

# A Global Approach to Energy and the Environment: The G-Cubed Model

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## Abstract

G-Cubed is a multi-country, multi-sector, intertemporal general equilibrium model that has been used to study a variety of policies in the areas of environmental regulation, tax reform, monetary and fiscal policy, and international trade. It is designed to bridge the gaps between three areas of research — econometric general equilibrium modeling, international trade theory, and modern macroeconomics — by incorporating the best features of each. This chapter describes the theoretical and empirical structure of the model, summarizes its applications and contributions to the literature, and discusses two example applications in detail.

## Keywords

Intertemporal modeling, international trade, international finance, energy policy, environmental policy, monetary and fiscal policy, trade liberalization, trade agreements, tax policy, climate policy, financial crises, pandemics, demographic change

## JEL classification codes

C54, C68, D58, E27, E44, E6, F1, F21, F3, F4, H23, H6, J11, O24, O4, O5, Q3, Q4, Q5

## 15.1 INTRODUCTION

G-Cubed is a multicountry, multisector, intertemporal general equilibrium model that has been used to study a variety of policies in the areas of environmental regulation, tax reform, monetary and fiscal policy, and international trade.<sup>1</sup> It is designed to bridge the gaps between three areas of research — econometric general equilibrium modeling, international trade theory and modern macroeconomics — by incorporating the best features of each.<sup>2</sup>

<sup>1</sup> Many applications are summarized in Section 15.3 below.

<sup>2</sup> The type of intertemporal general equilibrium model represented by G-Cubed with macroeconomic dynamics and various nominal rigidities is closely related to the dynamic stochastic general equilibrium models appearing in the macroeconomic and central banking literatures

From the trade literature, G-Cubed takes the approach of modeling the world economy as a set of autonomous regions — 12 in the version used in this paper — interacting through bilateral trade flows.<sup>3</sup> Following the Armington approach (Armington, 1969), goods produced in different regions are treated as imperfect substitutes.<sup>4</sup> Unlike most trade models, however, G-Cubed distinguishes between financial and physical capital. Financial capital is perfectly mobile between sectors and from one region to another, and is driven by forward-looking investors who respond to arbitrage opportunities. Physical capital, in contrast, is perfectly immobile once it has been installed: it cannot be moved from one sector to another or from one region to another. In addition, intertemporal budget constraints are imposed on each region: all trade deficits must eventually be repaid by future trade surpluses.

Drawing on the general equilibrium literature, G-Cubed represents each region by its own multisector econometric general equilibrium model.<sup>5</sup> Production is broken down into  $N$  industries and each is represented by an econometrically estimated cost function. Unlike many general equilibrium models, however, G-Cubed draws on macroeconomic theory by representing saving and investment as the result of forward-looking intertemporal optimization. Households maximize an intertemporal utility function subject to a lifetime budget constraint, which determines the level of saving, and firms choose investment to maximize the stock market value of their equity.<sup>6</sup>

Finally, G-Cubed also draws on the macroeconomic literature by representing international capital flows as the result of intertemporal optimization, and by including liquidity-constrained agents, a transactions-based money demand equation and slow nominal wage adjustment. Unlike typical macro models, however, G-Cubed has substantial sector detail and many of its parameters are determined by estimation rather than calibration.

This combination of features was chosen to make G-Cubed versatile. Industry detail allows the model to be used to examine environmental and tax policies which tend to

<sup>3</sup> Some well-known examples of other models with international trade flows include Deardorff and Stern (1985), Burniaux *et al.* (1992), and Hertel (1997).

<sup>4</sup> Given the model's level of aggregation, this is more a simple acknowledgement of reality than an assumption. Even if individual products from different countries were perfect substitutes, the aggregate products appearing in the model would not be because the composition of the aggregates differs between domestic production and imports. In motor vehicles, for example, even if there were individual domestic cars for which there were identical imported products, the mix of economy cars, luxury cars, trucks and vans in the overall motor vehicle aggregate differs between domestic production and imports.

<sup>5</sup> The computable general equilibrium (CGE) literature is quite large. Some well-known examples of single-country models are Johansen (1960), Dixon *et al.* (1982), Ballard *et al.* (1985), Jorgenson and Wilcoxon (1990), and Goulder and Summers (1989). See Shoven and Whalley (1984) for a survey.

<sup>6</sup> G-Cubed builds on elements from throughout the literature on macroeconomics. Our representation of saving and investment, in particular, descends from Abel and Blanchard (1983). Other intertemporal general equilibrium models that include some of the features in G-Cubed include Auerbach and Kotlikoff (1987), Goulder and Summers (1989), Jorgenson and Wilcoxon (1990), McKibbin and Sachs (1991), and Goulder (1992). The latter is also described in Bovenberg and Goulder (1996).

have their largest direct effects on small segments of the economy. Intertemporal modeling of investment and saving allows G-Cubed to trace out the transition of the economy between the short run and the long run. Slow wage adjustment and liquidity-constrained agents improves the empirical accuracy with which the model captures the transition. Overall, the model is designed to provide a bridge between computable general equilibrium models, international trade models and macroeconomic models by combining key features of each approach. The cost of this versatility is that G-Cubed is a fairly large model. It has over 10000 equations holding in each year, is typically solved annually for 100 years in each simulation, and has over 100 intertemporal costate variables. Nonetheless, it can be solved using software developed for a personal computer.

## 15.2 STRUCTURE OF THE MODEL

The key features of G-Cubed are summarized in Table 15.1. There are several different versions of G-Cubed that have been developed, depending on the question being analyzed. Versions have been built with two sectors (macroeconomic issues), six sectors (trade and growth issues), 12 sectors (energy and environmental issues), 21 sectors (India) and 57 sectors (Australia). There are also a large number of different country disaggregations. However, all versions of G-Cubed are global: each represents the economic activity of all countries in the world, either modeled individually or aggregated into regions.

**Table 15.1** Key features of G-Cubed

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1	Developed and developing countries are modeled in detail, including all trade and financial links between countries.
2	A full menu of financial assets is included and the valuations of those assets are driven by the real economy.
3	International flows of financial capital are modeled. An important distinction is made between the stickiness of physical capital within sectors and within countries and the flexibility of financial capital, which quickly flows to where expected returns are highest. This important distinction leads to a critical difference between the <i>quantity of physical capital</i> that is available at any time to produce goods and services, and the <i>valuation of that capital</i> as a result of decisions about the allocation of financial capital.
4	Households and firms are represented as mixtures of two types of agents: one group which bases its decisions on forward-looking expectations and a second group which follows simpler rules of thumb which are optimal in the long run, but not necessarily in the short run.
5	The model allows for short-run wage rigidity (varying in degree across countries) and therefore allows for significant periods of unemployment depending on the labor market institutions in each country. This assumption, when taken together with the explicit modeling of money and other financial assets, gives the model more realistic macroeconomic properties than conventional general equilibrium models.

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The most frequently used model and the version most relevant for environmental and energy questions is the 12 sector model. In this paper we will focus on the structure and specification of this version of G-Cubed. Within each region, production is disaggregated into 12 sectors: five energy sectors (electric utilities, natural gas utilities, petroleum refining, coal mining, and crude oil and gas extraction) and seven non-energy sectors (mining, agriculture, forestry and wood products, durable goods, non-durable goods, transportation and services). This disaggregation, summarized in Table 15.2, enables us to capture the sector level differences in the impact of alternative environmental policies.

Each economy or region in the model consists of several economic agents: households, the government, the financial sector and the 12 production sectors listed above. We now present an overview of the theoretical structure of the model by describing the decisions facing these agents. To keep our notation as simple as possible we have not subscripted variables by country except where needed for clarity. Throughout the discussion all quantity variables will be normalized by the economy's endowment of effective labor units. Thus, the model's long-run steady state will represent an economy in a balanced growth equilibrium.

**Table 15.2** Regions and sectors in G-Cubed

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*Regions (codes shown in parentheses)*

1	US (U or USA)
2	Japan (J or JPN)
3	Australia (A or AUS)
4	Western Europe (E or EUW)
5	Rest of the OECD (O or OEC)
6	China (C or CHI)
7	Other developing countries (L or LDC)
8	Eastern Europe and the Former Soviet Union (B or EEB)
9	Oil exporting countries and the Middle East (P or OPC)

*Sectors*

1	Electric utilities
2	Gas utilities
3	Petroleum refining
4	Coal mining
5	Crude oil and gas extraction
6	Other mining
7	Agriculture
8	Forestry and wood products
9	Durable goods
10	Non-durables
11	Transportation
12	Services

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### 15.2.1 Firms

We assume that each of the 12 sectors can be represented by a price-taking firm, which chooses variable inputs and its level of investment in order to maximize its stock market value. Each firm's production technology is represented by a tier-structured constant elasticity of substitution (CES) function. At the top tier, output is a function of capital, labor, energy and materials:

$$Q_i = A_i^O \left( \sum_{j=K,L,E,M} (\delta_{ij}^O)^{\frac{1}{\sigma_i^O}} X_{ij}^{\frac{\sigma_i^O-1}{\sigma_i^O}} \right)^{\frac{\sigma_i^O}{\sigma_i^O-1}}, \quad (15.1)$$

where  $Q_i$  is the output of industry  $i$ ,  $X_{ij}$  is industry  $i$ 's use of input  $j$ , and  $A_i^O$ ,  $\delta_{ij}^O$  and  $\sigma_i^O$  are parameters.  $A_i^O$  reflects the level of technology,  $\sigma_i^O$  is the elasticity of substitution and the  $\delta_{ij}^O$  parameters reflect the weights of different inputs in production; the superscript 'O' indicates that the parameters apply to the top, or 'output', tier. Without loss of generality, we constrain the  $\delta$ s to sum to one.

At the second tier, inputs of energy and materials,  $X_{iE}$  and  $X_{iM}$ , are themselves CES aggregates of goods and services. Energy is an aggregate of goods 1–5 (electricity through crude oil) and materials is an aggregate of goods 7–12 (mining through services). The functional form used for these tiers is identical to (1) except that the parameters of the energy tier are  $A_i^E$ ,  $\delta_{ij}^E$  and  $\sigma_i^E$ , and those of the materials tier are  $A_i^M$ ,  $\delta_{ij}^M$  and  $\sigma_i^M$ .

The goods and services purchased by firms are, in turn, aggregates of imported and domestic commodities, which are taken to be imperfect substitutes. We assume that all agents in the economy have identical preferences over foreign and domestic varieties of each commodity. We represent these preferences by defining 12 composite commodities that are produced from imported and domestic goods. Each of these commodities,  $Y_i$ , is a CES function of inputs domestic output,  $Q_i$ , and imported goods,  $M_i$ .<sup>7</sup> For example, the petroleum products purchased by agents in the model are a composite of imported and domestic petroleum. By constraining all agents in the model to have the same preferences over the origin of goods we require that, for example, the agricultural and service sectors have the identical preferences over domestic oil and oil imported from the Middle East.<sup>8</sup> This accords with the input-output data we use and allows a very convenient nesting of production, investment and consumption decisions.

Finally, the production function includes one additional feature to allow the model to be used to examine the effects of emissions quotas or tradable permit systems: each input

<sup>7</sup> The elasticity of substitution in this function is the Armington elasticity.

<sup>8</sup> This does not require that both sectors purchase the same amount of oil, or even that they purchase oil at all; only that they both feel the same way about the origins of oil they buy.

is used in fixed proportions to the use of an input-specific permit. The permits are owned by households and included in household wealth. Permit prices are determined endogenously by a competitive market for each type of permit. To run simulations without a permit system, the supply of permits can be set large enough so that the price of a permit goes to zero.

In each sector the capital stock changes according to the rate of fixed capital formation ( $J_i$ ) and the rate of geometric depreciation ( $\delta_i$ ):

$$\dot{K}_i = J_i - \delta_i K_i. \tag{15.2}$$

Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969), we assume that the investment process is subject to rising marginal costs of installation. To formalize this we adopt Uzawa’s approach by assuming that in order to install  $J$  units of capital a firm must buy a larger quantity,  $I$ , that depends on its rate of investment ( $J/K$ ):

$$I_i = \left(1 + \frac{\phi_i J_i}{2 K_i}\right) J_i, \tag{15.3}$$

where  $\phi$  is a non-negative parameter. The difference between  $J$  and  $I$  may be interpreted various ways; we will view it as installation services provided by the capital-goods vendor.

The goal of each firm is to choose its investment and inputs of labor, materials and energy to maximize intertemporal risk-adjusted net of tax profits. For analytical tractability, we assume that this problem is deterministic (equivalently, the firm could be assumed to believe its estimates of future variables with subjective certainty). Thus, the firm will maximize:<sup>9</sup>

$$\int_t^\infty (1 - \tau_2) \pi_t e^{-(R(s) + \mu_{ei} - n)(s-t)} ds, \tag{15.4}$$

where  $\mu_{ei}$  is a sector- and region-specific equity risk premium,  $\tau_2$  is the effective tax rate on capital income, and variables are implicitly subscripted by time. The firm’s profits,  $\pi$ , are given by:

$$\pi_i = P_i^* Q_i - W_{iL_i} - P_i^E X_{iE} - P_i^M X_{iM} - (1 - \tau_4) P^I I_i, \tag{15.5}$$

where  $\tau_4$  is an investment tax credit and  $P^*$  is the producer price of the firm’s output.  $R(s)$  is the long-term interest rate between periods  $t$  and  $s$ :

$$R(s) = \frac{1}{s - t} \int_t^s r(v) dv. \tag{15.6}$$

<sup>9</sup> The rate of growth of the economy’s endowment of effective labor units,  $n$ , appears in the discount factor because the quantity and value variables in the model have been scaled by the number of effective labor units. These variables must be multiplied by  $\exp(nt)$  to convert them back to their original form.

As all real variables are normalized by the economy's endowment of effective labor units, profits are discounted adjusting for the rate of growth of population plus productivity growth,  $n$ . Solving the top-tier optimization problem gives the following equations characterizing the firm's behavior:

$$X_{ij} = \delta_{ij}^O (A_i^O)^{\sigma_i^O - 1} Q_i \left( \frac{P_i^*}{P_j} \right)^{\sigma_i^O} \quad j \in \{L, E, M\} \tag{15.7}$$

$$\lambda_i = \left( 1 + \phi_i \frac{J_i}{K_i} \right) \left( 1 - \tau_4 \right) P^I \tag{15.8}$$

$$\frac{d\lambda_i}{ds} = (r + \mu_{ei} + \delta_i)\lambda_i - (1 - \tau_2)P_i^* \frac{dQ_i}{dK_i} - (1 - \tau_4)P^I \frac{\phi_i}{2} \left( \frac{J_i}{K_i} \right)^2, \tag{15.9}$$

where  $\lambda_i$  is the shadow value of an additional unit of investment in industry  $i$ .

