in both simulations

The reduction of tariffs raises the $\dot{F}=0$ and $\dot{K}=0$ locus to a higher level of capital and consumption. The fall in prices is large enough to shift the $\dot{F}=0$ locus so much that the saddle path cuts the original equilibrium point at a lower level of full-consumption. In other words the marginal utility of investment rises by so much that the desired savings imply greater work effort.

In the first panel of Fig 4.1c we can see that the price of capital is lower than the base case (0.5% lower in the first period), and keeps falling.[42] This is in line with the tariff reduction, tariffs were some 0.26% of GNP in 1980 This leads to an increase in investment and higher capital stock growth as shown in Fig. 4.1b. By the year 2000 the stock is 0.49% higher.

In parallel with this greater investment demand is the higher labor supply. With the lower prices of commodities (Fig 4.1c) the real wage (price of leisure) rises and this induces a lower leisure demand. There are thus two reinforcing factors for labor, the lower future prices shift aggregate goods-leisure consumption forward in time, and within the period the higher wages shift demand towards goods and away from leisure. This, of course, is not a necessity, the income effect could have dominated given a different parameterization.

Lower prices and the investment boom induce higher import demands. On the other side, exports also boom with the reduction of taxes on U.S. goods. Note from Table 4.1 that the world tariffs are generally higher than the American's. Given the elasticities used, the initial effect of this therefore is a tendency for exports to exceed imports. The current account, however, is set exogenously, the "exchange rate" thus have to appreciate a little to achieve the required higher imports. The appreciation is quite substantial

[42] The numeraire in the model is the wage rate, w. Given that there is capital accumulation and productivity growth, the real wage rate rises over time In comparing simulations, a falling price gap for capital means that the real wages rise even faster in the counterfactual.

relative to the other magnitudes -- 0.6%. Real commodity exports increases by 6.7% while real imports rises 7.5% in the first period.

Over time the differences between the simulations increase due to the higher capital stocks. By 2000 full-consumption is 0.17% higher, which is made up of 0.74% higher commodity consumption and -0.1% change in leisure. The consumer price index (relative to $w$) is 1.0% lower. The "exchange rate" appreciation becomes bigger due to the exogenous foreign price of imports.[43] As U.S. prices falls due to capital accumulation but the import prices are not adjusted, this means in increase in competitiveness. If the effect of foreign productivity of this multilateral tariff cut is greater than in the U.S. then $e$ will depreciate instead. The effect of this improvement in the terms of trade is that real exports are only 6.5% higher in 2000, while imports are 9.7% higher.

The average GNP growth rate between 1980 and 2000 rises from 2.34% per annum in the base case to 2.37% in a no tariff world. When the system reaches the stationary steady state, K is 0.59% higher, full-consumption 0.22%, consumption 0.82%, exports 7.1%, and imports 8.8%. Adding over the whole transition path, the welfare effects of this world cooperative move, in equivalent variation, is some 0.04% of full-wealth, or 3.5% of GNP in 1980.

*Sectoral Effects*

The industry effects are given diagrammatically in Figure 4.2 for the steady state, and in Table 4.2 we report the effects in the initial period. Table 4.3 shows the effects after 20 periods of additional capital accumulation in the U.S. (Base case values are also given in T4.3, the relative sizes of the sectors are quite similar between 1980 and 2000 given the small changes involved.)

[43] As described in the Appendix, the projections of prices after the sample period is done by simply setting to the last year of the sample

Firstly, the raw material industries (mining) have small trade flows and the decreases in exports are due to the appreciation of $e$. Agriculture trade is largely governed by quantitative rules, not to mention trade embargoes, which is not explicitly modeled. The small changes reported should thus be interpreted with that in mind. Similarly, the "non-tradeable" industries (Trade, Finance, Services) have largely intangible exports and imports with unit elasticities, and the small declines in exports noted are again due to the appreciation of $e$.

Turning to the more usual tradeable sectors, the most heavily taxed items are obviously the biggest gainers -- Textiles, Apparel, Rubber, Leather, (these two contains the large footwear imports), and Glass -- show the biggest increase in imports. For exports, Chemicals, Electrical Machinery (computers) and Instruments have the highest foreign tariffs and the biggest increase in volume among the non-trivial sectors. (There are some small exports of Textiles and Glass).

The output and employment effects parallel these shifts. Chemicals, Primary metal, Machinery, Electrical machinery and Instruments show the biggest increase in output and factor employment. Given that the capital stock is fixed initially unlike the labor supply, capital must be drawn away from the other sectors towards these export oriented industries. The biggest loser of capital is the household sector.

Import penetration is so high in the Food, Furniture and Leather industries that domestic output falls. With the reduction of high tariffs on these items factors shift out of these "import" sectors to the more competitive export sectors.

Table 4.1a Tariff rates and quota equivalents in 1980

| NO. | Sector | Tariff rates ROW | Tariff rates U.S. | Tax equiv. of VERs |
|---|---|---|---|---|
| 1 | Agriculture | | 0.035 | |
| 2 | Metal mining | | 0.000 | |
| 3 | Coal mining | | 0.000 | |
| 4 | Oil & gas mining | | 0.000 | |
| 5 | Non-metal mining | | 0.003 | |
| 6 | Construction | | 0.000 | |
| 7 | Food & kindred | | 0.027 | |
| 8 | Tobacco | | 0.111 | |
| 9 | Textile mill | 0.107 | 0.108 | 0.030 |
| 10 | Apparel | 0.207 | 0.218 | 0.063 |
| 11 | Lumber & wood | 0.027 | 0.020 | |
| 12 | Furniture | 0.103 | 0.035 | |
| 13 | Paper | 0.058 | 0.005 | |
| 14 | Printing & publishing | 0.029 | 0.008 | |
| 15 | Chemicals | 0.094 | 0.041 | |
| 16 | Petroleum refining | | 0.000 | |
| 17 | Rubber & plastic | 0.058 | 0.067 | |
| 18 | Leather | 0.045 | 0.097 | 0.056 |
| 19 | Stone Clay & Glass | 0.105 | 0.091 | |
| 20 | Primary metal | 0.058 | 0.030 | 0.048 |
| 21 | Fabricated metal | 0.090 | 0.057 | |
| 22 | Machinery | 0.067 | 0.041 | |
| 23 | Electrical machinery | 0.096 | 0.055 | |
| 24 | Motor vehicles | 0.077 | 0.023 | *0.047 |
| 25 | Transport. equipment | 0.077 | 0.026 | |
| 26 | Instruments | 0.078 | 0.065 | |
| 27 | Misc. manufactures | 0.078 | 0.058 | |
| 28 | Transportation | | | |
| 29 | Communications | | | |
| 30 | Electric Utilities | | | |
| 31 | Gas Utilities | | | |
| 32 | Trade | | | |
| 33 | Finance, Insurance | | | |
| 34 | Services | | | |
| 35 | Govt Enterprises | | | |

U.S. tariff rates are aggregated from International Trade Commission data. Rest-of-the-world (ROW) rates are from Deardoff & Stern (1986). See following Table 4.1b for quota equivalents.

Table 4.1b Tariff equivalents of selected quotas

| | Textile | Apparel | Leather | Primary | Motor v |
|---|---|---|---|---|---|
| 1973 | 0 | 0 | 0 | 0.032 | 0 |
| 1974 | 0.030 | 0.063 | 0 | 0.032 | 0 |
| 1975 | 0.030 | 0.063 | 0 | 0 | 0 |
| 1976 | 0.030 | 0.063 | 0 | 0 | 0 |
| 1977 | 0.030 | 0.063 | 0.056 | 0 | 0 |
| 1978 | 0.030 | 0.063 | 0.056 | 0.048 | 0 |
| 1979 | 0.030 | 0.063 | 0.056 | 0.048 | 0 |
| 1980 | 0.030 | 0.063 | 0.056 | 0.048 | 0 |
| 1981 | 0.030 | 0.063 | 0.056 | 0.048 | 0.047 |
| 1982 | 0.071 | 0.095 | 0 | 0.048 | 0.047 |
| 1983 | 0.071 | 0.095 | 0 | 0.048 | 0.047 |
| 1984 | 0.071 | 0.095 | 0 | 0.048 | 0.047 |
| 1985 | 0.071 | 0.095 | 0 | 0.048 | 0 |

Tariff equivalents of "voluntary export restrictions" are calculated from Hufbauer, Berliner, Elliot (1986) by aggregation to the model's classifications.

Table 5.1c Turner/Petri's Tariff-equivalents on U.S imports from Japan (%)

| Sector | 1970 | 1980 |
|---|---|---|
| Textiles, Apparel | 3.5 | 1.3 |
| Primary Metal | 6.0 | 7.0 |
| Electrical Macinery | - | 0.8 |

Taken from Petri (1984) page 138.

Figure 4.1a Dynamic Effects of Tariff elimination (% change)