Equation (15.7) gives the firm's factor demands for labor, energy and materials, and equations (15.8) and (15.9) describe the optimal evolution of the capital stock. By integrating (15.9) along the optimum path of capital accumulation, it is straightforward to show that  $\lambda_i$  is the increment to the value of the firm from a unit increase in its investment at time  $t$ . It is related to  $q$ , the after-tax marginal version of Tobin's Q (Abel, 1979), as follows:

$$q_i = \frac{\lambda_i}{(1 - \tau_4)P^I}. \tag{15.10}$$

Thus, we can rewrite (15.8) as:

$$\frac{J_i}{K_i} = \frac{1}{\phi_i} (q_i - 1). \tag{15.11}$$

Inserting this into (15.3) gives total purchases of new capital goods:

$$I_i = \frac{1}{2\phi_i} (q_i^2 - 1)K_i. \tag{15.12}$$

In order to capture the inertia often observed in empirical investment studies we assume that only fraction  $\alpha_2$  of firms making investment decision use the fully forward-looking Tobin's  $q$  described above. The remaining  $(1 - \alpha_2)$  use a slowly-adjusting version,  $Q$ , driven by a partial adjustment model. In each period, the gap between  $Q$  and  $q$  closes by fraction  $\alpha_3$ :

$$Q_{it+1} = Q_{it} + \alpha_3(q_{it} - Q_{it}). \tag{15.13}$$

As a result, we modify (15.12) by writing  $I_i$  as a function not only of  $q$ , but also the slowly adjusting  $Q$ :

$$I_i = \alpha_2 \frac{1}{2\phi_i} (q_i^2 - 1)K_i + (1 - \alpha_2) \frac{1}{2\phi_i} (Q_i^2 - 1)K_i. \tag{15.14}$$

This creates inertia in private investment, which improves the model's ability to mimic historical data and is consistent with the existence of firms that are unable to borrow. The weight on unconstrained behavior,  $\alpha_2$ , is taken to be 0.3 based on a range of empirical estimates reported by McKibbin and Sachs (1991).

So far we have described the demand for investment goods by each sector. Investment goods are supplied, in turn, by a 13th industry that combines capital, labor and the outputs of other industries to produce raw capital goods. We assume that this firm faces an optimization problem identical to those of the other 12 industries: it has a nested CES production function, uses inputs of capital, labor, energy and materials in the top tier, incurs adjustment costs when changing its capital stock, and earns zero profits. The key difference between it and the other sectors is that we use the investment column of the input-output table to estimate its production parameters.

### 15.2.2 Households

Households have three distinct activities in the model: they supply labor, they save, and they consume goods and services. Within each region we assume household behavior can be modeled by a representative agent with an intertemporal utility function of the form:

$$U_t = \int_t^{\infty} (\ln C(s) + \ln G(s)) e^{-\theta(s-t)} ds, \quad (15.15)$$

where  $C(s)$  is the household's aggregate consumption of goods and services at time  $s$ ,  $G(s)$  is government consumption at  $s$ , which we take to be a measure of public goods provided, and  $\theta$  is the rate of time preference.<sup>10</sup> The household maximizes (15.15) subject to the constraint that the present value of consumption (potentially adjusted by risk premium  $\mu_h$ ) be equal to the sum of human wealth,  $H$ , and initial financial assets,  $F$ :<sup>11</sup>

$$\int_t^{\infty} P^c(s) C(s) e^{-(R(s)+\mu_h-n)(s-t)} = H_t + F_t. \quad (15.16)$$

Human wealth is defined as the expected present value of the future stream of after-tax labor income plus transfers:

$$H_t = \int_t^{\infty} (1-\tau_1) (W(L^G + L^C + L^I + \sum_{i=1}^{12} L^i) + TR) e^{-(R(s)+\mu_h-n)(s-t)} ds, \quad (15.17)$$

<sup>10</sup> This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable.

<sup>11</sup> As before,  $n$  appears in (15.16) because the model's scaled variables must be converted back to their original basis.



where  $\tau_1$  is the tax rate on labor income,  $TR$  is the level of government transfers,  $L^C$  is the quantity of labor used directly in final consumption,  $L^I$  is labor used in producing the investment good,  $L^G$  is government employment, and  $L^i$  is employment in sector  $i$ . Financial wealth is the sum of real money balances,  $MON/P$ , real government bonds in the hand of the public,  $B$ , net holding of claims against foreign residents,  $A$ , the value of capital in each sector and holdings of emissions permits,  $Q_i^P$ :

$$F = \frac{MON}{P} + B + A + q^I K^I + q^C K^C + \sum_{i=1}^{12} q^i K^i + \sum_{i=1}^{12} P_i^P Q_i^P. \quad (15.18)$$

Solving this maximization problem gives the familiar result that aggregate consumption spending is equal to a constant proportion of private wealth, where private wealth is defined as financial wealth plus human wealth:

$$P^C C = (\theta + \mu_h)(F + H). \quad (15.19)$$

However, based on the evidence cited by Campbell and Mankiw (1990) and Hayashi (1982) we assume some consumers are liquidity-constrained and consume a fixed fraction  $\gamma$  of their after-tax income ( $INC$ ).<sup>12</sup> Denoting the share of consumers who are not constrained – and choose consumption in accordance with (15.19) – by  $\alpha_8$ , total consumption expenditure is given by:

$$P^C C = \alpha_8(\theta + \mu_h)(F_t + H_t) + (1 - \alpha_8)\gamma INC. \quad (15.20)$$

The share of households consuming a fixed fraction of their income could also be interpreted as permanent income behavior in which household expectations about income are myopic.

Once the level of overall consumption has been determined, spending is allocated among goods and services according to a two-tier CES utility function.<sup>13</sup> At the top tier, the demand equations for capital, labor, energy and materials can be shown to be:

$$P_i X_{Ci} = \delta_{Ci} P^C C \left( \frac{P^C}{P_i} \right)^{\sigma_C^0 - 1}, \quad i \in \{K, L, E, M\}, \quad (15.21)$$

<sup>12</sup> There has been considerable debate about the empirical validity of the permanent income hypothesis. In addition the work of Campbell, Mankiw and Hayashi, other key papers include Hall (1978) and Flavin (1981). One side-effect of this specification is that it prevents us from computing equivalent variation. Since the behavior of some of the households is inconsistent with (15.19), either because the households are at corner solutions or for some other reason, aggregate behavior is inconsistent with the expenditure function derived from our utility function.

<sup>13</sup> The use of the CES function has the undesirable effect of imposing unitary income elasticities, a restriction usually rejected by data. An alternative would be to replace this specification with one derived from the linear expenditure system.

where  $X_{Ci}$  is household demand for good  $i$ ,  $\sigma_C^O$  is the top-tier elasticity of substitution and the  $\delta_{Ci}$  are the input-specific parameters of the utility function. The price index for consumption,  $P^C$ , is given by:

$$P^C = \left( \sum_{j=K,L,E,M} \delta_{Cj} P_j^{\sigma_C^O - 1} \right)^{\frac{1}{\sigma_C^O - 1}}. \quad (15.22)$$

The demand equations and price indices for the energy and materials tiers are similar.

Household capital services consist of the service flows of consumer durables plus residential housing. The supply of household capital services is determined by consumers themselves who invest in household capital,  $K^C$ , in order to generate a desired flow of capital services,  $C^K$ , according to the following production function:

$$C^K = \alpha K^C, \quad (15.23)$$

where  $\alpha$  is a constant. Accumulation of household capital is subject to the condition:

$$\dot{K}^C = J^C - \delta^C K^C. \quad (15.24)$$

We assume that changing the household capital stock is subject to adjustment costs so household spending on investment,  $I^C$ , is related to  $J^C$  by:

$$I^C = \left( 1 + \frac{\phi^C J^C}{2 K^C} \right) J^C. \quad (15.25)$$

Thus, the household's investment decision is to choose  $I^C$  to maximize:

$$\int_t^{\infty} (P^{CK} \alpha K^C - P^I I^C) e^{-(R(s) + \mu_z - n)(s-t)} ds, \quad (15.26)$$

where  $P^{CK}$  is the imputed rental price of household capital and  $\mu_z$  is a risk premium on household capital (possibly zero). This problem is nearly identical to the investment problem faced by firms, including the partial adjustment mechanism outlined in equations 15.13 and 15.14, and the results are very similar. The only important difference is that no variable factors are used in producing household capital services.

### 15.2.3 Labor market

We assume that labor is perfectly mobile among sectors within each region but is immobile between regions. Thus, wages will be equal across sectors within each region, but will generally not be equal between regions. In the long run, labor supply is completely inelastic and is determined by the exogenous rate of population growth. Long-run wages adjust to move each region to full employment. In the short run,

however, nominal wages are assumed to adjust slowly according to an overlapping contracts model where wages are set based on current and expected inflation and on labor demand relative to labor supply. This can lead to short-run unemployment if unexpected shocks cause the real wage to be too high to clear the labor market. At the same time, employment can temporarily exceed its long-run level if unexpected events cause the real wage to be below its long run equilibrium.

### 15.2.4 Government

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among inputs in fixed proportions, which we set to 2006 values. Total government outlays include purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales taxes, capital and labor taxes, and from sales of new government bonds. In addition, there can be taxes on externalities such as carbon dioxide emissions. The government budget constraint may be written in terms of the accumulation of public debt as follows:

$$\dot{B}_t = D_t = r_t B_t + G_t + TR_t - T_t, \quad (15.27)$$

where  $B$  is the stock of debt,  $D$  is the budget deficit,  $G$  is total government spending on goods and services,  $TR$  is transfer payments to households and  $T$  is total tax revenue net of any investment tax credit.

We assume that agents will not hold government bonds unless they expect the bonds to be paid off eventually and accordingly impose the following transversality condition:

$$\lim_{s \rightarrow \infty} B(s) e^{-(R(s)-n)s} = 0. \quad (15.28)$$

This prevents *per capita* government debt from growing faster than the interest rate forever. If the government is fully leveraged at all times, (15.28) allows (15.27) to be integrated to give:

$$B_t = \int_t^{\infty} (T - G - TR) e^{-(R(s)-n)(s-t)} ds. \quad (15.29)$$

Thus, the current level of debt will always be exactly equal to the present value of future budget surpluses.<sup>14</sup>

<sup>14</sup> Strictly speaking, public debt must be less than or equal to the present value of future budget surpluses. For tractability we assume that the government is initially fully leveraged so that this constraint holds with equality.

The implication of (29) is that a government running a budget deficit today must run an appropriate budget surplus as some point in the future. Otherwise, the government would be unable to pay interest on the debt and agents would not be willing to hold it. To ensure that (15.29) holds at all points in time we assume that the government levies a lump sum tax in each period equal to the value of interest payments on the outstanding debt.<sup>15</sup> In effect, therefore, any increase in government debt is financed by consols and future taxes are raised enough to accommodate the increased interest costs. Other fiscal closure rules are possible, such as requiring the ratio of government debt to GDP to be unchanged in the long run or that the fiscal deficit be exogenous with a lump sum tax ensuring this holds. These closures have interesting implications but are beyond the scope of this paper.

### 15.2.5 Financial markets and the balance of payments

The nine regions in the model are linked by flows of goods and assets. Flows of goods are determined by the import demands described above. These demands can be summarized in a set of bilateral trade matrices which give the flows of each good between exporting and importing countries. There is one nine by nine trade matrix for each of the 12 goods.

Trade imbalances are financed by flows of assets between countries. Each region with a current account deficit will have a matching capital account surplus, and *vice versa*.<sup>16</sup> We assume asset markets are perfectly integrated across regions.<sup>17</sup> With free mobility of capital, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations of the following form:

$$i_k + \mu_k = i_j + \mu_j + \frac{\dot{E}_k^j}{E_k^j}, \quad (15.30)$$

where  $i_k$  and  $i_j$  are the interest rates in countries  $k$  and  $j$ ,  $\mu_k$  and  $\mu_j$  are exogenous risk premiums demanded by investors (possibly zero), and  $E_k^j$  is the exchange rate between the currencies of the two countries.<sup>18</sup> However, in cases where there are institutional rigidities to capital flows, the arbitrage condition does not hold and we replace it with an explicit model of the relevant restrictions (such as capital controls).

<sup>15</sup> In the model the tax is actually levied on the difference between interest payments on the debt and what interest payments would have been if the debt had remained at its base case level. The remainder — interest payments on the base case debt — is financed by ordinary taxes.

<sup>16</sup> Global net flows of private capital are constrained to be zero at all times — the total of all funds borrowed exactly equals the total funds lent. As a theoretical matter this may seem obvious, but it is often violated in international financial data.

<sup>17</sup> The mobility of international capital is a subject of considerable debate; see Gordon and Bovenberg (1994) or Feldstein and Horioka (1980).

<sup>18</sup> The one exception to this is the oil-exporting region, which we treat as choosing its foreign lending in order to maintain a desired ratio of income to wealth.

Capital flows may take the form of portfolio investment or direct investment but we assume these are perfectly substitutable *ex ante*, adjusting to the expected rates of return across economies and across sectors. Within each economy, the expected returns to each type of asset are equated by arbitrage, taking into account the costs of adjusting physical capital stock and allowing for exogenous risk premiums. However, because physical capital is costly to adjust, any inflow of financial capital that is invested in physical capital will also be costly to shift once it is in place. This means that unexpected events can cause windfall gains and losses to owners of physical capital, and *ex post* returns can vary substantially across countries and sectors. For example, if a shock lowers profits in a particular industry, the physical capital stock in the sector will initially be unchanged but its financial value will drop immediately.

### 15.2.6 Money and monetary rules

We assume that money enters the model via a constraint on transactions.<sup>19</sup> We use a money demand function in which the demand for real money balances is a function of the value of aggregate output and short-term nominal interest rates:

$$MON = PYi^\varepsilon, \quad (15.31)$$

where  $Y$  is aggregate output,  $P$  is a price index for  $Y$ ,  $i$  is the interest rate, and  $\varepsilon$  is the interest elasticity of money demand. Following McKibbin and Sachs (1991) we take  $\varepsilon$  to be  $-0.6$ .