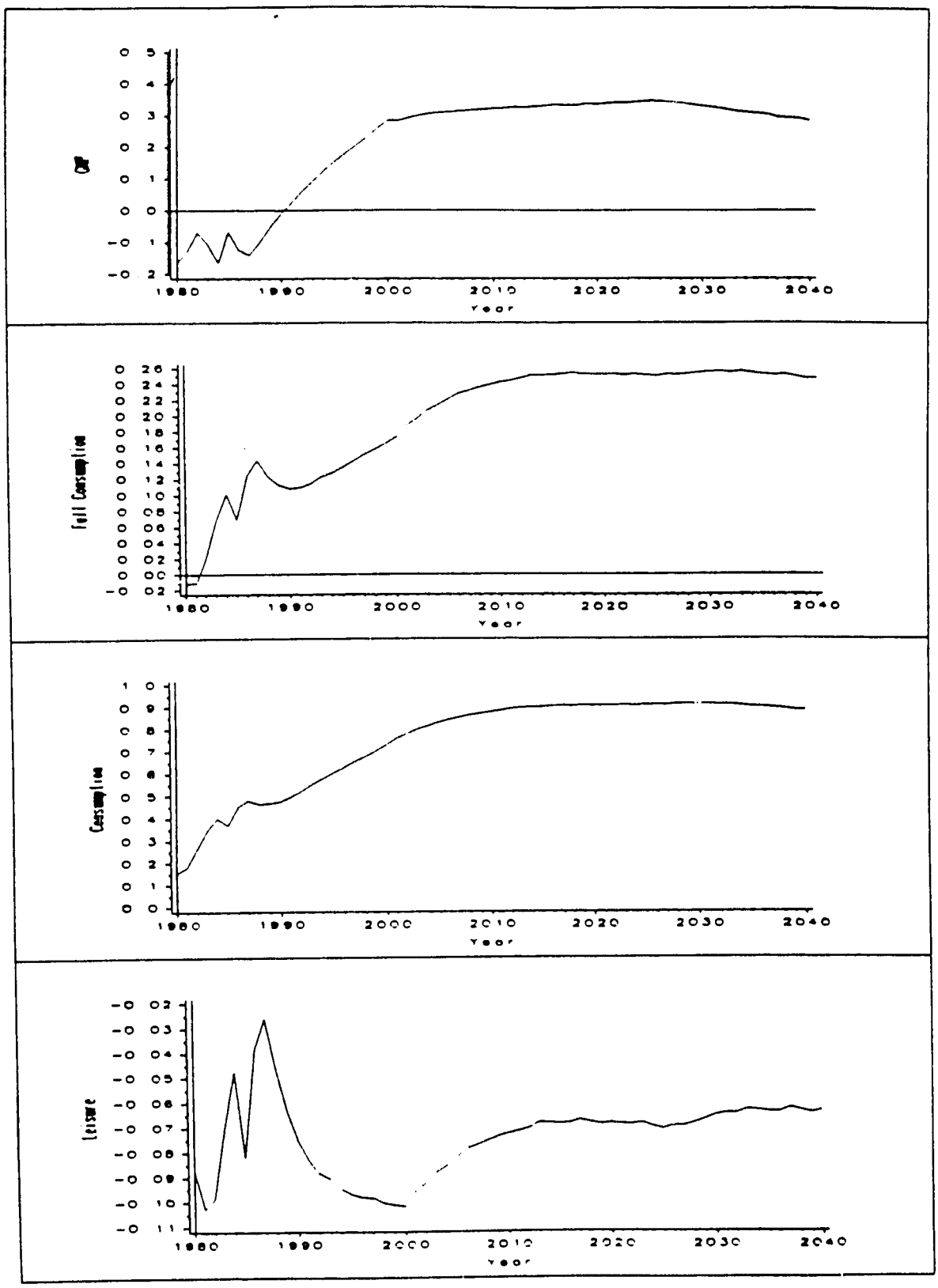


Figure 4.1b Dynamic Effects of Tariff elimination

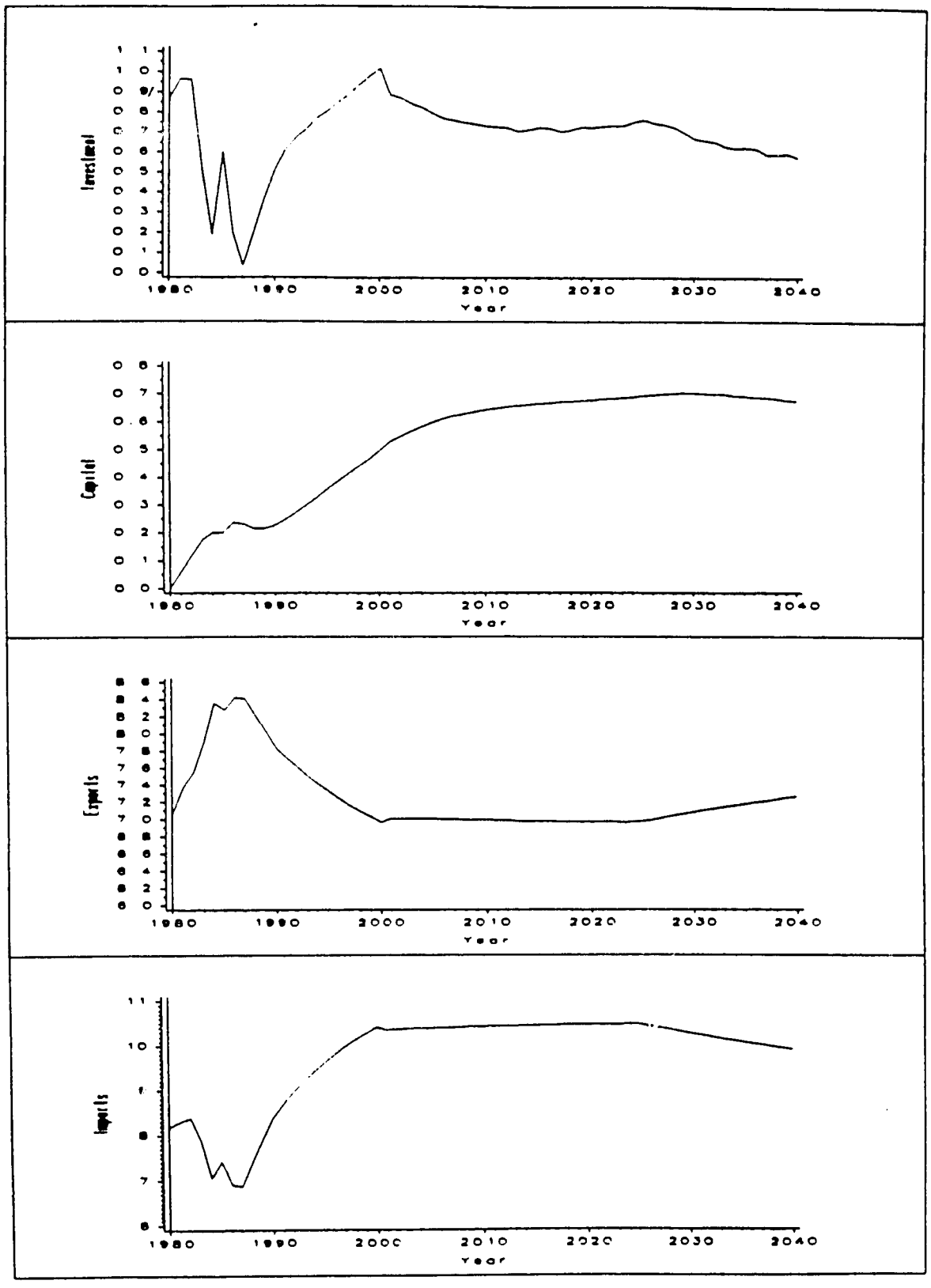


Figure 4.1c Dynamic Effects of Tariff elimination

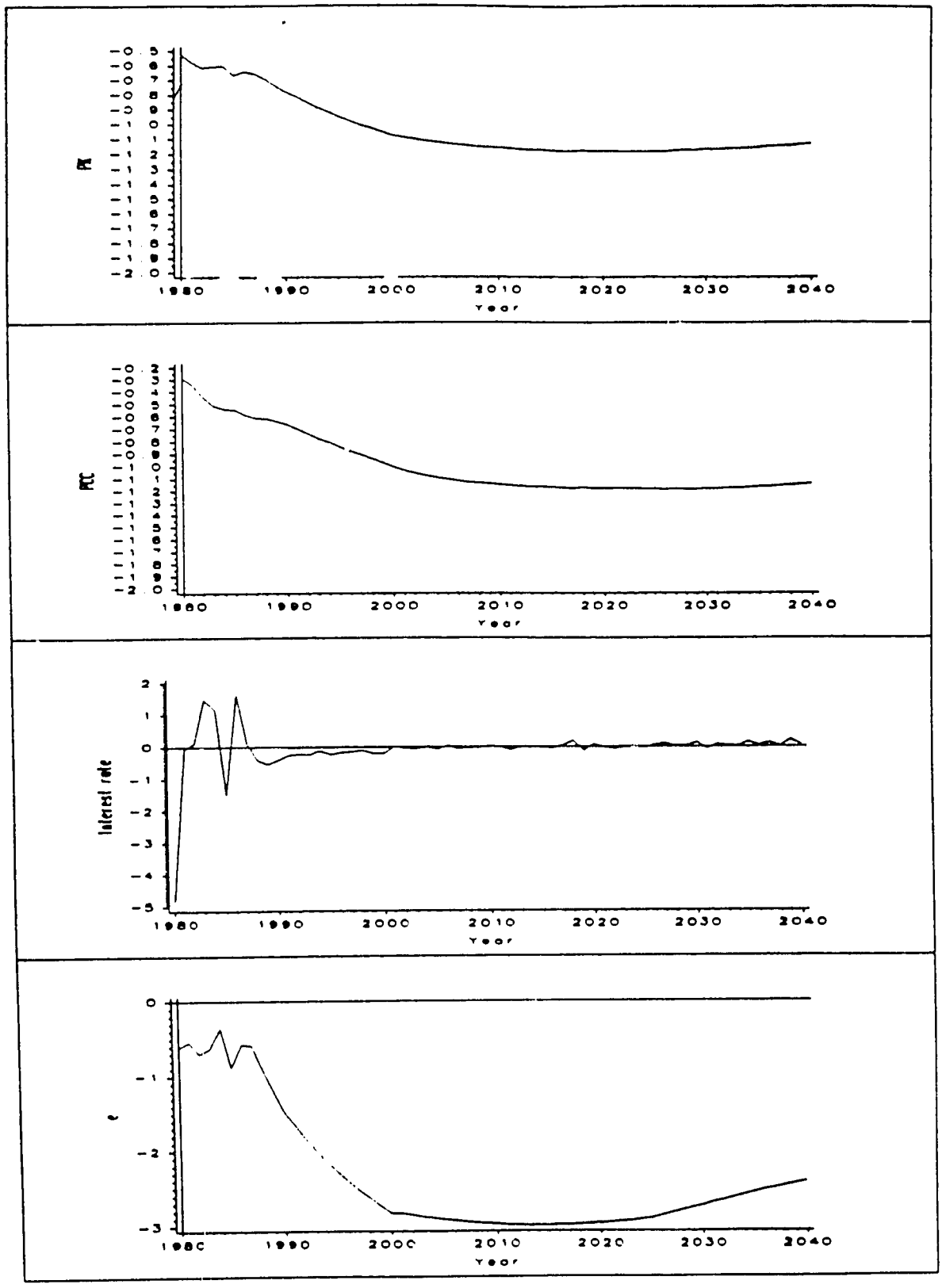
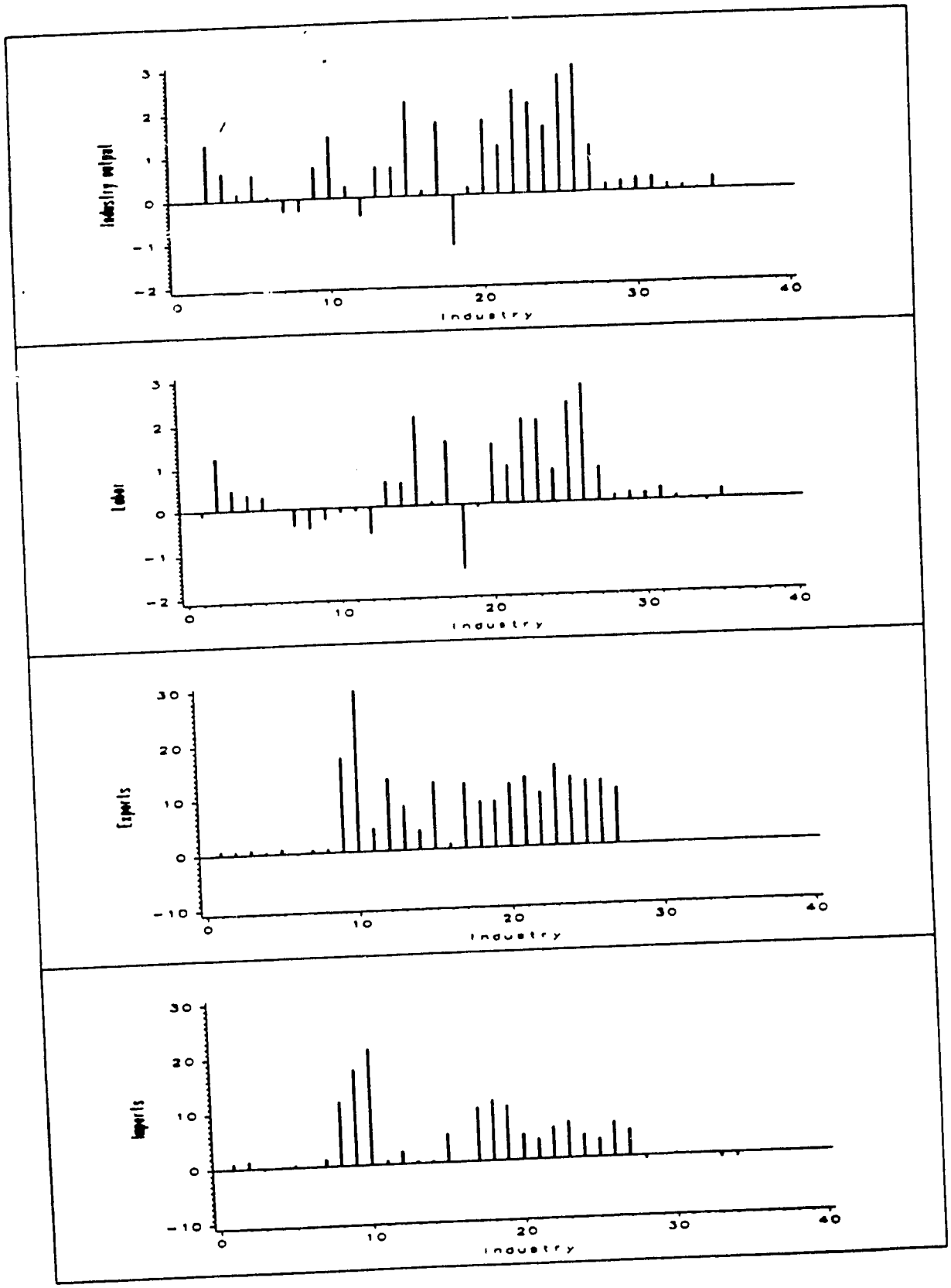


Figure 4.2 Steady state sectoral effects of tariff elimination.




Industry # refer to those in Table 1.

Table 4.2 Sectoral effects of eliminating all tariffs in 1980. (% change)

| Sector | Output | Capital | Labor | Exports | Imports |
|---|---|---|---|---|---|
| Agriculture | -0.32 | -0.44 | -0.47 | -0.34 | 2.09 |
| Metal mining | 2.17 | 2.08 | 2.04 | -0.43 | 2.31 |
| Coal mining | 0.36 | 0.26 | 0.17 | -0.44 | 0.84 |
| Oil & gas mining | 0.08 | 0.00 | 0.16 | -0.56 | 0.69 |
| Non-metal mining | 0.75 | 0.59 | 0.35 | -0.42 | 0.97 |
| Construction | 0.23 | 0.05 | 0.22 | -0.14 | |
| Food & kindred | -0.34 | -0.45 | -0.44 | -0.31 | 1.62 |
| Tobacco | -0.42 | -0.47 | -0.52 | -0.30 | 20.56 |
| Textile mill | 1.42 | 0.88 | 0.17 | 18.94 | 20.23 |
| Apparel | 1.71 | -0.26 | 0.09 | 29.07 | 31.06 |
| Lumber & wood | 0.25 | -0.06 | -0.35 | 3.39 | 4.59 |
| Furniture | -0.51 | -0.66 | -0.72 | 16.25 | 6.03 |
| Paper | 0.85 | 0.71 | 0.69 | 8.64 | 1.98 |
| Printing & publishing | 0.70 | 0.70 | 0.57 | 3.57 | 2.27 |
| Chemicals | 2.47 | 2.39 | 2.36 | 14.58 | 8.01 |
| Petroleum refining | 0.17 | 0.10 | 0.12 | -0.62 | 0.75 |
| Rubber & plastic | 1.71 | 1.58 | 1.45 | 12.74 | 15.07 |
| Leather | -1.40 | -2.17 | -1.75 | 5.93 | 16.93 |
| Stone Clay & Glass | 0.37 | 0.23 | 0.00 | 18.04 | 20.38 |
| Primary metal | 2.34 | 1.74 | 1.74 | 11.80 | 7.48 |
| Fabricated metal | 1.63 | 1.17 | 1.24 | 15.56 | 8.67 |
| Machinery | 2.51 | 1.94 | 1.87 | 11.11 | 10.52 |
| Electrical machinery | 2.29 | 1.84 | 2.06 | 16.77 | 11.17 |
| Motor vehicles | 1.84 | 1.44 | 0.85 | 13.08 | 5.76 |
| Transport. equipment | 2.93 | 2.30 | 2.38 | 12.65 | 7.09 |
| Instruments | 3.78 | 3.62 | 3.50 | 15.35 | 9.81 |
| Misc. manufactures | 1.44 | 1.23 | 1.07 | 12.94 | 11.23 |
| Transportation | 0.26 | 0.15 | 0.15 | -0.01 | 0.78 |
| Communications | 0.28 | 0.26 | 0.24 | -0.05 | |
| Electric Utilities | 0.22 | 0.21 | 0.13 | -0.06 | 0.09 |
| Gas Utilities | 0.40 | 0.32 | 0.34 | -0.03 | |
| Trade | 0.26 | 0.22 | 0.22 | -0.02 | |
| Finance, Insurance | 0.08 | 0.08 | 0.07 | -0.07 | 0.65 |
| Services | 0.02 | -0.01 | -0.09 | -0.11 | 0.61 |
| Govt Enterprises | 0.30 | 0.31 | 0.27 | -0.10 | |
| Household | | -0.54 | -0.27 | | |
| Govenrment | | 0.00 | -0.82 | | |

Entries are % change in the first period from base case.
Output is Industry output (not commodity supply)
Imports are competitive imports only.

Table 5.3 Sectoral effects of tariffs cuts after 20 periods.

| Sector | Value $82 bil. | | | % change from base | | |
|---|---|---|---|---|---|---|
| | Output | Exports | Imports | Output | Exports | Imports |
| Agriculture | 296.73 | 26.75 | 5.33 | -0.52 | -1.40 | 2.53 |
| Metal mining | 19.43 | 1.01 | 3.16 | 3.03 | -1.62 | 3.06 |
| Coal mining | 31.63 | 5.75 | 0.15 | 0.07 | -2.07 | 2.40 |
| Oil & gas mining | 278.60 | 0.89 | 40.23 | 0.02 | -1.52 | 2.76 |
| Non-metal mining | 26.00 | 0.60 | 2.11 | 1.42 | -1.75 | 2.60 |
| Construction | 691.57 | 0.16 | 0.00 | 0.25 | -0.46 | 0.00 |
| Food & kindred | 290.25 | 14.88 | 15.41 | -0.70 | -1.02 | 3.23 |
| Tobacco | 33.03 | 3.27 | 0.22 | -0.72 | -1.26 | 18.88 |
| Textile mill | 74.28 | 2.81 | 2.38 | 1.21 | 16.06 | 26.52 |
| Apparel | 125.52 | 2.92 | 40.94 | 2.58 | 34.46 | 26.14 |
| Lumber & wood | 63.22 | 4.70 | 4.82 | 0.15 | 1.04 | 6.86 |
| Furniture | 38.44 | 0.97 | 4.63 | -0.10 | 13.81 | 6.93 |
| Paper | 148.53 | 6.81 | 9.79 | 1.03 | 6.02 | 4.40 |
| Printing & publishing | 214.63 | 2.12 | 2.06 | 0.95 | 1.09 | 4.39 |
| Chemicals | 277.97 | 35.17 | 24.56 | 3.37 | 12.46 | 10.05 |
| Petroleum refining | 340.84 | 19.40 | 16.03 | 0.54 | -2.49 | 3.28 |
| Rubber & plastic | 131.93 | 19.31 | 7.50 | 2.04 | 9.02 | 16.33 |
| Leather | 18.80 | 0.97 | 13.10 | -1.47 | 8.42 | 16.54 |
| Stone Clay & Glass | 91.21 | 3.14 | 7.61 | 0.61 | 15.46 | 15.44 |
| Primary metal | 236.17 | 9.92 | 32.89 | 2.72 | 8.71 | 10.40 |
| Fabricated metal | 165.97 | 9.13 | 9.88 | 1.94 | 12.62 | 8.00 |
| Machinery | 434.94 | 96.62 | 25.92 | 3.18 | 8.33 | 13.59 |
| Electrical machinery | 217.47 | 42.98 | 43.60 | 3.38 | 14.54 | 12.63 |
| Motor vehicles | 213.08 | 36.81 | 45.83 | 2.75 | 11.25 | 10.34 |
| Transport. equipment | 202.95 | 46.70 | 6.81 | 3.66 | 9.51 | 9.06 |
| Instruments | 81.53 | 20.91 | 9.81 | 4.80 | 12.36 | 11.23 |
| Misc. manufactures | 36.83 | 3.18 | 17.55 | 1.92 | 12.05 | 10.26 |
| Transportation | 272.90 | 19.59 | 3.53 | 0.46 | 0.02 | 2.87 |
| Communications | 295.22 | 1.81 | 0.00 | 0.60 | -0.12 | 0.00 |
| Electric Utilities | 158.29 | 0.65 | 1.24 | 0.74 | 0.24 | 1.16 |
| Gas Utilities | 230.99 | 0.51 | 0.00 | 0.91 | 0.18 | 0.00 |
| Trade | 908.17 | 29.95 | 0.00 | 0.25 | -0.07 | 0.00 |
| Finance, Insurance | 689.19 | 9.43 | 0.26 | 0.26 | -0.12 | 2.73 |
| Services | 910.16 | 12.14 | 0.07 | 0.05 | -0.26 | 2.62 |
| Govt Enterprises | 150.18 | 0.51 | 0.00 | 0.50 | -0.15 | 0.00 |

Counterfactual simulation ran 1980:2100.
Entries in last 3 cols. compare variables at 2000.
Output is industry output. Imports are competitive imports only.

## 4.2 Quantitative restrictions on trade.

Trade regulation has, over the last fifteen years, shifted away from tariffs to quantitative restrictions, like quotas and "voluntary" export restraints. We have not explicitly modelled these quotas and have assumed that the realized import prices reflect the effects of these restrictions.

The reason for this approach is primarily simplicity. To take a concrete example, world trade in apparel is governed by the Multi-Fiber Agreements which allocate quotas to each exporting country. These quotas are very detailed covering many categories of "apparel". Some countries hit the limits of these quotas while others are constrained in some, or none, of the categories. Putting a constraint like :

$$M_{it} \leq \bar{M}_{it} \qquad i = 1,..,35$$

too, is merely an approximation at our level of aggregation.[44] Since we do not distinguish imports by origin, the "reality" cannot be described very simply.

We therefore, take a simpler approximation by assuming that the quotas result in a higher world price of imports $PM^*$. There are a few studies that provide estimates of tariff equivalents of quotas, notably Hufbauer et. al. and Turner. While bearing in mind the many possibilities of non-equivalence,[45] using these effective taxes is quite consistent with the framework of constant returns to scale and perfect competition in our model.

This counterfactual experiment therefore consist of eliminating all the tariffs in Table 4.1b -- the nominal tariffs in the U.S. and the rest-of-the-world -- and the tariff equivalents for textiles, apparel, shoes, steel and automobiles from Hufbauer et. al. (1986). These are the more significant but by no means all of U.S. quotas. We have

[44] Another example is motor vehicles. Japanese exports to the U.S. are under VERs, while those from Europe are not

[45] See Krishna (1985) for example

ignored restrictions on agricultural products and other types of vehicles. The tax equivalents are eliminated by reducing $PM_i^*$, i.e. foreigners losing the quota rents. Again this simulation is started in 1980 and ran forward till T=2100. We have chosen to combine both restrictions to give an estimate of all trade restrictions. Simulating separately with quotas alone, and adding the effects to §4.1's would be a little different given the non-linearities of the model.

At the aggregate level the results are broadly similar to the case of tariff cuts alone. The shape of the curves in Figure 4.3a and 4.3b are the same but more pronounced in their deviations from zero. (Recall that the graphs are the difference between the counterfactual and the base case.) The only exception is the graph for the terms-of-trade $e$.

In the case of quota elimination we have not implemented it as a multilateral liberalization. The effect of this is as though relative import prices for these goods have moved down. Given the exogenous trade balance the "exchange rate" has to depreciate in some years to induce higher exports to cover this increased demand for textiles, steel, autos, and shoes. In the initial year for example, the appreciation is only 0.53% versus 0.61% in the "no tariffs" case.

Thus by the year 2000 the welfare improvements are substantially larger than the case of tariff elimination alone. The % changes for the major variables are :

| | No tariffs | No t. & quotas |
|---|---|---|
| Capital | 0.50 | 0.54 |
| Full consumption | 0.17 | 0.26 |
| Consumption | 0.74 | 0.96 |
| C.P.I. | 1.00 | 1.25 |
| Exports | 6.54 | 7.19 |
| Imports | 9.72 | 10.68 |
| Price of capital | -.72 | -1.30 |

These dynamic gains come directly from the reductions in import prices of all the five

quota items, and indirectly from the reduction in the price of capital. Investment goods are big users of steel and motor vehicles, and thus are substantial gainers. For the economy as a whole this means more of output can be devoted to consumption. The effects on GNP growth is summarized below.

| | Base case | | |
|---|---|---|---|
| | Annual GNP growth rate % | | |
| 1980:1990 | 3.47 | 3.48 | 3.50 |
| 1980:2000 | 2.34 | 2.37 | 2.38 |

With the sharp drop in the price of capital goods due to the elimination of auto quotas in the 1980s the rate of investment and GNP growth rose substantially. (see Table 4.1b) These quotas were lifted in 1985 and the increase in the growth rate became smaller.

The sectoral effects of this experiment are given in Table 4.4. This should be compared with Table 4.2 for the case with only tariff cuts. The industry effects are quite similar except for the four items under quotas.[46] Apparel imports, for example, rises by 42% compared to the previous 31% gain. For iron and steel it's 15% vs. 7%, and for the leather (shoes) sector 28% vs. 17%. These shifts translate into parallel output changes, the leather industry's output falls by 2.5% (vs. 1.4%), while textiles rises only 1.2% (vs. 1.4%). Resources move out of apparel, but since its main intermediate input, textiles, also fall in price, output of apparel rises.

In sum, even though only few goods are under quotas are considered the effects are substantial. The five items alone would produce a consumption gain a quarter higher than the complete elimination of world tariffs. A multilateral reduction of non-tariff barriers would have even greater effects given the widespread belief that the rest of the world's restrictions are even tighter than the U.S.