On the supply side, the model includes an endogenous monetary response function for each region. Each region's central bank is assumed to adjust short-term nominal interest rates following a Henderson–McKibbin–Taylor rule as shown in the equation below. The interest rate evolves as a function of actual inflation ( $\pi$ ) relative to target inflation ( $\pi^T$ ), output growth ( $\Delta y$ ) relative to growth of potential output ( $\Delta y^T$ ) and the change in the exchange rate ( $\Delta e$ ) relative to the bank's target change ( $\Delta e^T$ ):

$$i_t = i_{t-1} + \beta_1(\pi_t - \pi_t^T) + \beta_2(\Delta y_t - \Delta y_t^T) + \beta_3(\Delta e_t - \Delta e_t^T). \quad (15.32)$$

The parameters in (32) vary across countries. For example, countries that peg their exchange rate to the US dollar have a very large value of  $\beta_3$ .

### 15.2.7 Parameterization

To estimate G-Cubed's parameters we began by constructing a consistent time series of input-output tables for the US. The procedure is described in detail in McKibbin and Wilcoxon (1999a) and can be summarized as follows. We started with the detailed

<sup>19</sup> Unlike other components of the model we simply assume this rather than deriving it from optimizing behavior. Money demand can be derived from optimization under various assumptions: money gives direct utility; it is a factor of production; or it must be used to conduct transactions. The distinctions are unimportant for our purposes.

benchmark US input–output transactions tables produced by the Bureau of Economic Analysis (BEA) and converted them to a standard set of industrial classifications and then aggregate them to 12 sectors.<sup>20</sup> Then, we corrected the treatment of consumer durables, which are included in consumption rather than investment in the US National Income and Product Accounts (NIPAs) and the benchmark input–output tables. Third, we supplemented the value added rows of the tables using a detailed dataset on capital and labor input by industry constructed by Dale Jorgenson and his colleagues.<sup>21</sup> Finally, we obtained prices for each good in each benchmark year from the output and employment data set constructed by the Office of Employment Projections at the Bureau of Labor Statistics (BLS).

This dataset allowed us to estimate the model's parameters for the US. To estimate the production side of the model, we began with the energy and materials tiers because they have constant returns to scale and all inputs are variable. In this case it is convenient to replace the production function with its dual unit cost function. For industry  $i$ , the unit cost function for energy is:

$$c_i^E = \frac{1}{A_i^E} \left( \sum_{k=1}^5 \delta_{ik}^E p_{ik}^{1-\sigma_i^E} \right)^{\frac{1}{1-\sigma_i^E}}. \quad (15.33)$$

The cost function for materials has a similar form. Assuming that the energy and materials nodes earn zero profits,  $c$  will be equal to the price of the node's output. Using Shephard's lemma to derive demand equations for individual commodities and then converting these demands to cost shares gives expressions of the form:

$$s_{ij}^E = \delta_{ij}^E \left( \frac{P_j}{A_i^E P_i} \right)^{1-\sigma_i^E}, \quad j = 1, \dots, 5, \quad (15.34)$$

where  $s_{ij}^E$  is the share of industry  $i$ 's spending on energy that is devoted to purchasing input  $j$ .<sup>22</sup>  $A_i^E$ ,  $\sigma_i^E$  and  $\delta_{ij}^E$  were found by estimating (15.33) and (15.34) as a system of equations.<sup>23</sup> Estimates of the parameters in the materials tier were found by an analogous approach.

<sup>20</sup> Converting the data to a standard basis was necessary because the sector definitions and accounting conventions used by the BEA have changed over time.

<sup>21</sup> Primary factors often account for half or more of industry costs so it is particularly important that this part of the data set be constructed as carefully as possible. From the standpoint of estimating cost and production functions, however, value added is the least satisfactory part of the benchmark input–output tables. In the early tables, labor and capital are not disaggregated. In all years, the techniques used by the BEA to construct implicit price deflators for labor and capital are subject to various methodological problems. One example is that the income of proprietors is not split between capital and imputed labor income correctly. The Jorgenson dataset corrects these problems and is the work of several people over many years. In addition to Dale Jorgenson, some of the contributors were L. Christensen, Barbara Fraumeni, Mun Sing Ho and Dae Keun Park. The original source of the data is the Fourteen Components of Income tape produced by the Bureau of Economic Analysis. See Ho (1989) for more information.

<sup>22</sup> When  $\sigma_i^E$  is unity, this collapses to the familiar Cobb–Douglas result that  $s = \delta$  and is independent of prices.

<sup>23</sup> For factors for which the value of  $s$  was consistently very small, we set the corresponding input to zero and estimated the production function over the remaining inputs.

The output node must be treated differently because it includes capital, which is not variable in the short run. We assume that the firm chooses output,  $Q_i$ , and its top-tier variable inputs (L, E and M) to maximize its restricted profit function,  $\pi$ :

$$\pi_i = p_i Q_i - \sum_{j=L,E,M} p_j X_{ij}, \tag{15.35}$$

where the summation is taken over all inputs other than capital. Inserting the production function into (15.35) and rewriting gives:

$$\pi_i = P_i A_i^O \left( \delta_{ik}^{\frac{\sigma_i^O}{\sigma_i^O-1}} K_i^{\frac{\sigma_i^O-1}{\sigma_i^O}} + \sum_{j=L,E,M} \delta_{ij}^{\frac{\sigma_i^O}{\sigma_i^O-1}} X_{ij}^{\frac{\sigma_i^O-1}{\sigma_i^O}} \right)^{\frac{\sigma_i^O}{\sigma_i^O-1}} - \sum_{j=L,E,M} P_j X_{ij}, \tag{15.36}$$

where  $K_i$  is the quantity of capital owned by the firm,  $\delta_{ik}$  is the distributional parameter associated with capital, and  $j$  ranges over inputs other than capital. Maximizing (15.36) with respect to variable inputs produces the following factor demand equations for industry  $i$ :

$$X_{ij} = \delta_{ij} P_j^{-\sigma_i^O} \delta_{ik}^{\frac{1}{\sigma_i^O-1}} K_i \left( (P_i A_i^O)^{1-\sigma_i^O} - \sum_k \delta_{ik} P_k^{1-\sigma_i^O} \right)^{\frac{\sigma_i^O}{1-\sigma_i^O}}, \quad \forall j \in \{L, E, M\}. \tag{15.37}$$

This system of equations can be used to estimate the top-tier production parameters. The results are listed in McKibbin and Wilcoxon (1999a).

Much of the empirical literature on cost and production functions fails to account for the fact that capital is fixed in the short run. Rather than using (15.37), a common approach is to use factor demands of the form:

$$X_{ij} = \delta_{ij} P_i^{-\sigma_i^O} \frac{Q_i}{A_i^O} \left( \sum_{k=K,L,E,M} \delta_{ik} P_k^{1-\sigma_i^O} \right)^{\frac{\sigma_i^O}{1-\sigma_i^O}}. \tag{15.38}$$

This expression is correct only if all inputs are variable in the short run. In McKibbin and Wilcoxon (1999a) we show that using equation (15.38) biases the estimated elasticity of substitution toward unity for many sectors in the model. In petroleum refining, for example, the fixed-capital estimate for the top tier elasticity,  $\sigma_3^O$ , is 0.54 while in the variable elasticity case it is 1.04. The treatment of capital thus has a very significant effect on the estimated elasticities of substitution.

Estimating parameters for regions other than the US is more difficult because time-series input-output data is often unavailable. In part, this is because some countries do not collect the data regularly and in part it is because many of G-Cubed’s geographic entities are regions rather than individual countries. As a result, we impose the

restriction that substitution elasticities within individual industries are equal across regions.<sup>24</sup> By doing so, we are able to use the US elasticity estimates everywhere. The share parameters (the  $\delta$ s in the equations above), however, are derived from regional input-output data taken from the GTAP version 7 database and differ from one region to another. In effect, we are assuming that all regions share a similar but not identical production technology. This is intermediate between one extreme of assuming that the regions share common technologies and the other extreme of allowing the technologies to differ in arbitrary ways. The regions also differ in their endowments of primary factors, their government policies, and patterns of final demands.

Final demand parameters, such as those in the utility function or in the production function of new investment goods were estimated by a similar procedure: elasticities were estimated from US data and share parameters were obtained from regional input-output tables. Trade shares were obtained from 2009 UN Standard Industry Trade Classification (SITC) data aggregated up from the four-digit level.<sup>25</sup> The trade elasticities are based on a survey of the literature and vary between 1 and 3.<sup>26</sup>

### 15.2.8 Numerical implementation

G-Cubed is implemented via three software components. The first consists of a sequence of programs written in the Ox language that construct G-Cubed's dataset from raw data.<sup>27</sup> The second component consists of a set of files specifying the model's economic structure in a portable, general-purpose language we developed called 'Sym'. Sym is a set-driven matrix language that descends from GAMS and GEMPACK. It imposes rigorous conformability rules on all expressions to eliminate a broad range of potential errors in the design and coding of the model. A useful consequence of these rules is that subscripts are generally unnecessary and the model can be expressed very concisely and clearly. The third component is a suite of Ox programs that are used for setting up simulations and solving the model according to the two-point boundary value algorithm described in McKibbin (1986).<sup>28</sup> It allows models with large numbers of forward-looking costate variables (G-Cubed has more than 100) to be solved quickly on computers with limited resources.

<sup>24</sup> For example, the top-tier elasticity of substitution is identical in the durable goods industries of Japan and the US. This approach is consistent with the econometric evidence of Kim and Lau (1994). This specification does not mean, however, that the elasticities are the same across industries *within* a country.

<sup>25</sup> A full mapping of SITC codes into G-Cubed industries is contained in McKibbin and Wilcoxon (1994).

<sup>26</sup> For a sensitivity analysis examining the role of the trade elasticities and several other key parameters, see McKibbin *et al.* (1999a, 1999b).

<sup>27</sup> Ox is available from [www.doornik.com](http://www.doornik.com) and described in Doornik (2007).

<sup>28</sup> For a more detailed description of the algorithm, see McKibbin and Sachs (1991, appendix C).



### 15.2.9 Generating a baseline

Because G-Cubed is an intertemporal model, it is necessary to calculate a baseline, or ‘business-as-usual’, solution before the model can be used for policy simulations. In order to do so we begin by making assumptions about the future course of key exogenous variables. We take the underlying long-run rate of world population growth plus productivity growth to be 2.5% *per annum* and take the long-run real interest rate to be 5%. We also assume that tax rates and the shares of government spending devoted to each commodity remain unchanged. Our remaining assumptions are listed by region in Table 15.3.

As these assumptions do not necessarily match the expectations held by agents in the real world, the model’s solution in any given year, say 2006, will generally not reproduce that year’s historical data exactly. In particular, it is unlikely that the costate variables based on current and expected future paths of the exogenous variables in the *model* will equal the *actual* values of those variables in 2006. This problem arises in all intertemporal models and is not unique to G-Cubed, but it is inconvenient when interpreting the model’s results.

To address the problem we add a set of constants, one for each costate variable, to the model’s costate equations. For example, the constants for Tobin’s  $q$  for each sector in each country are added to the arbitrage equation for each sector’s  $q$ . Similarly, constants for each real exchange rate are added to the interest arbitrage equation for each country, and a constant for human wealth is added to the equation for human wealth.<sup>29</sup> To calculate the constants we use Newton’s method to find a set of values that will make the model’s costate variables in 2006 exactly equal their 2006 historical values. After the constants have been determined, the model will reproduce the base year exactly given the state variables inherited from 2005 and the assumed future paths of all exogenous variables.<sup>30</sup>

One additional problem is to solve for both real and nominal interest rates consistently since the real interest rate is the nominal interest rate from the money market equilibrium less the *ex ante* expected inflation rate. To produce the expected inflation rate implicit in historical data for 2006 we add a constant to the equation for nominal wages in each country.<sup>31</sup>

Finally, we are then able to construct the baseline trajectory by solving the model for each period after 2006 given any shocks to variables, shocks to information sets (announcements about future policies) or changes in initial conditions.

<sup>29</sup> One interpretation of these constants is that they are risk premiums; another is that they are simply the residuals left between the actual data and the econometrically fitted values calculated by the model.

<sup>30</sup> In general, these constants affect the model’s steady state, but have little or no effect on the transitional dynamics.

<sup>31</sup> One way to interpret this is as a shift in the full employment level of unemployment. In that case this approach is equivalent to using the full model to solve for the natural rate of unemployment in each country.

**Table 15.3** Regional assumptions used in generating the baseline

	USA	Japan	Australia	Other OECD	China	Other developing countries	Eastern Europe and Former Soviet Union
Population growth (%)	0.5	0.0	0.8	0.7	1.5	1.0	0.5
Non-energy productivity growth (%)	2.0	2.5	2.2	2.3	4	2.5	2.0
Energy sector productivity growth (%)	1.5	2.0	1.7	1.8	4	2.5	1.5
Energy efficiency growth (%)	1	1	1	1	1	1	1
Monetary policy (fixed money growth rate, %)	2.9	1.25	1.64	3.98	12.84	6.48	23.81

### 15.3 SUMMARY OF KEY APPLICATIONS AND INSIGHTS

Originally developed to evaluate climate change policies, G-Cubed has been used to analyze trade policy, monetary and fiscal policy, financial crises, projections of global economic growth, the impacts of pandemics, and global demographic change.<sup>32</sup> It has been used by agencies within the governments of the US, Japan, Canada, Australia and New Zealand, as well as in reports by the Intergovernmental Panel on Climate Change, the UN, the Organization for Economic Cooperation and Development (OECD), the World Bank, the International Monetary Fund, the Asian Development Bank, and a number of corporations. Academic users can be found in the US, the UK, Germany, Austria, Australia, Indonesia and Japan. The remainder of this section outlines key applications of G-Cubed in the six areas: climate and energy policy, trade policy, analysis of financial crises, macroeconomic policy, the analysis of pandemics, and global demographic change.

#### 15.3.1 Climate and energy policy

G-Cubed was designed to contribute to the debate on environmental policy and international trade, with particular emphasis on climate change. It has been used for that purpose since 1992 and work using the model has roughly fallen into two areas of focus. One has been on generating projections of the future evolution of the world

<sup>32</sup> See details in the summary that follows.

economy and exploring the sensitivity of these projections to a variety of assumptions. The second focus has been on evaluating the impacts of a variety of policy changes on these projections. These two strands of research will be dealt with separately below.

### **15.3.1.1 Baseline issues**

In a study for the United Nations University, [Bagnoli et al. \(1996\)](#) found that over a 30-year horizon, assumptions about productivity growth and structural change are crucial for understanding an economy's energy intensity. Using the model, the authors made two projections of the world economy from 1990 to 2020. The first scenario assumed that all sectors in a given region experienced a uniform rate of technical change characteristic of that region. However, the rate varied across regions based on their historical performance, with higher rates in particular developing economies such as China. The second scenario allowed technical change to be heterogeneous at the sector level. Within each region, sectoral technical change followed historical patterns, but scaled so that each economy had the same average economy-wide GDP growth rate as in the first scenario.