[46] Motor vehicle imports were restricted only beginning in 1981

Figure 4.3a Dynamic effects of eliminating tariffs and quotas. (% change)

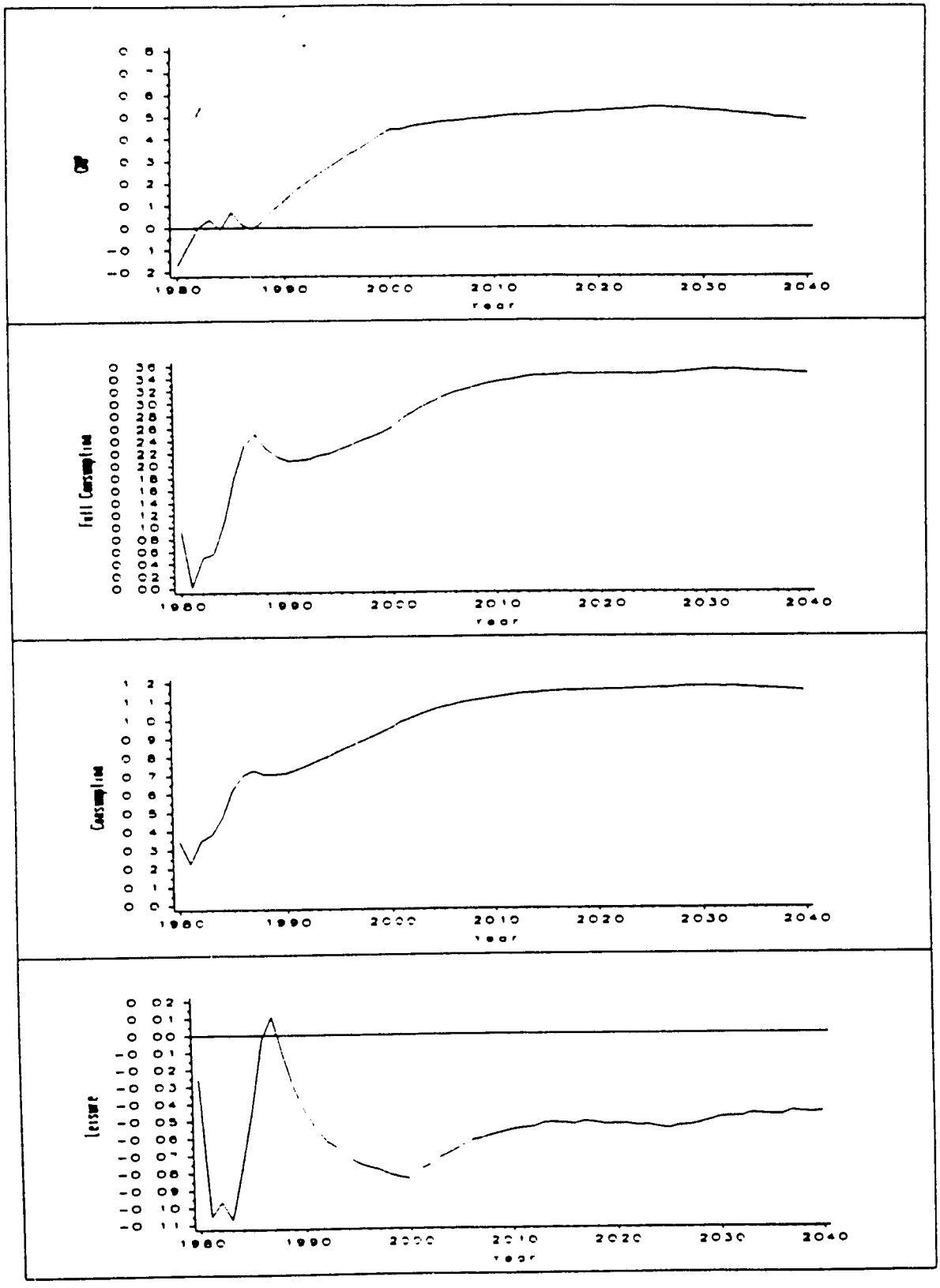


Figure 4.3b Dynamic effects of eliminating tariffs and quotas.

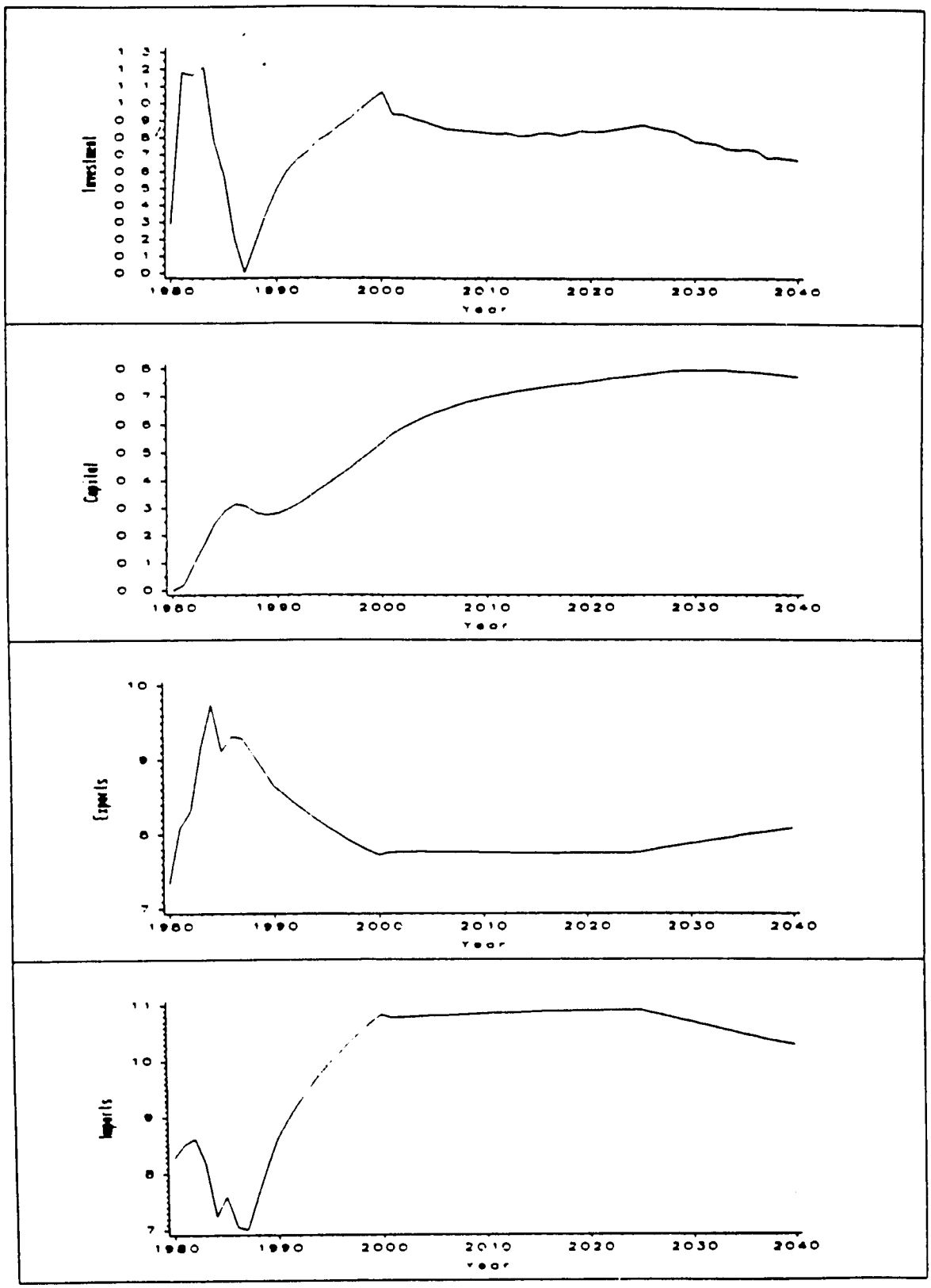


Figure 4.3c Dynamic effects of eliminating tariffs and quotas.

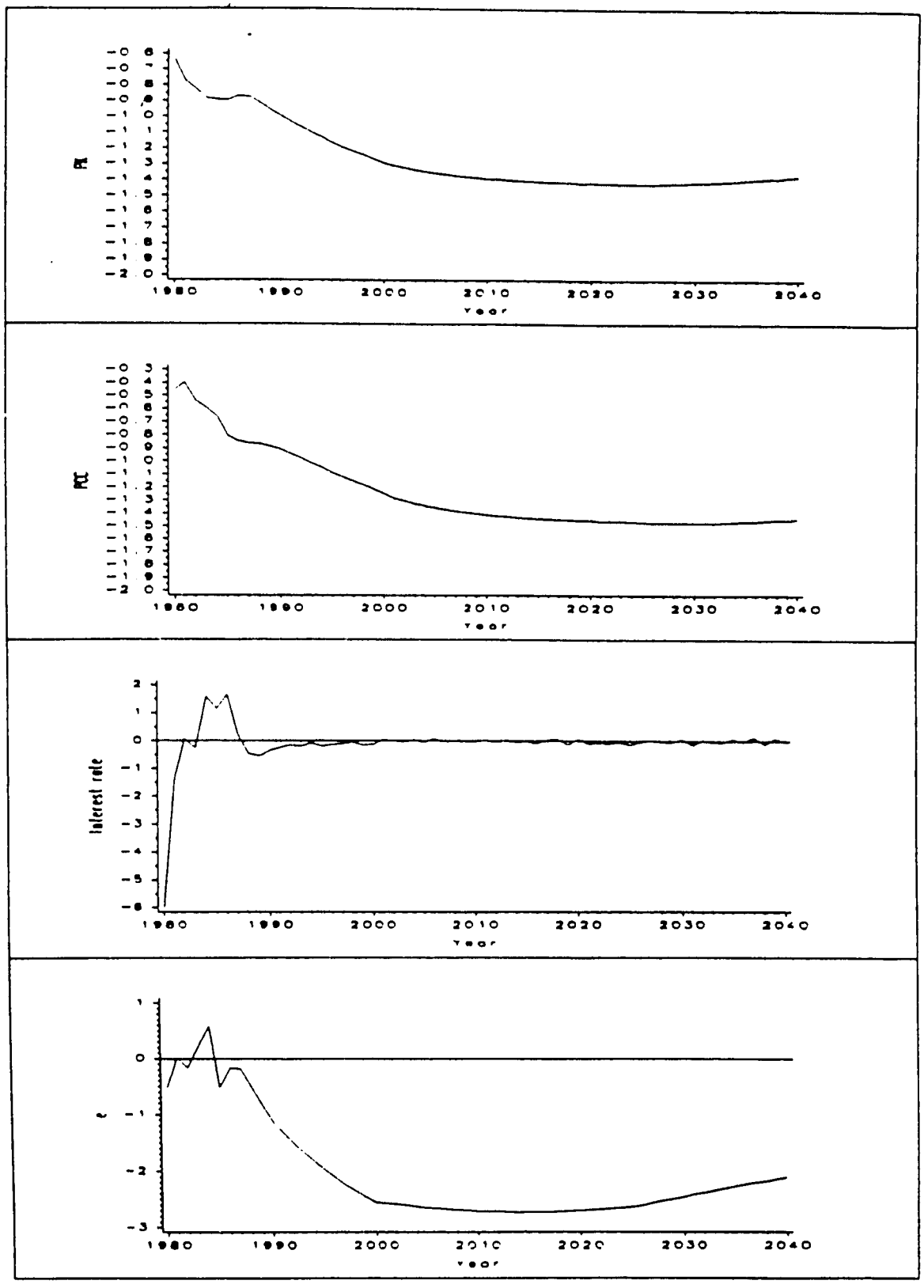


Table 4.4 Sectoral effects of eliminating tariffs and selected quotas.

| Sector | Output | Capital | Labor | Exports | Imports |
|---|---|---|---|---|---|
| Agriculture | -0.34 | -0.43 | -0.51 | -0.14 | 1.97 |
| Metal mining | 2.10 | 2.09 | 1.86 | -0.18 | 2.20 |
| Coal mining | 0.30 | 0.24 | 0.02 | -0.27 | 0.60 |
| Oil & gas mining | 0.07 | 0.00 | 0.15 | -0.32 | 0.56 |
| Non-metal mining | 0.50 | 0.32 | 0.03 | -0.23 | 0.68 |
| Construction | -0.15 | -0.30 | -0.17 | -0.21 | |
| Food & kindred | -0.50 | -0.56 | -0.62 | -0.13 | 1.37 |
| Tobacco | -0.54 | -0.54 | -0.73 | -0.09 | 20.06 |
| Textile mill | 1.19 | 0.61 | -0.24 | 19.91 | 25.64 |
| Apparel | 2.01 | -0.46 | -0.09 | 33.60 | 42.31 |
| Lumber & wood | -0.12 | -0.45 | -0.83 | 3.81 | 3.91 |
| Furniture | -1.20 | -1.35 | -1.49 | 16.81 | 4.93 |
| Paper | 0.81 | 0.67 | 0.62 | 8.94 | 1.75 |
| Printing & publishing | 0.90 | 0.93 | 0.72 | 3.89 | 2.29 |
| Chemicals | 2.45 | 2.38 | 2.31 | 15.13 | 7.74 |
| Petroleum refining | 0.18 | 0.19 | 0.09 | -0.44 | 0.62 |
| Rubber & plastic | 1.30 | 1.21 | 1.01 | 13.44 | 14.38 |
| Leather | -2.52 | -3.59 | -3.04 | 11.27 | 27.56 |
| Stone Clay & Glass | -0.04 | -0.16 | -0.47 | 18.83 | 19.56 |
| Primary metal | 2.40 | 1.33 | 1.32 | 13.57 | 15.09 |
| Fabricated metal | 1.66 | 0.86 | 0.95 | 16.42 | 8.23 |
| Machinery | 2.36 | 1.59 | 1.45 | 11.96 | 9.87 |
| Electrical machinery | 2.02 | 1.46 | 1.72 | 17.94 | 10.52 |
| Motor vehicles | 1.58 | 1.13 | 0.29 | 13.95 | 5.02 |
| Transport. equipment | 2.87 | 2.15 | 2.10 | 13.15 | 6.70 |
| Instruments | 3.56 | 3.40 | 3.21 | 16.41 | 9.42 |
| Misc. manufactures | 1.50 | 1.28 | 1.02 | 14.58 | 10.89 |
| Transportation | 0.10 | -0.01 | -0.03 | 0.00 | 0.49 |
| Communications | 0.21 | 0.20 | 0.14 | -0.07 | |
| Electric Utilities | 0.23 | 0.25 | 0.05 | -0.02 | 0.12 |
| Gas Utilities | 0.35 | 0.31 | 0.25 | -0.03 | |
| Trade | 0.10 | 0.06 | 0.05 | -0.04 | |
| Finance, Insurance | 0.04 | 0.09 | -0.01 | -0.09 | 0.46 |
| Services | -0.01 | -0.04 | -0.15 | -0.15 | 0.45 |
| Govt Enterprises | 0.23 | 0.28 | 0.18 | -0.14 | |
| Household | | -0.40 | -0.50 | | |
| Government | | | -0.99 | | |

Entries are % change from base case in the first year 1980
Imports are competitive imports only.

### 4.3 Unilateral tariff cut

While the option of a unilateral U.S. tariff reduction has seldom been discussed among official circles, it is analysed by economists, in particular those using the applied general equilibrium models. To show how this model compares with the others we shall run the counterfactual experiment of a unilateral elimination of all tariffs by the U.S. in 1980.

The results of comparing this simulation with the base case are given in Figure 4.4 and Table 4.5. Both full-consumption and Commodity consumption falls by 0.1% initially, with real exports rising 4.9% and imports 5.7%. The capital stock also falls, reaching the biggest gap in 1991 before recovering some ground.

The cause of this welfare loss can be found in the bottom panel of Figure 4.4. The "exchange rate" $e$, i.e. the terms of trade, deterioriates severely. The initial depreciation is some 4.8%, falling to 3.5% by the year 2000. This loss in the terms of trade comes about from the relatively inelastic import demands of the rest-of-the-world. When import prices fall due to the tariff cut, import demand rises. However, the trade balance is fixed and $e$ has to adjust to induce greater exports to pay for these increased imports. The magnitude of this adjustment is governed by the U.S. export demand elasticities as given in Chapter 4.

With our assumed parameters the required depreciation is so large that prices rise relative to wages. This cuts domestic consumption and factors move towards the more profitable export sectors. Sectoral effects are given in Table 4.5. The income effect on leisure is so large that it outweighs the price effect and labor supply rises. We thus have the same initial capital stock, greater labor input, lower consumption, higher exports, and surprisingly, lower aggregate output. This could be due to the movement of factors towards the less efficient industries.

The imports of the previously more heavily taxed items rise sharply -- textiles, apparel, leather (shoes), and glass -- while the depreciation of $e$ reduces the imports of oil, paper and vehicles. On the export side there is a rough even gain across the manufacturing industries. The combination of these shifts in trade and the reduction in demands of the poorer households resulted in the output changes given in the first column of Table 5.5. The Textile and Leather industries reduce their output with the increased imports, while Chemicals, Plastics, Machinery, Electrical Machinery, Transportation equipment and Instruments raise output for the higher export demands.

Figure 4.4 Dynamic effects of a unilateral tariff cut. (% change)

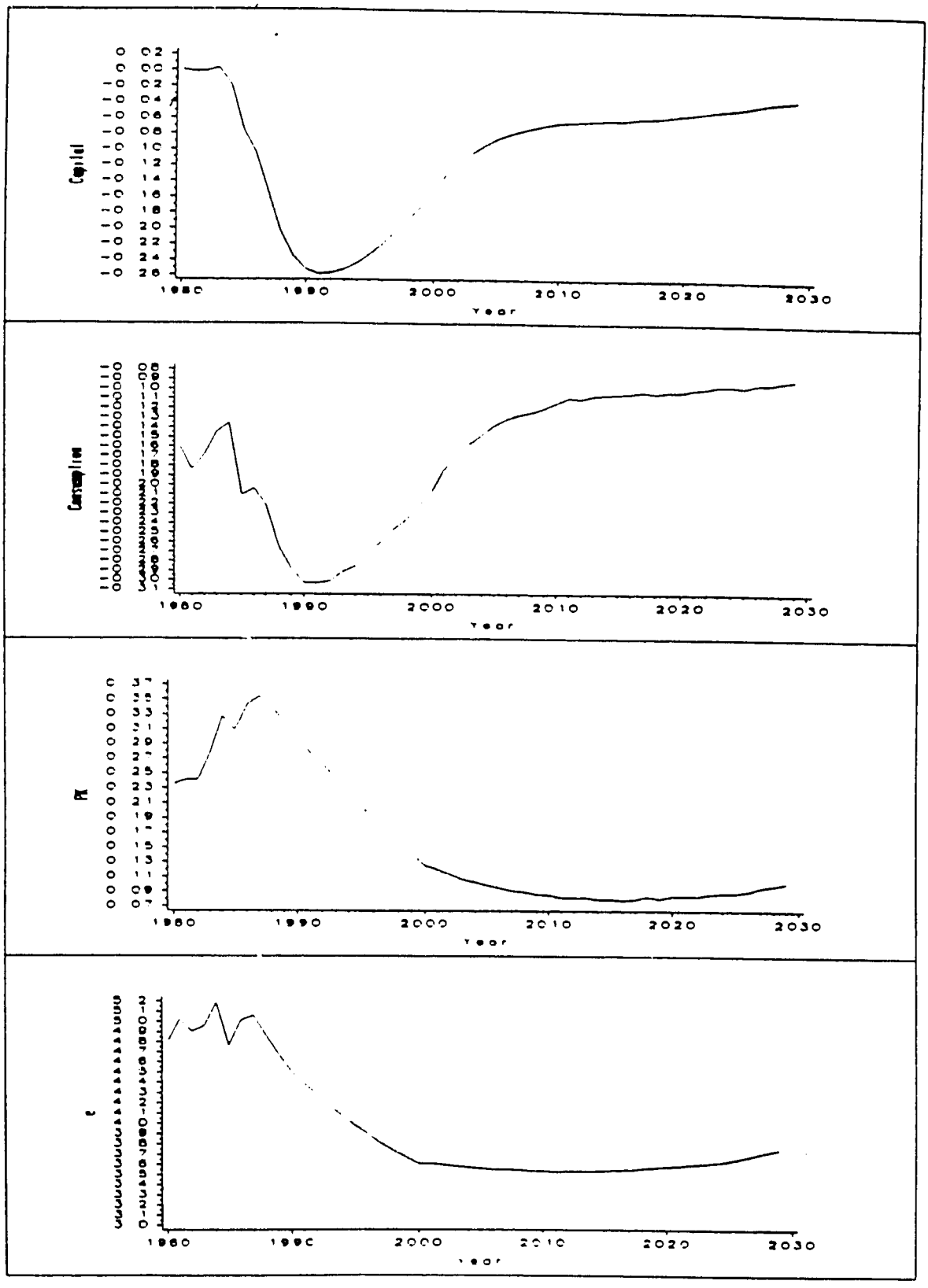


Table 4.5 Sectoral effects of a unilateral tariff cut.

| Sector | Output | Exports | Imports |
|---|---|---|---|
| Agriculture | 0.66 | 3.26 | 0.04 |
| Metal mining | -0.21 | 2.90 | -1.40 |
| Coal mining | 1.35 | 4.25 | -3.16 |
| Oil & gas mining | 0.27 | 2.72 | -3.66 |
| Non-metal mining | 0.35 | 3.91 | -0.79 |
| Construction | -0.03 | -0.19 | |
| Food & kindred | -0.12 | 2.42 | -1.22 |
| Tobacco | 0.19 | 2.87 | 11.22 |
| Textile mill | -0.04 | 7.77 | 9.65 |
| Apparel | 0.35 | 7.92 | 21.51 |
| Lumber & wood | 0.64 | 6.41 | -3.87 |
| Furniture | -0.10 | 6.67 | -1.98 |
| Paper | 0.47 | 6.54 | -4.03 |
| Printing & publishing | 0.64 | 6.41 | -3.77 |
| Chemicals | 1.07 | 6.37 | 0.59 |
| Petroleum refining | -0.51 | 4.38 | -4.16 |
| Rubber & plastic | 1.34 | 10.10 | 5.11 |
| Leather | -0.87 | 7.08 | 7.62 |
| Stone Clay & Glass | 0.26 | 7.51 | 9.18 |
| Primary metal | 0.99 | 8.64 | -0.93 |
| Fabricated metal | 0.64 | 7.36 | 1.96 |
| Machinery | 1.65 | 7.38 | 0.75 |
| Electrical machinery | 1.08 | 7.61 | 2.35 |
| Motor vehicles | 0.58 | 6.63 | -2.71 |
| Transport. equipment | 1.21 | 7.21 | -1.46 |
| Instruments | 1.97 | 8.99 | 3.47 |
| Misc. manufactures | 0.95 | 7.47 | 2.81 |
| Transportation | -0.11 | -0.07 | -4.39 |
| Communications | -0.01 | -0.04 | |
| Electric Utilities | 0.01 | -0.36 | 0.27 |
| Gas Utilities | -0.15 | -0.49 | |
| Trade | 0.12 | 0.00 | |
| Finance, Insurance | 0.03 | -0.05 | -4.45 |
| Services | -0.00 | -0.02 | -4.43 |
| Govt Enterprises | 0.08 | -0.05 | |

Entries are % change from base case in the initial year.
Output is industry output (not commodity supply)
Imports are competitive imports only.

### 4.4 Sensitivity Analysis

Given the imprecision of the price elasticities in the import demand equations and in the export elasticities taken from the literature, we repeated the experiment in §4.1 using different values of these parameters.

The strong feeling in the literature is that these substitution elasticities are biased downwards.[47] One problem as pointed out by Orcutt (1950) is that aggregates are dominated by the low elasticity-high price volatility components, which would bias the estimates downwards. Following Deardoff and Stern (1986) we therefore, simply doubled all elasticities.[48] We used the 1985 shares to calculate the more elastic parameters. The export elasticites $\eta_i$ are simply doubled.

In the steady state the capital stock gain due to a multilateral tariff elimination is 0.75%. in contrast to the 0.59% gain for base elasticities. Aggregate commodity consumption is 1.07% higher compared to 0.82% previously. Leisure falls 0.07% with the higher real wage. The real price of capital is 1.36% lower vs. 0.68%.

The steady state sectoral results of eliminating tariffs beginning in 1980 for the two sets of parameters are given in Table 4.6. The first three columns of numbers are the % changes in the §4.1 experiment, the last three columns are the changes with the doubled elasticities. The differences are unfortunately large (or fortunately depending on one's emphasis). The elasticities obviously have a significant effect on the estimates of output response, it may even change the sign.

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[47] See Chapter 4 of Ho (1989), and Golstein and Khan (1985).