The two scenarios produced dramatically different projections of world energy intensity by 2020. Countries had approximately the same GDP growth rates in both scenarios (by construction), but energy use was far lower in the second scenario. Sector-level differences in technical change caused structural changes that reduced economy-wide energy per unit of GDP by around 1% per year independent of any autonomous energy efficiency improvement (AEEI). This difference was purely due to the changing structure of economies over time in response to relative price changes induced by different sectoral rates of technical change. The difference was shown clearly in the carbon taxes required for stabilizing emissions: in the second scenario the taxes were typically half those for the first scenario.

This study and subsequent papers by [McKibbin et al. \(2007, 2009a\)](#) emphasized that a simple projection of GDP growth was insufficient for projecting carbon emissions. Although overall GDP growth matters, sectoral-level differences in productivity are critical for future emissions.<sup>33</sup>

The other issue that was emphasized in this study and related studies, is that the effect of small changes in low-level growth rates over 20 or more years can have enormous effects on composition of the economy. The large range of possible outcomes from small changes in growth rates is always a sobering reminder of the degree of uncertainty underlying climate policy. In particular, there is empirical evidence to suggest that many economic variables have a unit root or a stochastic trend. If this is correct, or even

<sup>33</sup> See also [McKibbin \(2000\)](#) for a discussion of the use of G-Cubed in a forecasting context.

approximately correct, then standard errors for projected levels of variables would quickly become large.

### **15.3.1.2 Policy issues**

G-Cubed has been used for a range of studies of alternative greenhouse policies. Carbon taxes are examined in McKibbin and Wilcoxon 1993, 1994, 1997. These studies all highlight that a surprise carbon tax leads to a reduction in real output with the greatest losses occurring in the short run. McKibbin et al. (1999a, 1999b) show that the adjustment of capital flows are important for the impacts of climate policy. An increase in the price of energy inputs makes goods produced using energy relatively more expensive in world markets. The conventional view is that the current account of a country would deteriorate as a result of a carbon tax. In McKibbin and Wilcoxon (1994) we showed on the contrary that the current account could improve if the revenue from the tax was used to reduce the fiscal deficit (i.e. holding government spending and transfers constant in spite of the rise in tax revenue). The rise in saving and fall in investment could easily lead to an improvement in the overall current account balance reflecting a capital outflow. The composition of the trade account would reflect the simple partial equilibrium reasoning but the economy-wide general equilibrium effect could go the other way.

This paper also illustrated that the way in which the revenue from a carbon tax is used can have important consequences for the costs of the carbon abatement policy. If the revenue is used to reduce another tax in the economy, then the costs of abatement can be reduced. For example, in the US if the revenue is used to reduce the fiscal deficit, there can be a fall in interest rates which stimulates economic growth and reduces the costs of the carbon abatement. However, this effect does not occur in a country like Australia because it is not a major participant in global capital markets and has very little impact on world interest rates. Nonetheless, using the revenue to reduce taxes on capital can help to offset the negative effects of a carbon abatement policy in Australia.

The trade implications of environmental policy are the focus of McKibbin and Wilcoxon (1993, 1999a, 1999b). These papers show that changes in environmental policy are unlikely to lead to major changes in trade flows through relocation of industry because the costs of environmental policy are generally small relative to the cost of relocating production facilities. This does not mean that environmental policies lead to small losses in economic output, but that policies are unlikely to be fully offset by substitution toward goods that are not subject to the same environmental regulation. In the context of US climate policy, the papers above have shown that for every 100 tons of reduction in US emissions, global emissions fall by 80–90 tons; only 10–20 tons are offset due to higher emissions elsewhere. A key insight from this research is that a significant part of energy use is for domestic transportation which is largely non-traded and therefore is unlikely to move overseas.

In McKibbin and Wilcoxon (1997) we found that many aggressive permit trading scenarios were infeasible in G-Cubed because of the instability they caused in the global

trade system. The main problem was the extent of stabilization proposed in the scenarios, which implied very high prices for emission permits. The result was wild fluctuations in real exchange rates and consequently in patterns of international trade. This pointed to a fundamental flaw in the global emission permit trading schemes frequently proposed, such as the Kyoto Protocol. These regimes could generate large transfers of wealth between countries. Supporters of a global permit system regard this as an advantage, because it would allow developed countries to compensate developing countries for reducing their emissions. However, G-Cubed suggests that such an approach would put enormous stress on the world trade system depending on the tightness of the emission targets, the extent to which the allocation of permits was different from the permits required to meet the targets, and the marginal cost of abatement in different countries, amongst other things. A developed country importing permits would see its balance of trade deteriorate substantially. Equally serious problems would be created for developing countries. Massive exports of permits would lead to exchange rate appreciation and a decline or collapse in traditional exports. In the international economics literature this is known as the 'Dutch Disease' or in Australia as the 'Gregory Thesis'. It occurs because the granting of permits has an impact on the wealth of the receiving countries, which changes their consumption patterns and comparative advantage.

In McKibbin et al. (1999a, 1999b) international capital flows are shown to play an important role in the adjustment process to emissions policies. A rise in the price of carbon leads to a fall in the return on capital in carbon-intensive economies and to capital outflow from carbon-intensive economies into large economies and less carbon-intensive economies. Although developing countries are generally less carbon intensive, they cannot absorb a large capital inflow because of the adjustment costs in physical capital formation. There is, therefore, much less carbon leakage in G-Cubed than in other trade models because of the impact of capital flows and adjustment costs in developing countries.

The appeal of an international permit program is strongest if participating countries have different marginal costs of abating carbon emissions. The analysis in McKibbin et al. (1999) suggests that abatement costs are quite heterogeneous and international trading offers large potential benefits to parties with relatively high mitigation costs. The analysis also highlights that in an increasingly interconnected world in which international financial flows play a crucial role, the impact of greenhouse abatement policy cannot be determined without attention to the impact of these policies on the return to capital in different economies. To understand the full adjustment process to international greenhouse abatement policy it is essential to explicitly model international capital flows.

An important but often neglected issue in climate policy design is the effect that the climate policy regime has on the transmission of economic shocks within a country and between countries. McKibbin et al. (2009d) explore potential interactions between climate policy, unanticipated macroeconomic events, and carbon emissions. They examine two kinds of unanticipated macroeconomic shocks under two global climate

policy architectures and pay special attention to outcomes that could undermine individual countries' incentives to remain party to the global agreement. They find that a regime of fixed emissions targets strongly propagates growth shocks between regions while price-based systems do not. Under a quantity-based policy, a positive growth shock in developing countries can raise the global price of permits enough that GDP in some economies actually contracts, creating an incentive for such countries to withdraw from the arrangement. They also find that in a global downturn, a price-based system exacerbates the economic decline. Overall, quantity-based policies perform badly during unexpected economic booms and price-based policies perform badly during downturns. They argue that a hybrid policy would be superior — performing like a price-based policy during a boom and like a quantity-based policy in a downturn.

G-Cubed also has been used to explore the characteristics of particular international agreements such as the Kyoto Protocol in McKibbin et al. (1999a, 1999b) and McKibbin and Wilcoxon (2004, 2007), and the Copenhagen Accord in McKibbin et al. (2010). In the latter paper, the authors used G-Cubed to convert a heterogeneous set of commitments by countries at Copenhagen into comparable policy effort by calculating the 'carbon price equivalence' of policies. Among other results, they showed that China's intensity targets, which some observers at the time regarded as insignificant, are actually a commitment to very significant reductions relative to the expected trajectory of Chinese emissions in the absence of the policy. India's intensity targets, on the other hand, are essentially non-binding.

G-Cubed also has been used for evaluating national carbon policy proposals such as the Carbon Pollution Reduction Scheme in Australia by the Australian Government (2008) and various national schemes in the US by McKibbin et al. (2009b, 2009c). In addition, we examined border tax adjustments for embodied carbon in McKibbin and Wilcoxon (2009a). Border taxes are calculated based on the carbon emissions associated with production of each imported product, and would be intended to match the cost increase that would have occurred had the exporting country adopted a climate policy similar to that of the importing country. We estimated how large such tariffs would be in practice, and then examined their economic and environmental effects. We found that the tariffs would be small on most traded goods, would reduce leakage of emissions reduction very modestly and would do little to protect import-competing industries. The benefits produced by border adjustments would be too small to justify their administrative complexity or their deleterious effects on international trade.

A consistent theme in analyses of climate policies using G-Cubed is that climate policy design should be robust to uncertainties about future economic conditions. The sensitivity of longer run projections to small changes in assumptions as shown in McKibbin et al. (2007) suggests that policies that rely heavily on precise forecasts about the future are likely to be vulnerable to collapse. This experience led to the development of a 'Hybrid' policy of taxes and permit trading set out in McKibbin and Wilcoxon

(2002a, 2002b, 2004, 2007, 2009b). A policy that is able to manage uncertainty is key in the climate policy debate.<sup>34</sup>

## 15.3.2 Trade policy

### 15.3.2.1 North American Free Trade Agreement

In a study for a report by the US Congressional Budget Office (CBO), G-Cubed was used to assess the North American Free Trade Agreement (NAFTA) (Congressional Budget Office, 1993; McKibbin, 1994; Manchester and McKibbin, 1994). At the time NAFTA was being evaluated, many studies suggested that it would lead to a flood of cheap goods into the US economy and a loss of jobs in the US. G-Cubed, however, showed the opposite. In these studies, the key aspect of NAFTA was not only the removal of US tariffs on Mexican goods, but the impact of the agreement on expected future productivity in Mexico and the reduction in the risk premium attached to Mexican assets by international investors. In the studies we followed the empirical link between closer economic integration and productivity growth surveyed in the case of Europe by Catinat and Italianer (1988). The risk premium shock was based on estimates by the Congressional Budget Office (1993a) that on average investment in Mexico required roughly a 10% higher return than investments in the US. We assumed that the risk premium which drove this differential was eliminated in three years from the announcement of NAFTA. G-Cubed predicted that NAFTA would lead to a large flow of financial capital from the rest of the world into the Mexican economy in response to a rise in the expected return to capital and a reduction in the Mexican risk premium. The Mexican real exchange rate was predicted to appreciate, crowding out net exports and leading to a rise in the Mexican current account deficit. The short-term impacts of NAFTA were consistent with G-Cubed predictions. The medium to long-run predictions from G-Cubed were more consistent with the majority of studies at the time. The additional insight from G-Cubed was the short-run adjustment process was largely driven by capital flows driving trade adjustment. The model predicted a large impact from expected long-term productivity improvements, and showed how, through the operation of intertemporal forces, this stimulated short-term capital inflows to Mexico. In the short term, this completely dwarfed the static effect (i.e. changing the composition of trade) of the tariff changes that was the focus of other studies. The scale of economies, as well as the sectoral adjustment within economies, can change significantly in dynamic models. Financial markets contain important information about absolute and relative returns to current and future activities.

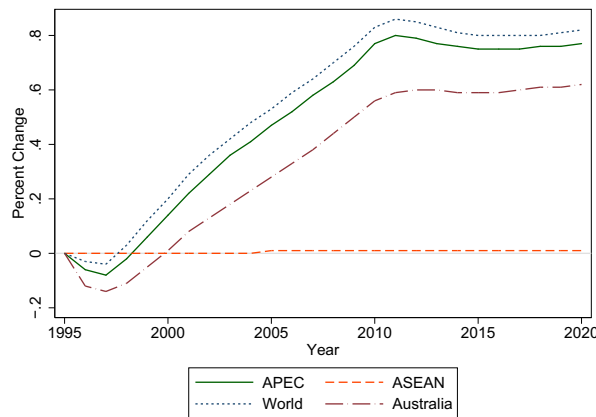
G-Cubed has also been applied to the Free Trade Agreement of the Americas (FTAA) — a proposed extension of NAFTA. That analysis is discussed in detail in Section 15.4.

<sup>34</sup> This is the focus of McKibbin and Wilcoxon (2009b).

### 15.3.2.2 Trade liberalization

The six-sector version of G-Cubed has been used to explore the impact of trade liberalization under alternative regional and multilateral arrangements<sup>35</sup> as well as unilateral trade liberalization in China.<sup>36</sup> In many of these studies, which are based on actual agreements, the trade liberalization is generally announced to be phased in over time. In this case, the key dynamic adjustment to the various trade policy changes is the instantaneous change in rates of return to capital and asset prices in the liberalizing economies. Changes in the return to capital change financial capital flows which cause exchange rate adjustments. These exchange rate adjustments then drive trade adjustment in the short run, even before substantial tariff reductions are implemented.

McKibbin (1998a, 1998b) examined different regional groupings for trade liberalization. Countries were assumed to reduce tariff rates from 1996 levels to zero by 2010 for developed countries, and by 2020 for developing countries. Figure 15.1 shows the impact on Australian real GDP of liberalization in alternative groupings. Liberalization within the regional groupings that include Australia (World, APEC and Australia) results in short-term losses as the tariff reductions are phased in. Over time however there are significant medium to long-term gains relative to the base scenario. There are significant



**Figure 15.1** Effects on Australian real GDP of trade liberalization. On graphs showing percentage changes, series are omitted when the corresponding reference case variable is very small (e.g. in a group of variables whose values are generally tens of billions of dollars, a variable changing from 0.01 to 0.02 billion would be omitted rather than shown as a 100% increase). Source: McKibbin (1998a).

<sup>35</sup> See McKibbin (1994, 1998a, 1998b), McKibbin and Salvatore (1995), and Stoeckel *et al.* (2000) on multilateral trade agreements; McKibbin *et al.* (2004) on Korea and Japan; Berkelmens *et al.* (2001) on Australia–US Free Trade Agreement.

<sup>36</sup> McKibbin and Tang (2000) and McKibbin and Woo (2004) on China.



additional benefits to joint liberalization in the short run but the majority of medium to long-term gains occur through own liberalization. Liberalization by other countries (ASEAN) results in only small GDP gains for Australia.

The adjustment path to phased liberalization can therefore exhibit short-run costs as resources begin to be reallocated before the trade reforms are implemented. Once the liberalization is announced, the return to capital in some sectors rises and capital flows in, appreciating the real exchange rate. This further dampens demand for exported goods as they temporarily become more expensive. Liberalization by other countries at the same time can help to reduce these short-run adjustment costs and real exchange rate changes. In the long run, own reforms give larger gains than foreign reforms and there is little benefit from a policy of free riding.