[48] The elasticity of substitution is : $E = \frac{B}{share} + share - 1$
where B is the price coefficient of eqn. 3 15

Table 5.6 Sensitivity test using more elastic trade parameters.

| Sector | Base elasticities | | | Doubled elasticities | | |
|---|---|---|---|---|---|---|
| | Output | Exports | Imports | Output | Export | Import |
| Agriculture | -0.56 | -0.88 | 1.85 | -1.59 | -2.94 | 5.71 |
| Metal mining | 2.74 | -1.13 | 2.39 | 2.91 | -3.72 | 2.68 |
| Coal mining | 0.29 | -1.37 | 1.83 | -0.32 | -4.20 | 3.92 |
| Oil & gas mining | 0.08 | -1.12 | 2.19 | -0.47 | -2.56 | 3.63 |
| Non-metal mining | 1.32 | -1.15 | 2.01 | 1.23 | -3.76 | 3.12 |
| Construction | -0.05 | -0.53 | 0.00 | -0.02 | -0.63 | 0.00 |
| Food & kindred | -0.98 | -0.66 | 2.48 | -1.68 | -2.27 | 5.30 |
| Tobacco | -0.83 | -0.78 | 15.08 | -1.48 | -2.54 | 32.51 |
| Textile mill | 1.04 | 17.44 | 22.83 | -2.55 | 34.31 | 39.56 |
| Apparel | 2.54 | 31.52 | 24.59 | -2.28 | 66.07 | 39.73 |
| Lumber & wood | 0.22 | 2.17 | 4.89 | -0.55 | 2.12 | 9.60 |
| Furniture | -0.22 | 15.03 | 5.55 | -0.04 | 28.84 | 11.36 |
| Paper | 1.00 | 7.09 | 3.45 | 0.87 | 12.30 | 7.33 |
| Printing & publishing | 0.96 | 2.18 | 3.45 | 1.01 | 1.83 | 6.55 |
| Chemicals | 3.31 | 13.56 | 8.97 | 4.74 | 25.76 | 16.41 |
| Petroleum refining | 0.54 | -1.70 | 2.63 | 0.56 | -4.02 | 5.65 |
| Rubber & plastic | 1.99 | 10.78 | 13.85 | 1.23 | 18.51 | 23.16 |
| Leather | -1.56 | 9.09 | 14.76 | -12.87 | 13.47 | 22.39 |
| Stone Clay & Glass | 0.51 | 17.05 | 12.38 | -0.39 | 32.60 | 21.65 |
| Primary metal | 2.76 | 10.23 | 9.13 | 2.91 | 17.73 | 15.83 |
| Fabricated metal | 1.83 | 13.91 | 7.00 | 2.49 | 26.43 | 12.40 |
| Machinery | 3.54 | 9.63 | 11.79 | 6.43 | 16.58 | 40.20 |
| Electrical machinery | 3.55 | 15.84 | 11.53 | 4.24 | 29.95 | 20.00 |
| Motor vehicles | 2.89 | 12.52 | 8.93 | 2.78 | 23.14 | 17.94 |
| Transport. equipment | 3.77 | 10.79 | 7.87 | 6.10 | 19.62 | 17.07 |
| Instruments | 4.70 | 13.82 | 10.38 | 8.42 | 24.65 | 21.46 |
| Misc. manufactures | 1.90 | 13.21 | 8.93 | -1.11 | 23.24 | 13.91 |
| Transportation | 0.32 | 0.01 | 1.99 | 0.33 | 0.02 | 2.86 |
| Communications | 0.55 | -0.14 | 0.00 | 0.71 | -0.17 | 0.00 |
| Electric Utilities | 0.76 | 0.22 | 0.65 | 0.86 | 0.41 | 0.56 |
| Gas Utilities | 0.84 | 0.13 | 0.00 | 1.22 | 0.37 | 0.00 |
| Trade | 0.11 | -0.07 | 0.00 | 0.11 | -0.09 | 0.00 |
| Finance, Insurance | 0.24 | -0.12 | 1.91 | 0.26 | -0.15 | 2.85 |
| Services | 0.02 | -0.27 | 1.82 | 0.03 | -0.34 | 2.75 |
| Govt Enterprises | 0.45 | -0.16 | 0.00 | 0.55 | -0.20 | 0.00 |

Entries are % changes between "no-tariffs" and "base" case.
Base trade elasticities are those estimated in Ho (1989).

Overall, the magnitudes of export and import changes are increased and with no changes in sign. Output responses are different, despite the increased aggregate labor supply some sectors show a reduction in output in response to the increased import competition. That is, in the more elastic case the Textile, Apparel, Lumber, and Miscellaneous manufactures industries have negative output responses to tariff reduction, while in the base elasticities case they are positive due to stronger export effects.

The positive aspect of this imprecision is that the welfare gains are higher in the more substitutable case. That is, our base calculations give the conservative estimates of welfare gains of trade liberalization. This degree of uncertainty is quite typical, and point to the obvious need for better data.

### 4.5 Comparisons with other studies

The major studies of tariff reductions for the U.S. using numerical general equilibrium models are Deardoff and Stern (1986), Whalley (1985),[49] and Goulder and Eichengreen (1989b). While the results of these studies and ours are not completely comparable due to different classifications and maintained hypotheses, it is still useful to examine them together to see how the differences might be accounted for.

At the aggregate level for the same experiment of eliminating all post-Tokyo round tariffs D&S reports a static welfare gain of 0.1% of GNP. Their simulations are based on a 1976 reference year.[50] Whalley reports a similar 0.1% gain with 1977 as the base year.[51] The most recent major partial equilibrium study is by Cline et. al. (1978) and they report a 0.07% welfare gain from a 60% tariff cut in 1973, again roughly 0.11% of GNP for a complete cut.

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[49] Short versions of their results are in Srinivasan and Whalley (1986)

[50] Deardoff and Stern (1986) page 68

[51] Whalley in Srinivasan and Whalley page 205 The estimate reported is $1.1 bil. for a 50% multilateral cut. I multiplied this by two and divided by the 1977's GNP.

In our dynamic model the increase in consumption in the first period is 0.16% which is about 0.1% of GNP in 1980. This must be considered together with the 0.87% increase in investment and the 0.09% reduction in leisure. Discounting at the low interest rates generated by the model (real interest rates about 3%), the present value of the gains in full-consumption is 0.04 % of full-wealth or 3.5% of annual GNP.

The sectoral effects of a multilateral reduction in tariffs of the three models are given in Table 4.7. Besides the differences noted in the previous sections regarding the use of flexible functional forms, these models use very different working assumptions, the Michigan model has endogenous aggregate spending to keep employment constant, capital is fixed for each sector. Whalley's model is highly aggregated, and has mobile capital and a fixed labor supply. In our model labor supply is endogenous, and as described above, there is an increase in total labor input in the "tariff cut" case. In the other studies labor input is measured simply as the number of employed workers (or manhours), in our case labor is adjusted for compositional effects when it is moved across sectors. Also included in Table 4.7 for comparison are results from one of the most detailed partial equilibrium studies, that by Cline, Kawanabe, Kronsjo and Williams (1978).

One of the biggest difference between these models is that the others use pre-1973 input-output tables whereas ours use 1985 data. The import elasticities that they use are from the much cited bibliography of Stern, Francis and Schumacher (1976) which collected results estimated from data before the early 1970s.

There is broad agreement among the models that tariff reductions will induce movements of factors from the non-tradeable sectors to the manufacturing industries. There is a clear majority (Whalley's aggregation makes comparisons more difficult) opinion about the negative effects on the Lumber, Furniture, and Leather (footwear) industries. Labor increasing industries are generally agreed to be Paper, Chemicals, Machinery, Electrical

Machinery and Transportation Equipment.

Our different results for Primary Metals is due to our allowance for the demand for investment goods to rise, and the possibility of increased aggregate labor input. A minor effect comes from the very high world tariffs on this item which are eliminated in the experiment. A similar effect may be working in the Apparel sector, the income and export effects may dominate the price effect.

For the sectors usually considered to be "non-tradeable" we have some minor exports in our accounting framework and few imports. The small increases in labor input in these industries is probably due in part to our specification of these exports. The major reason for this increased labor use in "non-tradeables" is the extra labor supply and corresponding higher output demand.

*Studies of quotas*

Comparisons of studies of quotas present yet extra diffculties. Deardoff and Stern reports only estimates of agriculture restrictions. Whalley uses the UNCTAD data from Yeats (1976) and miscellaneous "product-specific sources" but does not report the magnitudes. His experiments are global, i.e., the removal of all the non-tariff barriers he identified.

We have not done such a global quota removal simulation since we do not have the estimates of current tariff equivalents for many commodities. We therefore are only able to compare our results with Hufbauer et. al. from whom we took the tariff equivalents.

For textiles and apparel combined they reported a reduction of imports equal to 15% of domestic production in 1981 due to quotas and tariffs. From our **Table 4.4** the increase in imports in 1980 is only 5.3% of domestic output. The difference is due to (a) our broader commodity definition ($150 bil. vs $100 bil. of output) and lower estimated

tariffs (b) the depreciation on $e$ in our general equilibrium model.

In their estimates of steel alone the reduction of imports was 4.6% of domestic output in 1981. For our Primary Metals industry (of which steel constitutes only about 30%) the reduction is equivalent to 2.1% of output. This lack of compatibility in classification and scope is unfortunate, but these two studies serve quite different purposes.

*Unilateral Reductions in Tariffs*

This is the area of most disagreement among the models given the asymmetry of the experiment. Using their dynamic model, Goulder & Eichengreen (1989b) simulated a 50% unilateral reduction in U.S. tariffs and reports a 0.04% increase in first period consumption and a -0.12% reduction in steady state consumption. In our case of a complete elimination of tariffs the corresponding figures are -0.16 and -0.08. These differences are due to the capital mobility features, our higher labor supplied, and our less elastic import parameters.

For the static models, Whalley's 50% unilateral reduction produces a static loss in welfare equal to 0.25% of 1977 consumption. D&S on the other hand reports a welfare gain of 0.03% of GNP.[52] In the first period of our simulation the loss in commodity consumption was some 0.06% of GNP, rising to 0.16% at the peak 10 years later. In all the welfare losing models this is due to the loss in the terms of trade. The "endogenous spending to hit employment" feature of the Michigan Model may be the cause of their results.

[52] Srinivasan and Whalley for both results p 178,205.

Table 4.7 Comparisons of sectoral effects (% change in labor input).

| Sector | Michigan | Whalley | Cline | Ours |
|---|---|---|---|---|
| Agriculture | 1.56 | -0.08 | - | -0.47 |
| Metal mining | -0.03 | 0.64 | 0.23 | 2.04 |
| Coal mining | -0.03 | 0.64 | 0.23 | 0.17 |
| Oil & gas mining | -0.03 | 0.86 | - | 0.16 |
| Non-metal mining | -0.03 | 0.64 | 0.23 | 0.35 |
| Construction | 0.02 | -0.30 | - | 0.22 |
| Food & kindred | 0.06 | -0.08 | -0.17 | -0.44 |
| Tobacco | 0.06 | -0.08 | -0.17 | -0.52 |
| Textile mill | 0.75 | 0.28 | -2.76 | 0.17 |
| Apparel | -1.33 | 0.28 | -2.76 | 0.09 |
| Lumber & wood | -0.06 | 0.28 | -0.25 | -0.35 |
| Furniture | -0.01 | 0.28 | -0.25 | -0.72 |
| Paper | 0.10 | 0.28 | 0.58 | 0.69 |
| Printing & publishing | -0.02 | 0.28 | 0.58 | 0.57 |
| Chemicals | 0.42 | 0.28 | 0.52 | 2.36 |
| Petroleum refining | 0.10 | 0.86 | - | 0.12 |
| Rubber & plastic | -0.57 | 0.28 | -0.15 | 1.45 |
| Leather | -1.84 | 0.28 | - | -1.75 |
| Stone Clay & Glass | -0.41 | 0.28 | -0.12 | 0.00 |
| Primary metal | -0.26 | 0.28 | -0.30 | 1.74 |
| Fabricated metal | 0.07 | 1.56 | - | 1.24 |
| Machinery | 0.24 | 1.56 | 0.82 | 1.87 |
| Electrical machinery | 0.52 | 1.56 | 0.82 | 2.06 |
| Motor vehicles | 0.40 | 1.56 | 0.00 | 0.85 |
| Transport. equipment | 0.40 | 1.56 | 0.00 | 2.38 |
| Instruments | -0.41 | 1.56 | - | 3.50 |
| Misc. manufactures | -0.41 | 1.56 | - | 1.07 |
| Transportation | -0.04 | -0.30 | - | 0.15 |
| Communications | -0.04 | -0.30 | - | 0.24 |
| Electric Utilities | -0.12 | 0.86 | - | 0.13 |
| Gas Utilities | -0.12 | 0.86 | - | 0.34 |
| Trade | 0.07 | -0.30 | - | 0.22 |
| Finance, Insurance | -0.08 | -0.30 | - | 0.07 |
| Services | -0.06 | -0.30 | - | -0.09 |
| Govt Enterprises | - | - | - | 0.27 |
| Government | - | - | - | -0.82 |

"Michigan" is Deardoff & Stern (1986) page 75.
"Whalley" is from Srinivasan & Whalley p 208. [Reported effects of a 50% cut is multiplied by 2. Only 6 sectors are distinguished]
"Cline" is from Cline et. al. (1978) p 132. [Reported effects of a 60% cut is scaled up linearly]
"Ours" is taken from Table 4.2 above.
See text for details.

## 5 Conclusion

In this paper we have presented an implementation of a forward-looking dynamic multi-sector general equilibrium model to analyse the effects of government policies on growth and welfare. By incorporating the intertemporal aspect we can capture important dynamic effects of shocks on savings and investment that static models ignore. Very often these effects dominate in the long run and thus the welfare impact calculated in the traditional models may be substantially understated.

In our examination of the effects of government imposed trade barriers we found that the undiscounted consumption gain rapidly builds up to be half an order of magnitude greater due to the savings effect on the capital stock. A multilateral elimination of tariffs alone beginning in 1980 (when the average rate was 2.9%) raised long run consumption by 0.82% compared to 0.16% initially. The present value of all gains in full-consumption is some 1.7% of GNP in 1980.

When both tariffs and major quotas were lifted the long run gain in consumption is estimated to be 1.08% compared to the static 0.36%. The reduction in the price of capital goods (steel and vehicles) spurred investment and savings resulting in a higher rate of growth of GNP -- 2.38% vs. 2.34%. While the increase may seem small, the magnitude of the experiment should be kept in mind. Total tariffs collected was only 0.26% of GNP with an even smaller reduction in quota equivalents. It should also be pointed out again that these are the estimates using the "pessimistic" elasticities. From these figures we see that the ratio of welfare cost to the tariffs is thus about 2. With more comprehensive estimates of tax equivalents of the quotas that we have ignored here the welfare and growth effects would of course be higher.

These changes to the aggregate growth rates and sectoral allocation is captured by the flexible specification of the model. With the forward looking consumer, savings and

labor supply changes in response to shocks. Investment is further affected by the reduction in the relative price of capital goods, a feature captured by distinguishing the different commodities unlike the aggregated models. This model can thus be used to analyse many other policies like capital taxation and environmental regulation, as well as exogenous disturbances like the oil shocks of the 1970s.

## Appendix

### A.1 Household sector.

*Stage 1.* The aggregate household objective function (eqn. 3.1) may be rewritten as:

$$\sum_{t=1}^{\infty} \frac{N_t}{(1+\rho)^t} \left(\frac{F_t}{N_t}\right)^{1-\frac{1}{\sigma}} + \lambda\left(WF - \sum_{t=1}^{\infty} \frac{PF_t F_t}{\prod_{s=1}^{t} 1+r_s}\right) \tag{A.1}$$

where $\lambda$ is the Lagrange multiplier on the budget constraint. Differentiating w.r.t. $F_t$ and $F_{t-1}$ we obtain the Euler equation :

$$\left[\frac{F_t/N_t}{F_{t-1}/N_{t-1}}\right]^{\frac{1}{\sigma}} = \frac{1+r_t}{1+\rho}\frac{PF_{t-1}}{PF_t} \tag{A.2}$$

Given last period's F and PF and the current prices the Euler equation gives this period's full-consumption, $F_t$, and hence savings,

$$S_t = YF_t - PF_t F_t \tag{A.3}$$

where $YF$ is "full income," the sum of capital income and "human income," $\bar{w}LH + misc$. $misc$ is government transfers less lump sum taxes, $fees$ and private transfers abroad.

*Stage 2.* Full consumption is allocated to commodities (CC) and leisure (LEIS) using a homothetic, no "price illusion," translog utility function:

$$-\ln VV = \ln p'\alpha + \tfrac{1}{2}\ln p' B \ln p - \ln MF \tag{A.4}$$

where $\ln p = (\ln PCC, \ln w)'$ is the vector of log prices. We refer the reader to Jorgenson, Lau and Stoker (1982) for details on the derivation and restrictions. Homotheticity implies that $B'\iota = 0$ and Slutsky symmetry gives $B' = B$. Assuming the usual regularity conditions the inequality in (3.2) holds exactly, i.e., $MF = PF.F = PCC.CC + w.LEIS$.

From Roy's identity we can derive the share demand equations:

$$shr = \begin{bmatrix} PCC.CC/MF \\ w.LEIS/MF \end{bmatrix} = \alpha + B \ln p \tag{A.5}$$

With the homothetic restriction one can see that the price terms of (A.4) correspond to the translog cost function of a constant returns to scale production function (see §A.2 below):

$$\ln PF = \ln p' \alpha + \tfrac{1}{2} \ln p' B \ln p \tag{A.6}$$

where we have used the suggestive notation $PF$ to denote the price of "output," which in this case is full consumption, $F$.

Substituting (A.6) into (A.4) we have $VV = F$. That is, $F$ is the level of "static utility" in any given period. From (A.5) and (A.6) we can derive the consumption demands (CC and LEIS) and the price $PF$, given input prices, and by the definition of $MF$ we then get the quantity of full consumption.

Equations (A.5) and (A.6) are not used in the way as written. A closer examination of the data showed that the non-price component of the shares, $\alpha$, changed considerable over our sample period. In particular the leisure share dropped dramatically with the heightened entry of women into the labor force beginning in the early 70s. Given the lack of easily available micro estimates we took a simple direct approach by putting $\alpha$ as a logistic function of time. This fitted the data quite well and still allow for a steady state.

*Stage 3.* Household j's utility function over the 35 commodities and 3 non-produced "inputs," are assumed to be separable into nested functions. At the top tier we have 5 commodity groups, $C_i^j$ $i = 1,..5$ (energy, food, non-durables, services, capital), and the indirect utility function is written as :

$$\ln V^j = \ln(\frac{p}{Y_j})'\alpha + \tfrac{1}{2}\ln(\frac{p}{Y_j})' B \ln(\frac{p}{Y_j}) + \ln(\frac{p}{Y_j})' B_{pA} A_j \tag{A.7}$$

Again using Roy's identity we can derive the expenditure share equations :

$$shr^j = \frac{1}{D_j}(\alpha + B\ln\frac{p}{Y_j} + B_{pA}A_j) \tag{A.8}$$

where $shr^j = (p_1 C_1^j/Y_j, \ldots, p_5 C_5^j/Y_j)'$ and the denominator $D_j$ is :

$$D^j = \iota'\alpha + \iota' B\ln\frac{p}{Y_j} + \iota' B_{pA}A_j$$

From the conditions of exact aggregation,[53] the shares must be linear in $A_j$, hence:

$$\iota' B\iota = 0$$
$$\iota' B_{pA} = 0$$

Since (A.8) is homogenous in the coefficients we normalise by choosing $\iota'\alpha = 1$. The share equations are thus reduced to :

$$shr^j = \frac{1}{D}(\alpha + B\ln p - B\iota\ln Y_j + B_{pA}A_j) \tag{A.8'}$$

where the denominator is now independent of j, $D = -1 + \iota' B\ln p$.

The aggregate share equations are the weighted sum of the individual shares :

$$\begin{aligned} shr &= \frac{1}{D}(\alpha + B\ln p - B\iota\frac{\sum Y_j \ln Y_j}{\sum Y_j} + B_{pA}\frac{\sum Y_j A_j}{\sum Y_j}) \\ &\equiv \frac{1}{D}(\alpha + B\ln p - B\iota\xi^d + B_{pA}\xi^L) \end{aligned} \tag{A.9}$$

where $shr = (p_1 C_1^g/PCC.CC, \ldots, p_5 C_5^g/PCC.CC)'$. The value of aggregate commodity consumption expenditures is $PCC.CC = \sum Y_j$. The term $\xi^d$ is a measure of the distribution of expenditures over the households, and $\xi^L$ is the vector of shares of aggregate expenditure spent by each of the 672 demographic groups that are identified. The estimation of these terms and the coefficients are described in Jorgenson and Slesnick (1987), while Ho (1989) describes the projections of $\xi^d$, $\xi^L$ after the sample period.

[53] See Jorgenson, Lau and Stoker (1982) for details.

Corresponding to this aggregate share equation we have the price frontier for $PCC$ which is written as the social cost-of-living index in Jorgenson (1988):

$$\ln PCC = \iota B \ln p \ln PCC.CC/N - \alpha \ln p + \tfrac{1}{2} \ln p' B \ln P \tag{A.10}$$

In the tiers below this top one these five commodity groups are allocated to the individual commodities. The details of the nested structure is given in Ho (1989 p. 48). For these sub-tiers we use the same functional form as (A.7) and (A.8') but ignore the demographics, i.e. $B_{pA}=0$. We also impose homotheticity, which implies $B\iota=0$. The share equations at the $m$th node ($m \neq 1$) thus reduce to a simple:

$$shr^m = \alpha^m + B^m \ln p^m \tag{A.11}$$

where $p^m$ is the vector of prices of the components of the $m$th node, and $shr^m$ is the vector of value shares. Thus given prices and the value of total consumption from Stage 2 we can derive the demands for the individual commodities.

## A.2 Producer Sector

For our model of producer behavior we have modified the translog cost function that is discussed in detail in Jorgenson (1986) to eqn. (3.7), repeated here with the industry superscript suppressed :

$$\ln PO = \alpha_0 + \alpha_p' \ln P + \tfrac{1}{2} \ln P' B \ln P + \ln P' B_{pt} g(t) + \alpha_t g(t) + \tfrac{1}{2} \beta_{tt} g(t)^2 \tag{A.12}$$

That is, instead of a linear trend we have a logistic function $g(t)$. Differentiating w.r.t. the log prices we obtain the share equations:

$$shr = \alpha_p' \ln P + B \ln P + B_{pt} g(t) \tag{A.13}$$

The reader is referred to Jorgenson (1986) for details, here we shall merely describe the restrictions that are imposed. As mentioned in §3.1 we assume constant returns to scale, we also impose Slutsky symmetry and local concavity. These restrictions imply that:

$$\alpha_p{}'\iota = 1 \qquad B'\iota = 0 \qquad B_{pt}\iota = 0$$
$$B' = B$$

The local concavity restriction (i.e. concave at historical price ratios, not any random prices) is applied on the $B$ matrix in the estimation (see Ho (1989)).

The vector $\alpha_p$ gives the input value shares at unit relative prices (i.e. shares in the base year), while matrix $B$ is the *share elasticity* matrix which gives the elasticity of substitution between any pair of the four inputs. When $B$ is zero the production function reduces to a Cobb-Douglas one. $B_{pt}$ are the *biases of technical change*, changes in relative input prices may speed up or slow down technical progress. Given the highly significant estimates of $B_{pt}$ that we found, this is an important improvement over most models which ignores this.

Equations (A.12) and (A.13) are used to characterize the top tier of the production functions where we identify four inputs -- capital, labor, energy and materials. The energy and material inputs are aggregated from the 35 commodities and imports. The demands for the individual commodities are derived by "cost functions" arranged in a nested structure.

For the tiers below the top, the cost function used is simplified to:

$$\ln P_m = \ln P^m{}'\alpha^m + \tfrac{1}{2}\ln P^m{}'B^m \ln P^m \tag{A.14}$$

at each node $m \neq 1$. $P_m$ is the price of the input aggregate $m$, $P^m$ is the vector of prices of the components at node $m$. The corresponding share equations are:

$$shr^m = \alpha^m + B^m \ln P^m \tag{A.15}$$

While ignoring the time trends we still allow full substitution among the components of $m$. Incorporating time is an involved exercise given that there are 12 tiers for each of the 35 industries.

The sub-model embodied in (A.12-A.15) is implemented for each of the 35 industries. There is, however, a modification for the Oil and Gas Extraction sector. This industry was tightly regulated for much of the sample period with both price and quantity controls. In particular prices for domestic producers were kept down far below world levels in the 70s. Modelling the complex web of regulations is beyond the scope of the present study, we simplify them by setting the capital stock, which consist mostly of oil wells, equal to the historical data and allow the cost of capital to adjust differently from the other industries. (See Ho (1989) for further details).

The transformation of industry outputs ($QI$) to commodity supply ($QC$) is done quite simply via a Cobb-Douglas formula:

$$PC_i QC_i = \sum_j M_{ij} PI_j QI_j \qquad i = 1,\ldots,35 \tag{A.16}$$

where $M_{ij}$ are the row shares of the "make matrix" in Fig. 3.1. $PI$ is the price after sales taxes $\Pi_j = (1+T_j)PO_j$.