The key insight provided by G-Cubed is the short-run adjustment process. The impact of a policy change can be perverse in the short run in the sense that capital flowing into a liberalizing economy can cause such a large real exchange rate appreciation that there is a significant deterioration in the trade account as real resources flow into the economy. If the adjustment process is poorly understood, policy makers can become disaffected or can implement inappropriate policy responses such as tightening macroeconomic policy in order to improve the external balance thus slowing down economic activity. However, the capital inflows are needed to build future capacity in expanding sectors. The appreciation of the real exchange rate and worsening of the trade balance is not a loss of underlying competitiveness because of a bad policy change. The reallocation of resources is driven by the signals in financial markets of where expected returns are highest after the reforms are implemented.

### **15.3.2.3 Trade imbalances**

G-Cubed has been used in a number of studies to explore the role of macroeconomic policies and shocks in generating trade imbalances between regions of the world. In G-Cubed the trade deficit of a country not only represents an excess of imports of goods and services over exports of goods and services. A trade deficit also reflects an excess of investment over savings in a country. Lee et al. (2006) used the model to explore the sensitivity of the trade flows between the US and Asia. They found the fundamental cause of trade imbalance since 1997 is changes in saving—investment gaps, attributed to the surge of the US fiscal deficits and the decline of East Asia's private investment after the 1997 financial crisis. In exploring the impact of nominal exchange rate realignment the results from G-Cubed show that a revaluation of East Asia's exchange rates by 10% (effectively a shift in monetary policy) cannot resolve the imbalances. They also found that a concerted effort by East Asian economies to stimulate aggregate demand can have significant impacts on trade balances globally, but the impact on the US trade balance is not large. US fiscal contraction was estimated to have large impacts on the US trade position overall and on the bilateral trade balances with East Asian economies. These results suggest that in order to

improve the transpacific imbalance, macroeconomic adjustment will need to be made on both sides of the Pacific.

### 15.3.3 Macroeconomic policy

An antecedent of G-Cubed called the McKibbin—Sachs Global (MSG) model was originally designed to explore macroeconomic policy issues. G-Cubed has similar macroeconomic properties and has been used to explore a wide range of issues in macroeconomics. Monetary and fiscal regime design in Europe has been explored using G-Cubed by Allsop et al. (1996, 1999), Gagnon et al. (1996), Haber et al. (2001), McKibbin and Bok (2001), and Neck et al. (2000, 2005). In these papers the key insight was that the fixed exchange rate regime of the euro zone would be under serious stress if fiscal policies in Europe were not coordinated in the face of various economic shocks. Macroeconomic policy issues in Japan have been examined using G-Cubed by McKibbin (2002) and Callen and McKibbin (2003) where the experience of Japan during the 1990s was captured by the model as a series of policy errors particularly in announcing fiscal expansion and generating crowding out through asset markets, but then not delivering the fiscal spending causing a persistent downward drop in GDP; in India by McKibbin and Singh (2003) where nominal income targeting was shown to be a far better monetary regime than inflation targeting given the prevalence of supply side rather than demand-side shocks in the Indian economy; in China by McKibbin and Tang (2000) and McKibbin and Huang (2000) where financial reforms were found to have profound effects on economic growth and the balance of payments adjustment but that a loss in confidence in China could devastate economic growth; and in Asia in McKibbin and Le (2004) and McKibbin and Chanthapun (1999) where flexible exchange rate regimes were found to be far better at insulating East Asian economies against global economic shocks that pegging to either the US dollar or a common Asia currency.

Theoretical issues in monetary policy design are investigated using G-Cubed in Henderson and McKibbin (1993); and McKibbin (1997). Trade imbalances caused by macroeconomic policies and shocks are explored in Lee, McKibbin and Park (2006). The impacts of the end of the cold war and large shift in military spending on the global economy are explored by McKibbin and Thurman (1995), McKibbin (1996) and Congressional Budget Office (1996b); the spillover of macroeconomic policies between countries are explored in McKibbin and Bok (1995) and McKibbin and Tan (2009); and theoretical issues in the design of models for policy analysis are explored in McKibbin and Vines (2000) and Pagan et al. (1998).

Global fiscal consolidation is explored in McKibbin and Stoeckel (2012) which examines the direct impact of a large-scale reduction in government outlays on economies as well as the implications that a global fiscal adjustment might have on country risk premia. One key result in this paper is that substantial fiscal consolidation by

high-income economies (in proportion to the size of their debt problem) has the temporary effect of lowering economic activity in those economies, but has a positive effect on developing countries and a few high-income economies not undertaking fiscal consolidation. The reason is that the negative flow-on effects through trade linkages by high-income economies reducing imports and stimulating exports with the developing world are offset by favorable financial flow-on effects, which provides capital for developing countries to increase GDP. Secondly a credible phasing in of fiscal cuts can reduce expected future tax liabilities of households and firms which dampens the negative direct effects of cuts in government spending. The paper also explores the outcome if all countries coordinate their fiscal adjustment except the US. A coordinated fiscal consolidation in the industrial world that is not accompanied by US actions is likely to lead to a substantial worsening of trade imbalances globally as the release of capital in fiscally contracting economies flows into the US economy, appreciates the US dollar and worsens the current account position of the US. The scale of this change is likely to be sufficient to substantially increase the probability of a trade war between the US and other economies. In order to avoid this outcome, a coordinated fiscal adjustment is clearly in the interest of the global economy.

### **15.3.4 Financial crises**

#### ***15.3.4.1 Asian crisis***

In McKibbin and Martin (1998), the six-sector version of G-Cubed was used to simulate the Asian currency and economic crisis. Data from the key crisis economies of Thailand, Korea and Indonesia were used as inputs for simulations to see if the model could generate the scales of adjustment in asset markets as well as the sharp declines in economic activity that occurred.

The study considered three key factors in explaining the qualitative and quantitative events that unfolded in the crisis economies: (i) revisions to growth prospects, (ii) changes in risk perceptions and (iii) policy responses in individual countries. The role of asset markets and financial flows was critical. Downward revision in expected growth led to falling asset prices, which reduced current income and wealth. Combined with increased risk premia, calibrated to generate an exchange rate depreciation of the size being observed in real time in these economies, meant investment and growth collapsed. The extent to which financial markets responded through intertemporal arbitrage was crucial to the risk shocks. Finally, the ability to model the anticipated policy responses, both through price-setting and asset-market adjustments, was crucial to understanding the subsequent outcomes.

McKibbin (1999) focuses on the second of these factors: the impact on Asian countries of a jump in the perceived risk of investing in these economies. This paper argued that a financial shock can quickly become a real shock because of the interdependence of the real and financial economies. Too often policy makers and modelers

ignore this interdependence. The reaction of policy makers directly, and in the implications for risk of their responses are crucial to the evolution of the crisis.

Both McKibbin (1999) and McKibbin and Martin (1998) conclude that the risk shock was crucial to understanding the Asian crisis. The results for a risk shock are similar to the results for a fall in expected productivity. The shock leads to capital outflow from crisis economies and a sharp real and nominal exchange-rate depreciation. This reduces the value of capital, which, together with a significant revaluation of the US dollar denominated foreign debt, causes a sharp fall in wealth and a large collapse of private consumption expenditure. The fall in the return to capital, and the large rise in real long-term interest rates, lead to a fall in private investment.

Early in the debate over the Asian crisis, the results from G-Cubed were interesting and controversial because they were counter to popular commentary, both in Australia and in the US. The model showed that although the international trade effects were negative for countries that export to Asia, the capital outflow from crisis economies would push down world interest rates and stimulate non-traded sectors of economies that were not affected by changes in risk assessment. The model suggested that a country like Australia would slow only slightly in the short run and the US would experience stronger growth as a result of the capital reallocation. This is now conventional wisdom. Furthermore, for Australia, in particular, the existence of markets outside Asia, and changes in relative competitiveness, meant that substitution was possible for Australian exports. Models with an aggregate world growth variable or a single exchange rate variable would not capture this international substitution effect. Models with exogenous balance of payments could replicate the shock, but it required an exogenous change in the trade balance and other factors that are exogenous to the model.

#### **15.3.4.2 Global financial crisis**

In a number of papers McKibbin and Stoeckel (2010a, 2010b) used the approach of McKibbin and Martin (1998) together with shock to US housing markets and policy responses of central banks and fiscal authorities around the world to model the global financial crisis of 2008. Specifically they modeled the key aspects of the crisis as: (i) the bursting of the housing bubble and loss in asset prices and household wealth with consumers cutting back on spending and lifting savings; (ii) a sharp reappraisal of risk with a spike in bond spreads on corporate loans and interbank lending rates with the cost of credit, including trade credit, rising with a commensurate collapse of stock markets around the world; and (iii) a massive policy response including a monetary policy easing, bailouts of financial institutions and fiscal stimulus.

Simulating the loss in confidence through higher risk premia on the US alone (the 'epicenter' of the crisis) showed several things. Had there not been the contagion across other countries in terms of risk reappraisal, the effects would not have been as dramatic as subsequently occurred. The adverse trade effects from the US downturn would have

been offset to some degree by positive effects from a global reallocation of capital. Were the US alone affected by the crisis, Chinese investment could have actually risen. The world could have escaped recession. When there is a reappraisal of risk everywhere including China, investment falls sharply — in a sense there is nowhere for the capital to go in a global crisis of confidence. The implication is that if markets, forecasters and policy makers misunderstand the effects of the crisis and mechanisms at work, they can inadvertently fuel fears of a ‘meltdown’ and make matters far worse.

The bursting of the housing bubble had a bigger effect on falling consumption and imports in the US than does the reappraisal of risk, but the reappraisal of risk has the biggest effect on investment. Rising risk causes several effects. The cost of capital rises that leads to a contraction in the desired capital stock. Hence, there is disinvestment by business and this can go on for several years — a deleveraging in the popular business media. The higher perception of risk by households causes them to discount future labor incomes at a higher risk adjusted interest rate that leads to higher savings and less consumption, fuelling the disinvestment process by business.

When there is a global reappraisal of risk there is a large contraction in output and trade — the scale of which depends on whether the crisis is believed to be permanent or temporary. The long-run implications for growth and the outlook for the world economy are dramatically different depending on the degree of persistence of the shock. These papers found that, as expected, the effects of the crisis are deeper and last longer when the reappraisal of risk by business and households is expected to be permanent versus where it is expected to be temporary. A third combination was explored in [McKibbin and Stoeckel \(2010b\)](#) where agents unexpectedly switch from one scenario of believing the shock to be permanent to one the temporary scenario several years later. The dynamics for 2010 are quite different between the temporary scenario and the expectation revision scenario even though the shocks are identical from 2010 onwards.

One of the key results of both these studies was that there was a substantially larger contraction in exports relative to the contraction in GDP in all economies. This was observed in the actual data. This massive shift in the relationship between trade and GDP is not the result of an assumption about the income elasticity of imports. It reflects some key characteristics of the model. First, imports are modeled on a bilateral basis between countries where imports are partly for final demand by households and government and partly for intermediate inputs across the six sectors. In addition, investment is undertaken by a capital sector that uses domestic and imported goods from domestic production and imported sources. As consumption and investment collapse more than GDP, imports will contract more than GDP. One country’s imports are another country’s exports; thus exports will contract more than GDP unless there is a change in the trade position of a particular country. The assumption that all risk premia rise and the results that all real interest rates fall everywhere implies small changes in trade balances but big changes in the extent of trade in durable goods. As durable goods have a much bigger share in trade

than in GDP the compositional shift of demand away from durable goods due to higher risk premia causes a structural change in the relationship between trade and GDP.

### 15.3.5 Pandemics

As part of research for the World Health Organization (WHO) G-Cubed was adapted to explore two major pandemics: (i) the SARS (severe acute respiratory syndrome) outbreak in 2003, which was explored in [Lee and McKibbin \(2004\)](#) (ii) the potential of a pandemic resulting from the outbreak of bird flu, which was examined in [McKibbin and Sidorenko \(2006\)](#).

In [Lee and McKibbin \(2004\)](#) the authors used emerging data on changes in risk premiums observed in financial pricing and changes in spending behavior in the affected countries on Hong Kong, China to develop shocks to country risk, based on observed exchange rate changes, sector specific shifts in demand away from sectors with high human-to-human contact (mostly services) and an increase in the input costs of the service sector of roughly 5%. This study was the first of a new approach to analyzing the macroeconomic costs of diseases through general equilibrium modeling. The key insight for policy design and investment in public health was that the short-run cost of major disease outbreaks is significant. Traditional estimates based on loss of life and income foregone underestimate the costs of large-scale change in economic behavior and the spillovers between economies of disease outbreaks. The authors estimated that the cost in 2003 of SARS for the world economy as a whole was close to \$40 billion, which is the official WHO estimate of the SARS outbreak.

The approach in [Lee and McKibbin \(2004\)](#) on SARS was significantly extended in [McKibbin and Sidorenko \(2006\)](#) to explore the possible implications of more widespread influenza pandemics. Based on historical experience of influenza pandemics, [McKibbin and Sidorenko \(2006\)](#) considered four mortality scenarios under current economic linkages in the global economy. The scenarios were: (i) a 'mild' pandemic, modeled on 1968–1969 Hong Kong Flu; (ii) a 'moderate' pandemic, modeled on the Asian Flu of 1957; (iii) a 'severe' pandemic similar to the lower estimates of mortality and morbidity in the Spanish flu of 1918–1919; and (v) an 'ultra' pandemic, modeled on high-end estimates of the Spanish Flu. These scenarios were used to generate a range of shocks to individual countries and sectors due to the pandemic (including mortality and morbidity shocks to labor force, increase in cost of doing business, an exogenous shift in consumer preferences away from exposed sectors, and a re-evaluation of country risk premiums). These shocks generate a complex response of incomes and prices driving global economic outcomes. The results illustrated that even a mild pandemic can have significant consequences for global economic output, with the developing countries experiencing the largest economic loss due to the compounding effect of a weaker public health response, capital reallocation and monetary policy responses within different exchange rate regimes. The use of a general equilibrium model that included changes in

behavior of a large scale in response not only to market signals, but also changes in risk perceptions can cause a much larger economic loss than conventional estimates of pandemics imply.

### 15.3.6 Demographic change

In a series of papers, McKibbin and Nguyen (2004), Bryant and McKibbin (2004), McKibbin (2006b), and Nguyen (2011) have incorporated overlapping cohorts of generations in G-Cubed, in order to explore demographic change in various countries. The approach followed is based on the work of Blanchard (1985), Yaari (1965), and Weil (1989) as extended by Faruqee (2003). This work was also adapted in Batini et al. (2005) for the International Monetary Fund *World Economic Outlook* (International Monetary Fund, 2004).

The basic approach was to introduce individual cohorts of agents into G-Cubed. By following the Blanchard approach and assuming a constant probability of death across cohorts we are able to aggregate agents outside the model and feed in the change in productivity by agent cohort using estimated age-earnings profiles to generate shocks to effective labor supply in the model. This short cut approach of assuming a constant probability of death across cohorts is a strong assumption. To abandon that simplifying assumption requires an explicit multicohort OLG model which is recently undertaken in Nguyen (2011).

An analysis of the impact of the global and regional differences in demographic change needs to take into account the effects of changing growth rates as well as the numbers of adults and children. McKibbin (2006b) incorporated these projections into a general equilibrium model that allows for the changing composition of the population, and captures its effect on labor supply, investment, growth potential, saving, asset markets, international trade and financial flows.

There are at least two most important policy implications from this research. The first is that the projected demographic transition in the global economy will likely have important macroeconomic impacts on growth, trade flows, asset prices (real interest rate and real exchange rates) and investment rates. The second result is that policy makers should not ignore the global demographic transition when focusing on domestic issues related to demographics. The fact that the demographic transition is at different stages across countries, particularly in industrialized countries relative to developing countries, implies that the global nature of demographic change cannot be ignored. McKibbin (2006b) showed that the developing world has important impacts on the industrial economies.

As well as creating a framework for exploring a range of possible policy responses directly related to demographics, the model could be used to explore how other policies, apparently unrelated to demographics, might impact on the macro economy to offset any negative consequences or reinforce any positive consequences of global demographic

change. A first attempt at this is contained in [Batini et al. \(2005\)](#), which explored the impact of productivity improvements induced by economic reform and lowering barriers to international capital flows in developing countries. By using a general equilibrium model other policies in other parts of the economy might have a more substantial positive contribution to dealing with demographic change than the more direct policies that are usually proposed, such as increased migration, subsidies to child birth or changes in retirement ages.

## 15.4 SAMPLE APPLICATIONS

In this section we present results illustrating the use of G-Cubed for analysis of financial shocks and international trade agreements. The first analysis draws on [McKibbin and Stoeckel \(2010b\)](#) and examines the effects of a financial crisis on the global economy. The second analysis draws on [McKibbin and Wilcoxon \(2003\)](#) and examines the effects of the proposed FTAA on trade patterns and carbon emissions.

### 15.4.1 Financial crisis

#### 15.4.1.1 Modeling approach

To analyze a financial crisis, we used an extended version of the model (Aggregation N) which has greater regional detail. There are seven additional regions including five new countries (Canada, the UK, Germany, India and New Zealand) and two new aggregates (Other Asia and Latin America). In addition, the aggregate region representing Europe has been replaced with a narrower aggregate representing the euro zone countries other than Germany. The full list of regions is shown in [Table 15.4](#).

We model financial crises as changes in the risks perceived by investors, which are reflected in the risk premia they demand for holding assets. Risk premia enter the model in a number of places. They play an important role in the model's calibration as well as having large impacts on economic outcomes through intertemporal relationships. For example, risk premia  $\mu_k$  and  $\mu_j$  appear in equation (15.30), the arbitrage equation between returns on domestic and US bonds, which is repeated below:

$$i_k - \mu_k = i_j - \mu_j + \frac{\dot{E}_k^j}{E_k^j}. \quad (15.39)$$

In addition, as shown in equation (4) there are risk premia,  $\mu_{ei}$ , between bonds and equity in each sector within each economy, which represent the sector's equity risk premium. There is also a risk premium,  $\mu_h$ , on the rate at which households discount future after tax labor income, as shown in equation (15.16).

In calibrating the model, these risk premia are calculated so that the model's solution values for forward looking variables in the base year (2006) are equal to the historical



**Table 15.4** Regions in G-Cubed aggregation N

	<b>Region</b>	<b>Short name</b>	<b>Model code</b>
1	US	USA	U
2	Japan	JPN	J
3	UK	GBR	K
4	Germany	DEU	G
5	Rest of the Euro Zone	EUZ	E
6	Canada	CAN	N
7	Australia	AUS	A
8	New Zealand	NZL	Q
9	Rest of the OECD	OEC	O
10	China	CHI	C
11	India	IND	D
12	Other Asia	OAS	X
13	Latin America	LAM	V
14	Other Developing Countries	LDC	L
15	Eastern Europe and the Former USSR	EEB	B
16	Oil Exporting Developing Countries	OPC	P

values of those variables. For example, in the case of country risk ( $\mu$ ), a constant is chosen so that the current exchange rate, which is the expected future path of interest differentials plus the period  $T$  exchange rate, is equal to the actual exchange rate in the base period 2006. The equity risk premium in each sector in each country is chosen so that the stock market value for sector  $i$  in country  $n$  is equal to its actual stock market value in 2006.

Once the risk premia are calculated they held constant for most simulations. However, they can be shocked to explore the impact of changes in perceived risks.

#### **15.4.1.2 Overview of simulations**

To illustrate the importance of these risk premia, two experiments are presented in this section. The first is a rise in country risk in Europe (consisting of the country models for Germany, the rest of the euro zone and the UK). This shock could represent a sovereign debt crisis in this region or some other change in perceived risk that causes investors to demand a higher rate of return on government bonds from that region (relative to the US government bond rate adjusted by expected exchange rate changes). The second experiment examines a broader risk shock that extends to the US as well. In this case the relative risk between Europe and the US is unchanged from the baseline but the risk of both regions relative to all other countries rises.

#### **15.4.1.3 Reference case**

In the reference case the world economy is assume to grow along the model's baseline projections. All risk premia are held constant at their calibrated values discussed above.

#### 15.4.1.4 Increased risk in Europe

In the first simulation, country risk in Europe (including Germany, the rest of the euro zone and the UK) is assumed to rise unexpectedly in 2011 by 300 basis points. This increase is assumed to be permanent. As a result, investors demand that all financial assets within Europe pay an additional 300 basis points (relative to competing assets) to compensate for the additional risk.

The immediate effect of the shock is a reduction in the financial value of European assets as investors reallocate their portfolios away from those assets. Financial capital flows out of Europe causing a sharp fall in nominal and real European exchange rates. For example, Figure 15.2 shows the percentage change in the real effective exchange rate, measured in units of foreign currency per unit of domestic currency, for four key regions: the US, Germany, the rest of the euro zone ('Rest of Europe' in the figure) and China. Results for the Europe-only financial crisis are shown by the solid line labeled 'eur' and those for the broader Europe-US crisis are shown by the dashed red line labeled 'both'. Germany's trade-weighted real effective exchange rate falls by about 20% and that of the rest of the euro zone falls by about 40%. In contrast, the real exchange rates of the US and China increase as capital flows into both regions.

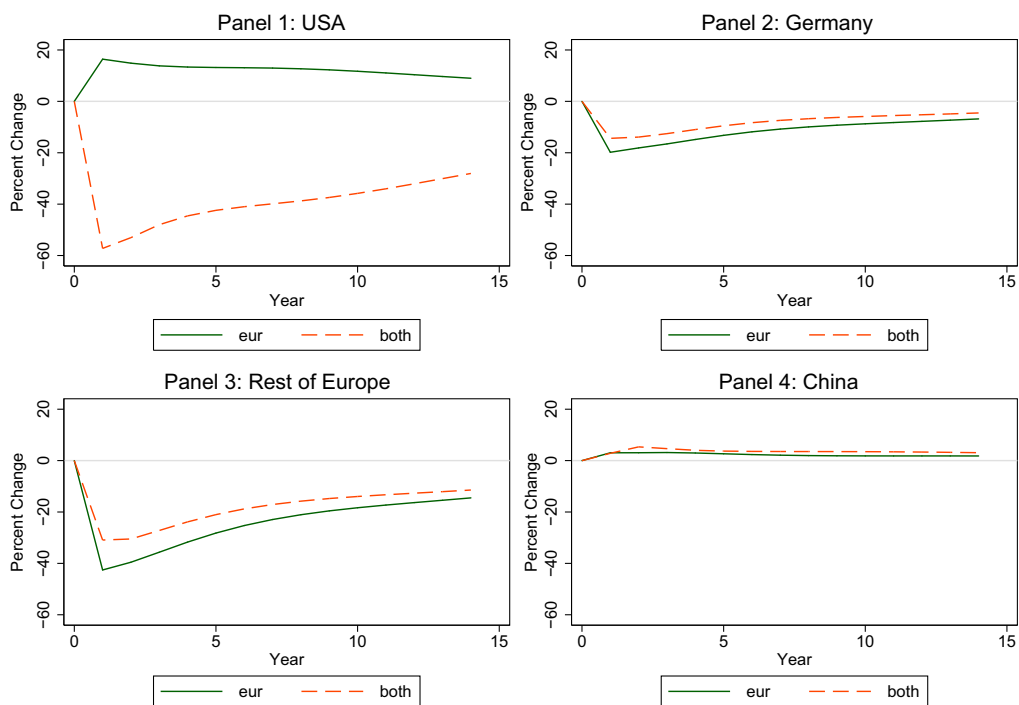


Figure 15.2 Real effective exchange rate.

These changes in exchange rates and financial flows are reflected in the trade balances of each region. As shown in Figure 15.3 European regions experiencing exchange rate declines and capital outflows see their trade balances move sharply toward surplus: their exports become more competitive and investors are less willing to finance trade deficits. For similar reasons, the trade balances of the US and China (where exchange rates have strengthened and capital inflows have increased) move toward deficit.

In the longer term, the change in the required financial return causes the marginal physical product of capital in Europe to rise to re-equilibrate the arbitrage condition between bonds and equity. This comes about via a decline in European capital stocks: the stocks initially in place when the shock occurs are too high to generate the physical return required. The expectation that increased risk is permanent leads to a long period of falling European capital and higher European interest rates relative to the reference case. As shown in Figure 15.4 the shock raises European real interest rates by more than 100 basis points. Interest rates in the US and China, on the other hand, fall slightly. Real investment, shown in Figure 15.5 also changes as expected: a sharp immediate drop in Europe, followed by a gradual recovery as European capital

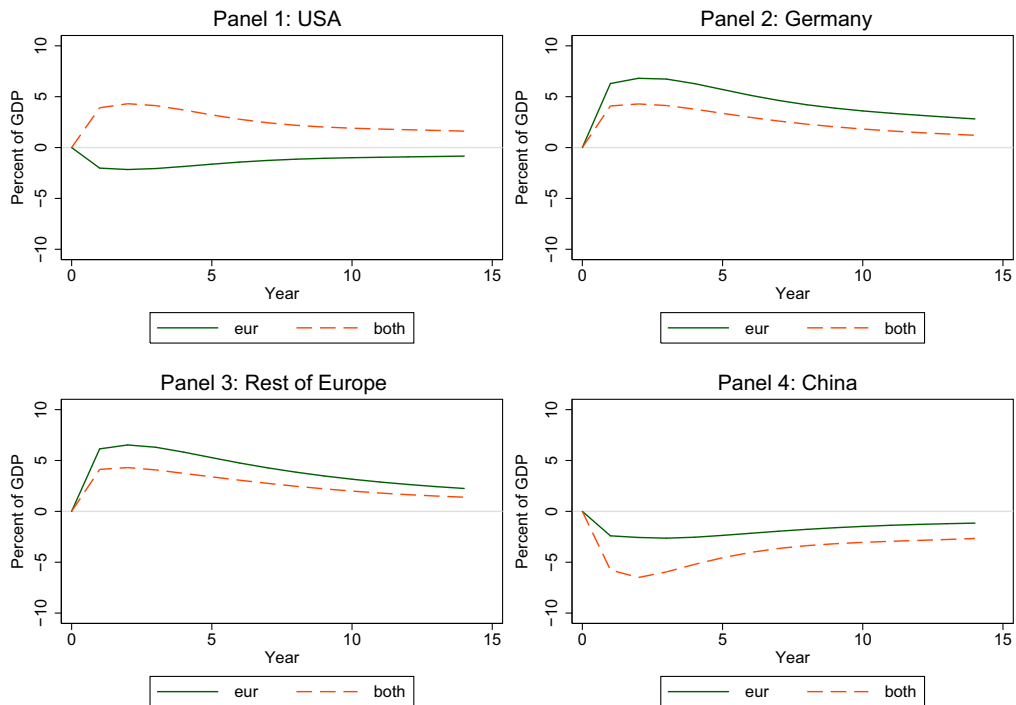


Figure 15.3 Trade balance.

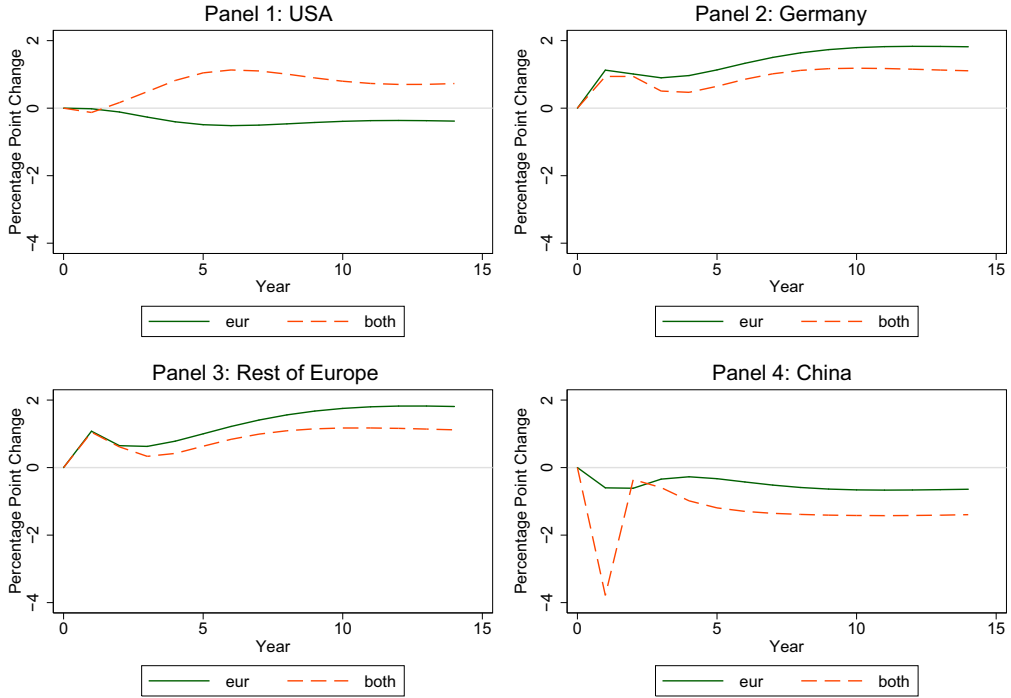


Figure 15.4 Real short-term interest rate.