## A.3 Cost of capital and Investment

The cost of capital equation (3.11) may be derived following the approach of Hall and Jorgenson (1967) and Hayashi (1982). The investor maximizes the discounted stream of net rental income by choosing a path of investment:

$$\max \sum_{t=u}^{\infty} \frac{(1-tk)[PKD_t K_{t-1} - tpPK_{t-1}K_{t-1}] - PII_t I_t}{\prod_{s=u}^{t} 1+r_s} \tag{A.17}$$

subject to

$$K_t = (1-\delta)K_{t-1} - I_t$$

$PKD$ is the aggregate rental price and $PII$ is the price of aggregate capital goods. $K$ and $I$ are the aggregate capital stock and investment. $tk$ is tax rate on capital income, $tp$ is

the property tax rate, where we have simplified the tax detail by ignoring investment credits and depreciation allowances. Such an elaboration is straightforward and is used in Jorgenson and Yun (1986).

Setting up the Hamiltonian for this dynamic problem, and differentiating, we obtain:

$$(1+r_t)PII_{t-1} = (1-tk)[PKD_t - tpPK_{t-1}] + (1-\delta)PII_t \tag{A.18}$$

This equation (the correct form for 3.11) relates the rental cost of capital to the nominal interest rate and must be satisfied along the dynamic equilibrium path.

*Investment demand by commodities* Aggregate investment, $PII_t I_t$, is allocated across the 35 commoditites and non-competitive imports via a nested structure of demand functions. At the first tier this is divided into fixed and inventory investment using historical shares.[54] At the nodes of each of the subsequent tiers the disaggregated demands are derived from a translog price frontier:

$$\ln PII_m = \ln P^{m\prime}\alpha^m + \tfrac{1}{2}\ln P^{m\prime}B^m \ln P^m \tag{A.19}$$

$$shr^m = \alpha^m + B^m \ln P^m$$

where $PII_m$ is the price of sub-aggregate m, and $P^m$ is a vector of the component prices, and $shr^m$ is the value shares vector.

The tier structure and parameter estimates are reported in Ho (1989 p. 96).

## A.4 Government and Rest-of-the-world.

*Stocks and flows of debt* In our model government and current account deficits are carefully cumulated into the stock of assets. Government debt is owned by domestic

[54] Our non-stochastic model obviously cannot explain the well known fluctuations in inventories. Using actual shares seems to be the most straightforward approach for our purposes.

households ($BG_t$), and foreigners ($BG_t{}^*$). The public deficit $\Delta G_t$ is financed by issuing these two bonds, and through seignorage $\Delta P_t^{BG}$ :[55]

$$BG_t = BG_{t-1} + \Delta G_t + GFI + \Delta P_t^{BG} \tag{A.20}$$

$$BG_t{}^* = BG_{t-1}{}^* - GFI - \Delta P_t^{BG^*}$$

$GFI$ denotes government foreign investment, i.e. the negative of the flow of government debt to foreigners.[56] The government deficit is eqn. (3.13) written out in full:

$$\begin{aligned}\Delta G_t = {} & VGG_t + iBG_{t-1} + iBG_{t-1}{}^* + transfers \\ & - \sum t_j PO_j QI_j - \sum tr_i PM_i M_i - \sum tr_i^n PNCI_i NCI_i \\ & - tk(PKD.KD + i.BG + e.i^*BF) - tl.w.LS - tp.PK.K - fees - TLUMP\end{aligned} \tag{A.21}$$

where $fees$ are exogenous governtment revenues and $TLUMP$ is the lump-sum tax variable used in the simulations.

The current account surplus goes into the accumulation of private net foreign assets $BF$. and government net foreign claims $-BG^*$ :

$$BF_t = BF_{t-1} + CA_t - GFI_t + \Delta P^{BF} \tag{A.22}$$

where $\Delta P^{BF}$ is the capital (exchange rate) gain on the foreign claims. The equation for the government stock is course equation A.20 above.

All the variables described so far in this section are set equal to the historical data or projected exogenously. In a revised version of the model the current account and stock claims will be endogenized by a simple asset demand model.

*Trade flows* In eqn. (3.15) we have represented the demand for imports by the share

[55] The notation is meant to suggest the devaluation of the value of government bonds through inflation The definition of BG is given in Christensen and Jorgenson, it includes money and assets of social insurance funds.

[56] All stocks and flows are in net terms. In the official data the government is both borrower and lender.

equations derived from a translog price frontier. A close perusal of the share data show a rapidly rising trend for almost all commodities with little change in relative prices. One may regard this as the result of a non-homothetic demand function where imports are luxuries. Alternatively, as Petri (1984) suggested, it may be due to structural factors, e.g. the emergence of manufactured exports from the more advanced developing countries. It is not the goal of this paper to solve this important puzzle, one would need detailed "micro" data on imports. Pending a more convincing model for these trends, we chose a simple functional form that turned out to fit the data very well. We write the share equation as a logistic function of time:

$$shr^i \equiv \begin{bmatrix} PC_i QC_i / PS_i QS_i \\ PM_i M_i / PS_i QS_i \end{bmatrix} = \alpha_0^i + \frac{\beta_0^i}{1+e^{-\mu_i(t-\tau_i)}} + B^i \ln p^i \qquad \text{(A.23)}$$

where $p^i$ is the price vector $(PC_i, PM_i)'$. The value of total supply to the market is simply $PS_i QS_i = PC_i QC_i + PM_i QM_i$. Equation (A.23) was estimated for all the non-service industries over the sample period 1964:85.[57]

The base exports $EX_{i0}(Y^*)$ in equation 3.17 are set to the historical exports in sample period, and projected out of sample via:

$$\ln EX_{ti} = \alpha_i^x + \lambda_i^x \ln Y_t^* \qquad \text{(A.24)}$$

This equation was estimated for all commodities using our data for the period 1964:85.[58] World income Y* is assumed to grow initially at 2% and slowing down to the presumed steady state of zero growth in 2050.

[57] The results are reported in Chapter 4 of Ho (1989)

[58] The omitted variable bias of $\lambda$ has the same sign as $corr(Y^*, P_i^*/P_i^{US})$ on which we can put no clear priors. We believe that the magnitude of this bias is small enough for (A.24) to be a usable starting point for the projections.

## A.5 Solution of model and Exogenous variables

As described in §3.7 the model is solved by iterating on a guess of the path of the costate variable. Here we shall describe how the intraperiod equilibrium is solved given the capital stock $K_{t-1}$ and the guess of $PF_tF_t$.

For each period, variables regarded as exogenous include the stocks of debt, $BF, BG, BG^*$; public sector deficit, government interest payments and transfers, $\Delta G, iBG$; the current account balance, foreign factor income, import prices and base exports, $CA, e.i^*BF, PM, PNCI, EX$; the number of households and time endowment, $N, LH$; the composition adjustment coefficients, $\psi^K, \psi^L$. These variables are set equal to the data during 1947:85 and projected after that.[59]

The population is projected using a more elaborate version of the Social Security Agency's population projection model. We impose a stationary population in the steady state by adjusting the rate of immigration to fit the base fertility and mortality assumptions of the SSA. From the model we derive the number of households and adjust it by the distribution indices $\xi^d, \xi^L$ from Jorgenson and Slesnick. We also derive a forecast of the population by educational attainment groups and adjust them by relative wages to give the time endowment. Since the population converged rather slowly, and in waves, we simplified by stopping all demographic changes in the year 2050.

In line with this, all exogenous variables reach their targets in 2050. As mentioned, the terminal date for the simulations is 2100, this allows 50 periods for the system to "settle down" (i.e. converge to the steady state ratios of consumption, investment, etc.). The point to note about these projections is that they play no important role in comparing the results of two simulations. They matter, of course, to the base simulation.

[59] The details of the projections are given in Appendix F in Ho (1989).

Projections of government variables are taken in part from Anderson et al. (1987). We follow them by assuming a long run inflation rate $\pi$ of 4%. The only point where inflation matters in our model is that the government deficit in the steady state is set to this seignorage. We assume that the government deficit declines steadily towards $\pi BG$ in 2025 and remain at this fraction thereafter. From this deficit we obtain the stocks of public debt. The external accounts are projected by setting $CA_t$ to rise gradually to zero by 2000, after which it is set to a surplus so that the steady state stock of foreign assets bear the same relation to total wealth as that in 1982.[60]

Relative import prices are set to the latest data available, the absolute price are these exogenous prices multiplied by the "exchange rate." Base exports are described in eqn. (A.23).

*Intraperiod Equilibrium* Given the dynamic variables and these exogenous variables we can now solve the intraperiod equilibrium. Our model is homogenous of degree zero in prices and obeys Walras' Law. The labor supply=demand equation is dropped and we chose the wage rate as the numeraire. The static model was "triangularized" into two loops:[61] in the outer loop there are 4 unknowns -- $PKD, PII.I, VGG, e$ -- and, 4 equations -- capital market (3.20), savings-investment (3.22), government deficit (3.13), current account (3.18). The inner loop consist of 35 unknowns -- $PO_j$ -- and, 35 equations -- the price frontiers (3.7).

Given the outer loop variables, the input-output matrix can be solved by iterating on a guess of $PO_j$.[62] Given the i-o matrix the total demands and supplies can be

[60] These are arbitrary assumptions Since there is no successful model of the current account or assets demands, let alone in a model without stochastic elements, we chose the most straightforward assumptions

[61] The model as written above has thousands of equations and endogenous variables Fortunately the dimension can be reduced to a manageable number Instead of solving $f(x)=0$ directly for the whole vector x, it is first rewritten as $f(x^1(y),y)=0$, where y is a small sub-vector of x

[62] In the notation of the previous footnote, f is a vector of the price frontiers, y=PO, and x consist of the price and value i-o matrices, including the whole tier structure.
Given the non-linearities of the consumption function there is another inner loop with 1 unknown -- PCC, and equation (A 10)

calculated and then the 5 unknown equations of the outer loop can be used to revise the guesses of the 5 unknowns.[63]

## A.6 Data and Parameters

The data for this model covers the period 1947 to 1985 and follows the methodology of Christensen and Jorgenson (1973) and Jorgenson, Gollop, and Fraumeni (1987) (JGF). The goal of the exercise is to construct a time series of input-output tables (both "use" and "make" matrices) over which one can estimate the production and demand functions. In addition we also need financial accounts that are not in the i-o tables.

The construction of the i-o matrices are described in Wilcoxen (1988), basically, the official tables published every 5 years are interpolated using annual industry data.[64] The capital and labor inputs (the value-added rows in the i-o table) are updated with some improvements following the approach in JGF.[65] The detailed investment data from the BEA is cumulated into stocks of capital by Divisia aggregation, the rental price of capital is calculated from National Income Accounts (NIA) using an equation similar to A.18. Labor input is aggregated over the labor force cross-classified by sex, age, educational attainment and industry. With the Divisia aggregation we take into account the different productivities of the various groups, instead of a simple sum of hours.

The final demand columns are estimated from the NIA and "bridge tables" from the official i-o tables. Imports are aggregated from trade data classified according to the SITC,[66] and price indices from the BLS are used where available (unit values are used

[63] The iterative procedure for solving $f(x)=0$ is Wilcoxen's implementation of Broyden's modification of the Newton method.

[64] I-O data are from the Bureau of Economic Analysis, the latest version is described in the *Survey of Current Business* May 1984. Annual industry output and prices are from the Bureau of Labor Statistics database *Time Series on Output, Prices and Employment*.

[65] These are described in Ho (1989) We made use of more recent estimates of depreciation rates and a more refined classification. For the labor data we incorporated the 1980 Census of the Population.

[66] At the 4-digit level and supplemented by more detailed data where necessary to get a better price index. The former are from the OECD database and the 7-digit data from the Census Bureau's *US Imports by SITC*

otherwise). The financial accounts (stocks of debt, government accounts, tax rates, etc.) are from the *US Worksheets* which are revised versions of Christensen and Jorgenson.

The top tier of the production functions are estimated using the "use matrix," while the bottom tiers are from Hudson and Jorgenson. The first two stages of the household model are estimated from aggregate data in the *US Worksheets*. The top tier of the Consumption function is from Jorgenson and Slesnick, while the bottom tiers are estimated from the i-o table, as are the invesment functions. The import share equations are estimated from the "import" and "total output" columns of the i-o table. All estimates are reported in Chapters 4 and 5 of Ho (1989).

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