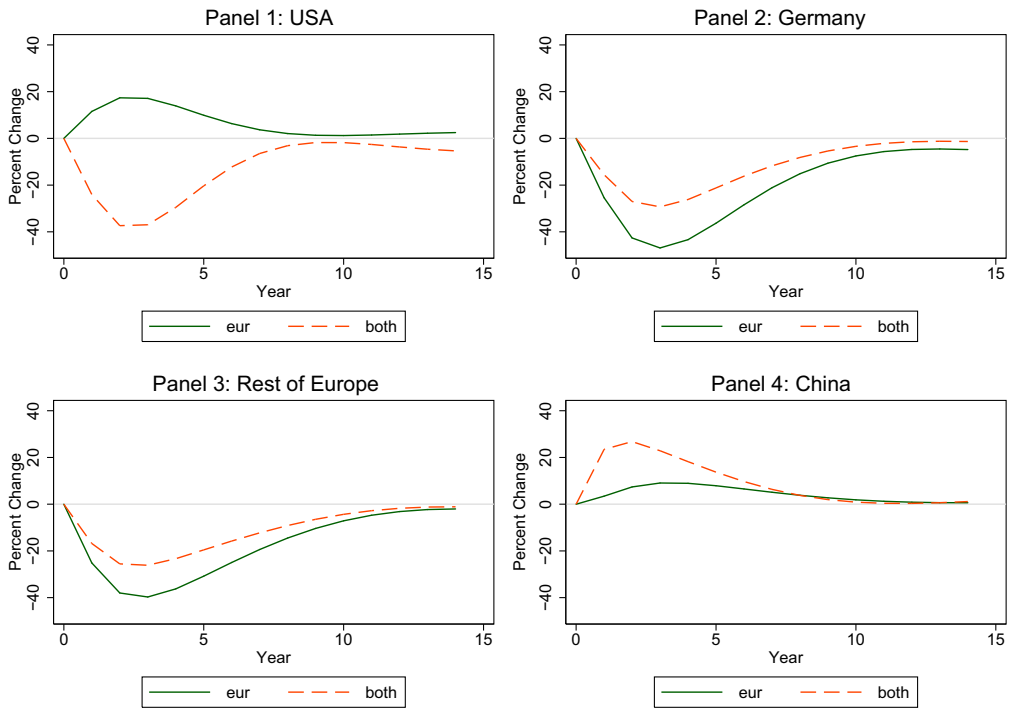


Figure 15.5 Real investment.

stocks converge to their new, lower, long-term levels; and the reverse in the US and China.

The drop in asset values in Europe lowers the wealth of European households and causes private consumption to fall, as shown in Figure 15.6 Relative to the reference case, consumption increases slightly in the US and somewhat more in China due to China’s slightly large fall in interest rates.

Overall, European regions experience lower consumption and investment, and higher net exports. On balance, the effect on European GDP is negative, as shown in Figure 15.7. The results are consistent with supply-side effects: European capital stocks gradually fall over time and the loss of GDP is exacerbated in the short run by temporary unemployment. The change in risk is sufficient to cause a recession in Europe with GDP in the first year down by nearly 5% relative to its reference level. In contrast, consumption, investment and GDP all rise slightly in the US and China under the Europe-only shock.

Interestingly, the transmission of the shock to countries outside Europe is positive (i.e. other countries gain) despite the fall in European GDP. The large outflow of financial capital from Europe to the rest of the world pushes down long-term real interest rates in other regions, stimulating non-European investment and expanding

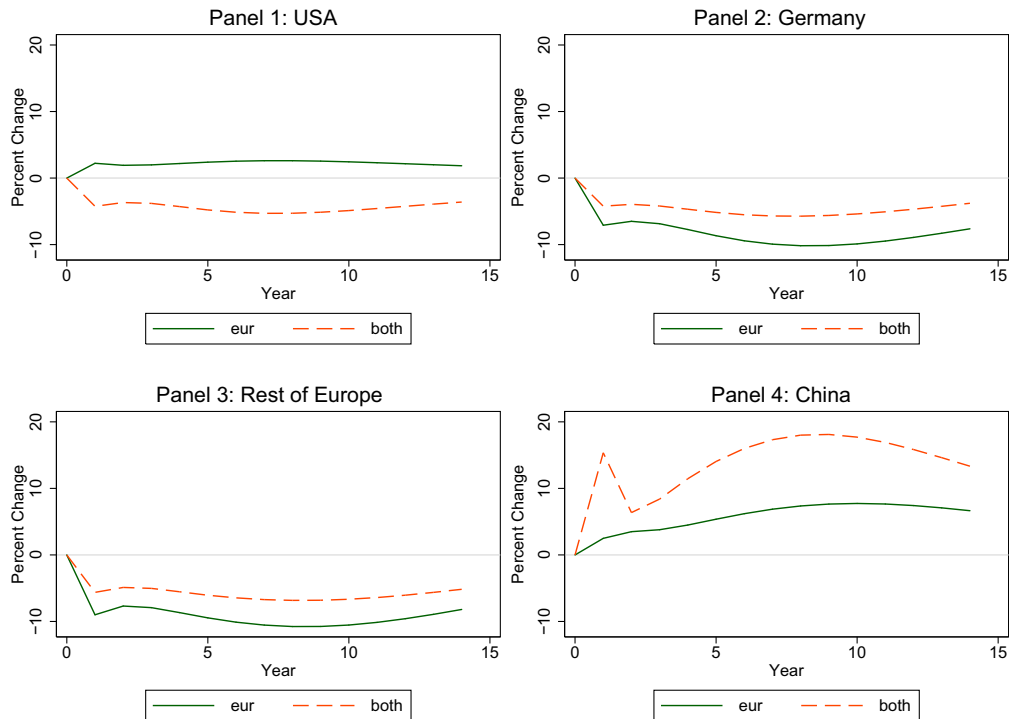


Figure 15.6 Real consumption.

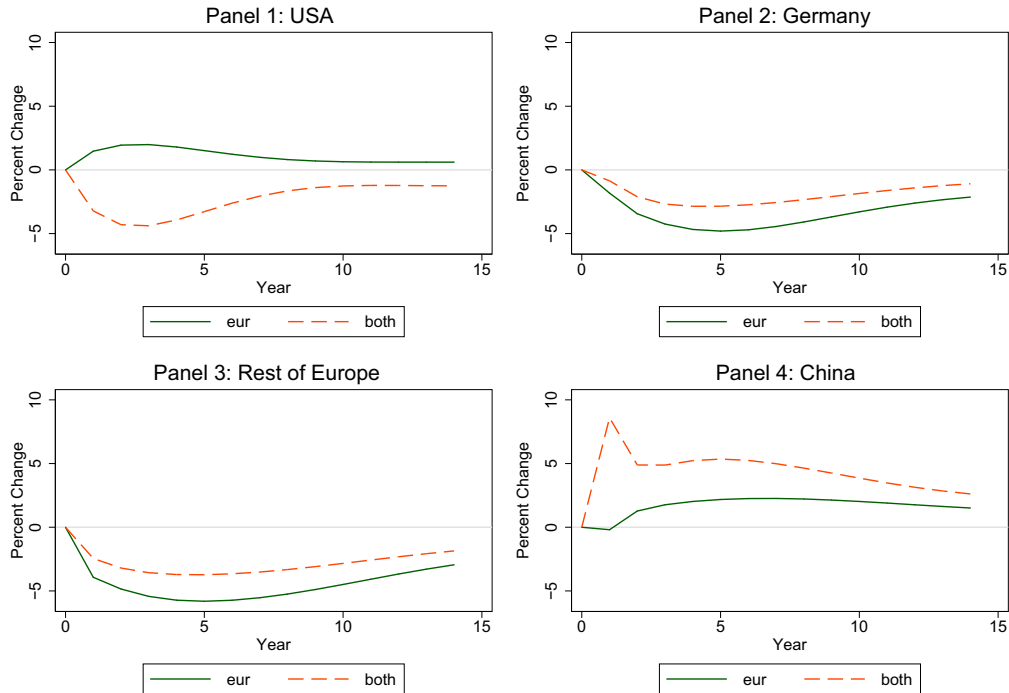


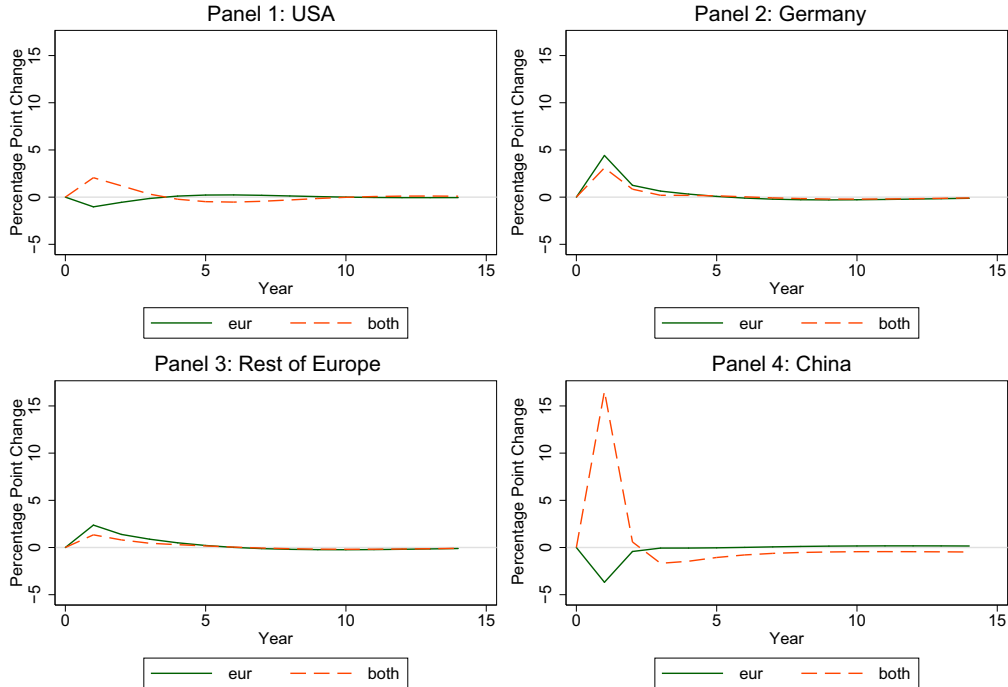
Figure 15.7 Real gross domestic product.

the supply side of other economies. The capital reallocation effect is sufficiently large that for most other regions it more than offsets the negative effect of lower import demands from a weaker Europe. Roughly speaking, the shock tends to reallocate financial capital rather than destroy it. Although the value of capital drops sharply in Europe (as reflected in the real exchange rate shown in Figure 15.2), it rises in the US and China.

#### 15.4.1.5 Increased risk in Europe and the US

In the second simulation, the US also experiences an increase in perceived risk (perhaps through contagion or its own fiscal crisis). As noted above, results for this simulation are shown in the earlier figures along with those for the European financial crisis. Broadly speaking, the effects of the broader crisis on the US are much like those of the narrower crisis on Europe: the real exchange rate falls, the trade balance moves toward surplus, the real interest rate increases, and investment, consumption and GDP decline.

Interestingly, however, the spread of the crisis to the US also attenuates the effects on Germany and the rest of Europe: European losses in consumption, investment and GDP are reduced relative to the case when the shock is confined to Europe. This result reflects the role of adjustment costs in capital accumulation in each sector. The US is a large economy that can absorb a lot of the capital that flows out of Europe without much being



**Figure 15.8** Inflation rate.

lost to adjustment costs (see equation 15.3). In contrast, when the inflow from Europe to the US is reduced by the rise in US risk, adjustment costs cause less capital to flow out of Europe. The remaining countries (other than the US and Europe) have much less capacity to absorb large inflows of additional capital without incurring rising adjustment costs from expanding their physical capital stocks. Thus, more financial capital stays within Europe under the second simulation, reducing the loss of European GDP. This result illustrates one of the benefits of intertemporal general equilibrium models that explicitly model the supply side of economies: in more traditional Keynesian macroeconomic models, this effect does not exist and demands driven by trade dominate the results for the international transmission of economic shocks.

Finally, the results for China in the second simulation show the importance of assumptions about monetary policy. In G-Cubed, China is assumed to peg its nominal exchange rate to the US dollar.<sup>37</sup> As a result, China effectively loosens its monetary policy at the onset of the US shock in order to have its nominal exchange rate move with the US dollar. Thus, there is a substantial monetary expansion in China. Short-term interest rates fall, real consumption, investment and GDP rise sharply, and inflation spikes markedly, as shown in Figure 15.8 (panel 4).

<sup>37</sup> Strictly speaking, China is assumed to follow the US dollar via a crawling peg that adjusts gradually.

### 15.4.1.6 Summary

These results illustrate the power of G-Cubed to contribute to understanding of important macroeconomic transmission channels in the global economy. Integrating the flows of capital and goods, together with explicit modeling of the demand and supply sides of economies, fundamentally changes the nature of the international transmission of macroeconomic shocks. The model's results offer an explanation of the puzzle of 'delinking' of trade and financial flows often discussed in the popular press. When both flows are incorporated in a model, as they are in G-Cubed, it is clear that the details of a shock's effects on trade and financial flows are pivotal in determining the outcome of the transmission process. Real versus financial shocks can affect trade and finance differently and hence there need not be anything mysterious about changes in the comovements of the GDP of countries over time when the nature of the macroeconomic shocks they face changes. For example, our results in this section show that nominal rigidities, such as pegging a nominal exchange rate, can have significant short-term real consequences during the adjustment period.

## 15.4.2 FTAA

Our second illustration of analysis using G-Cubed focuses on the proposed FTAA. We evaluated the FTAA by comparing the evolution of the world economy with and without the agreement.<sup>38</sup> In McKibbin and Wilcoxon (2003) we considered a range of competing assumptions about the manner in which the FTAA would be implemented and the effects it would have on individual economies. In particular, we evaluated the FTAA under two different assumptions about its effect on productivity growth and under alternative assumptions about how governments respond to a decline in tariff revenue. In this section we discuss a subset of those results.

### 15.4.2.1 Trade liberalization and growth

The direct effect of reducing tariffs is to improve the efficiency of an economy's resource allocation by reducing the wedge between a buyer's willingness to pay for an imported product and the product's marginal cost. Traditionally, general equilibrium studies of trade reform have focused on measuring these efficiency gains, and measuring them at a given point in time, usually either the immediate short run after the reform has been implemented, or far in the future at the model's long run equilibrium. By this standard, trade liberalization is usually found to improve welfare

<sup>38</sup> Other papers in the literature on trade and the environment include Strutt and Anderson (1999), who find that trade can improve environmental quality in some circumstances and does little harm otherwise, and Tsigas *et al.* (2002), who find that the effect of trade on the environment is ambiguous. Other general equilibrium studies of the FTAA include Diao and Somwaru (2000) and Adkins and Garbaccio (2002).



but the magnitude of the improvement tends to be small. For example, Hertel et al. (1999) find that a worldwide cut in tariffs of 40% would raise world GDP by 0.24%.<sup>39</sup>

However, liberalization leads to a host of indirect dynamic effects as well. These can cause profound changes in an economy by altering its rate of growth. Unfortunately, they are often very difficult to measure, particularly because competing effects can work in opposite directions. For example, reductions in tariffs cause imports to rise, pushing a country's trade balance toward deficit, leading to a depreciation of its exchange rate and a consequent increase in its exports. Deterioration of the trade balance is accompanied by inflows of capital from abroad which augment domestic saving and tend to raise the rate of investment. At the same time, the drop in tariff revenues will push the country toward fiscal deficit, raising government borrowing and tending to crowd out private investment. To further complicate matters, capital accumulation is also affected by reductions in the prices of imported durable goods, which tend to reduce the cost of new capital and thereby increase the rate of capital formation and growth. Disentangling these effects requires a multisector general intertemporal equilibrium model with considerable financial detail.

In addition to changing capital accumulation, the empirical literature suggests that trade improves industry productivity by placing additional competitive pressure on previously protected industries, and by increasing the flow of investment and embodied technical change across borders (Frankel and Romer, 1999; Chand, 1999). Moreover, these studies find that trade liberalization has much larger effects than traditional static analysis suggests: Frankel and Romer, for example, find that a one percentage point increase in the ratio of trade to GDP raises *per capita* income by 2–3%.

Although there is clear evidence of a link between trade and productivity at the aggregate level, the literature is not yet sufficient to permit precise predictions about the magnitude of improvement in productivity of individual industries. As a result, we approach the issue by running two sets of simulations. The first employs the traditional assumption that firms in liberalizing economies do nothing when faced by increased competition from imports (apart from substituting toward cheaper inputs): they do not cut costs or adopt better management practices or newer technology. Although this assumption is conventional, it is quite strong. It says, in effect, that a firm's technology choice is not affected by its industry's level of protection. It is hard to find any empirical support for that position and there is much evidence for the reverse: there are countless

<sup>39</sup> Martin *et al.* (2003) point out that traditional general equilibrium measures of the gains from liberalization are biased downward very significantly by aggregation across goods. Tariff rates differ sharply between individual products and efficiency costs are proportional to the square of the price changes caused by the tariffs. When products are aggregated, however, their individual tariffs are replaced by a weighted average. The efficiency cost of an average tariff can be shown to be smaller than the average of the efficiency costs of the individual tariffs it replaced.

examples of industries clinging to obsolete, high-cost technology because protection allowed them to do so.

Our second set of simulations introduces a link between trade and productivity by assuming that previously protected industries are able to take modest steps to reduce their costs.<sup>40</sup> It captures, at least to first order, the empirical features seen in the econometric literature on trade and growth. Since both sets of simulations depend on assumptions about the link between trade and productivity, neither one can be interpreted as a precise forecast of the FTAA's effects. However, they characterize the set of possible outcomes. Other general equilibrium studies that have introduced a link between trade and productivity include Stoeckel et al. (1999), *Diao and Somwaru (2000)*, and *Monteagudo and Watanuki (2001)*.

Finally, a third indirect effect of trade agreements is that increased openness lowers the risk premium attached to a country's sovereign debt by rating agencies such as Standard and Poor's and Moody's (Stoeckel et al., 1999). This can lead to pronounced increases in capital inflows, particularly for developing countries. However, that mechanism will not be discussed here.

#### **15.4.2.2 Modeling approach**

G-Cubed's basic design is well-suited to the task because it has a full, integrated treatment of international trade and financial flows: each country's current account position must be offset by its capital account, which in turn leads to accumulation or erosion of its stock of foreign assets and thus to changes in its future flow of interest payments. In addition, it accounts for the relative immobility of physical capital and the high mobility of financial capital.

To analyze the FTAA, we developed an extended version of the model with greater regional detail in the Western Hemisphere. It includes five regions particularly relevant for the FTAA: the US, Canada, Mexico, Brazil and an aggregate region representing the rest of Latin America. To keep the size of the model manageable, Australia was merged into the Rest of the OECD. The full list of regions is shown in [Table 15.5](#). Within each region, the disaggregation of production remained the same: the 12 sectors shown in [Table 15.2](#).

The structure of the model was also modified to facilitate simulations involving preferential trade agreements. The updated version allowed each region to have two sets of tariffs: one set for imports from countries within a preferred trade area and one for imports from everywhere else. For free trade agreements such as NAFTA or the FTAA, the tariffs on trade within the preferential area are set to zero. It should be noted that the model does *not* require participants in a free trade agreement have harmonized external

<sup>40</sup> The magnitude of the productivity improvements will be discussed below.

**Table 15.5** Regions in the FTAA-extended G-Cubed model

	<b>Region</b>	<b>Short name</b>	<b>Model code</b>
1	US	USA	U
2	Japan	JPN	J
3	Canada	CAN	N
4	Europe	EUW	E
5	Rest of the OECD	OEC	O
6	China	CHI	C
7	Brazil	BRA	I
8	Mexico	MEX	M
9	Rest of Latin America	RLA	V
10	Other Developing Countries	LDC	L
11	Eastern Europe and the Former USSR	EEB	B
12	Oil Exporting Developing Countries	OPC	P

tariffs: each country retains its original tariffs on trade outside the free trade area unless otherwise specified in a simulation.

#### **15.4.2.3 Overview of simulations**

To determine the effects of the FTAA we carried out a suite of simulations: a reference case having no multiregion free trade areas; a pair of simulations examining the effects of NAFTA and the FTAA under the assumption that tariff reductions and trade flows have no effect on industry productivity; a pair of simulations examining the effect of NAFTA and the FTAA under an alternative assumption in which tariff reductions and increased trade lead to modest improvements in the productivity of previously protected industries; and a pair of simulations investigating the effect of announcing NAFTA or the FTAA 5 years before it is actually implemented. In this chapter we focus only on the simulations that include productivity effects; full results including the other simulations can be found in McKibbin and Wilcoxon (2003). The simulations discussed in here are listed in Table 15.6.

#### **15.4.2.4 Reference case**

The first was a reference case having no multiregion free trade agreements, not even NAFTA.<sup>41</sup> In this simulation, each region's tariff rates do not distinguish between imports from different trading partners. For example, the US imposes a single tariff on imports of durable goods, regardless of whether any particular imported good originates in Canada, Europe, Brazil or somewhere else. As it does not include NAFTA, the reference case does not represent the current world economy. However, it allows us to

<sup>41</sup> That is, no free trade area not wholly contained within one of the model's regions (such as Europe).

**Table 15.6** Descriptions of simulations

	Name	Trade Area	Description
1	Reference	None <sup>a</sup>	No free trade agreements: each region imposes identical tariffs on imports from all of its trading partners
2	NAFTA-p	NAFTA	The existing NAFTA: no tariffs on trade between the US, Canada and Mexico plus productivity improvements in the industries whose tariffs have been reduced
3	FTAA-p	FTAA	The FTAA implemented immediately: no tariffs on trade between the US, Canada, Mexico, Brazil and the Rest of Latin America plus productivity improvements
4	NAFTA5-p	NAFTA	Counterfactual in which NAFTA is announced immediately, but implemented 5 years later; used as a point of reference for comparison with the FTAA5 simulation
5	FTAA5-p	FTAA	The FTAA announced immediately but not taking effect until 5 years later; examines the effects of anticipation of the agreement. Includes productivity improvements

<sup>a</sup>Other than Europe, which is treated as a single region in the model.

simulate the adoption of NAFTA itself, which is very useful for putting the FTAA results in context. The reference case tariff rates were derived by aggregating historical data and are listed in Table 15.7.<sup>42</sup>

The pattern of trade under the reference case is exemplified by the figures shown in Table 15.8 for year 12 of the simulation; refer to Table 15.5 for a list of region codes.<sup>43</sup> Each panel of the table gives the bilateral trade matrix for a particular good; panel nine, for example, shows trade in durable goods. The columns of Table 15.8 indicate the origin of each trade flow and the rows indicate the destination. Each entry is the US dollar value of the corresponding flow of goods.<sup>44</sup> For example, in panel 5 the value in the 'U' row and 'P' column is 35.3, which indicates that shipments of crude oil from OPEC to the US were worth \$35.3 billion. Where the value of trade was less than \$0.1 billion, the entry is left blank.

As exports from different regions are imperfect substitutes, most goods flow in both directions between each pair of regions. For example, the US exports \$45.5 billion dollars' worth of durables to Japan while simultaneously importing \$145.3 billion dollars of Japanese durables. At G-Cubed's level of aggregation, traded goods are generally far from homogeneous due to differences in the product mix of exports from different countries. Aircraft, for example, are an important component of durables exported by the US but are not a significant portion of US imports of durables from Japan.

<sup>42</sup> See Hertel (1997) for the original data.

<sup>43</sup> Results are presented for year 12 because it is a representative medium-run year for both the immediate and anticipated versions of the trade agreement.

<sup>44</sup> Throughout the paper all values are in constant dollars.

**Table 15.7** Initial tariffs, by country and product (%)

Product	Region											
	U <sup>N,F</sup>	J	N <sup>N,F</sup>	E	O	C	I <sup>F</sup>	M <sup>N,F</sup>	V <sup>F</sup>	L	B	P
Electric utilities									0.02	0.11	2.06	0.34
Gas utilities											1.44	0.28
Petroleum refining	2.24	3.31	6.20	3.81	0.44	8.33	5.69	7.07	6.96	10.77	4.93	6.29
Coal mining						4.72		5.46	1.51	1.82	1.81	5.90
Crude oil and gas extraction	0.39						5.25		3.90	4.78	0.77	2.31
Other mining	0.38		0.01	0.02	0.12	0.44	1.95	8.33	3.35	3.08	2.17	6.25
Agriculture	4.72	110.21	12.88	25.44	0.96	26.00	30.41	18.08	9.51	20.30	24.56	37.05
Forestry and wood products	2.08	2.29	5.02	2.57	3.90	8.72	13.07	12.52	12.77	6.06	12.22	12.64
Durable goods	2.60	0.58	4.14	4.17	4.82	14.87	18.00	11.30	12.93	7.81	9.92	11.09
Non-durables	6.93	31.36	21.61	25.74	6.81	28.77	13.91	21.78	15.22	14.04	15.26	34.80
Transportation					0.27				1.19	0.55	1.00	0.12
Services					0.03				2.83	0.25	0.55	0.11

<sup>N</sup>Member of NAFTA<sup>F</sup>Member of the FTAA.

**Table 15.8** Bilateral trade flows in the reference case (billion US\$)

<b>Industry 1: Electric Utilities</b>													
	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA		2.0										2.1
J		NA											
N	0.3		NA										0.3
E				NA						0.1	0.7	0.1	0.8
O					NA								
C						NA				0.1			0.1
I							NA						0.2
M								NA					
V									NA				
L				1.1		0.7				NA	0.1		2.0
B				0.1							NA		0.1
P												NA	
Sum	0.3		2.0	1.0		0.7				0.2	0.8	0.1	5.1
<b>Industry 2: Gas Utilities</b>													
	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA		3.0						0.1			0.1	3.2
J		NA								0.9		1.4	2.4
N	0.1		NA										0.1
E				NA							1.6	1.3	3.0
O					NA								
C						NA				0.2		0.1	0.3
I							NA						0.1
M	0.2							NA				0.1	0.2
V									NA				
L				0.8	0.3	0.1				NA	0.2	1.1	2.6
B											NA		
P												NA	
Sum	0.3		3.0	0.9	0.4	0.1			0.1	1.1	1.9	4.1	11.9
<b>Industry 3: Refining</b>													
	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA	0.3	0.2	3.3	0.1	0.1	0.3	0.8	2.2	1.6	0.2	2.3	11.3
J	0.3	NA		0.1	0.1	0.1			0.1	4.4		2.4	7.6
N	1.3		NA	0.2						0.1			1.7
E	1.0	0.1	3.4	NA		0.1		0.2	0.4	2.4	7.0	3.9	18.5
O	0.2				NA					0.7		0.2	1.3
C	0.1	0.4		0.1		NA				2.6	0.2	0.1	3.6
I	0.2		0.1	0.3			NA		0.1			0.4	1.1
M	5.0			0.2		0.1		NA	0.2			0.2	5.7
V	1.4			0.5		0.1	0.2	0.1	NA	0.8	0.9	0.6	4.6

*(Continued)*

**Table 15.8** Bilateral trade flows in the reference case (billion US\$)—cont'd

L	1.3	1.0		12.7	1.1	1.3			0.1	NA	1.3	7.4	26.3
B				2.3		0.1				0.1	NA		2.6
P	0.2	0.1		0.5		0.1			0.2	0.5		NA	1.7
Sum	11.1	1.9	3.7	20.3	1.3	2.1	0.6	1.1	3.3	13.4	9.7	17.4	85.9

**Industry 4: Coal**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA	0.2	0.3			0.1			0.2			0.1	1.0
J	0.2	NA	0.7		2.9	0.6				0.2	0.1	0.5	5.1
N	1.0		NA							0.1			1.1
E	1.1		0.3	NA	1.2	0.3			0.7	1.2	1.5	0.3	6.7
O					NA								
C					0.1	NA							0.1
I	0.4	0.1	0.1		0.3	0.1	NA			0.1	0.1		1.1
M	0.3							NA					0.4
V									NA				
L	0.3	0.1	0.4	0.2	2.2	1.1			0.1	NA	0.3	0.9	5.7
B	0.1				0.1						NA		0.3
P												NA	0.1
Sum	3.3	0.3	1.9	0.2	7.0	2.2			1.2	1.5	2.1	1.8	21.6

**Industry 5: Crude Oil and Gas**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA		18.6	6.2	0.4	0.1		10.8	6.3	18.4	0.1	35.3	96.2
J	0.4	NA		0.2	0.3	0.5		0.4	0.1	14.5		20.2	36.6
N	0.5		NA	2.9				0.3		0.7		1.9	6.4
E				NA				1.2	0.1	12.4	16.2	36.3	66.2
O					NA					3.0		1.6	4.7
C	0.1			0.8	0.3	NA				3.6	0.1	2.0	6.9
I				0.1		0.1	NA		0.1	1.3	0.1	3.5	5.3
M	0.5							NA	0.1			0.2	0.8
V				0.1				1.1	NA	0.4	4.4	5.8	11.8
L	0.4			4.0	2.1	0.4			0.5	NA	2.0	47.7	57.1
B				2.3						0.3	NA	1.8	4.4
P					0.1	0.1		0.1	0.1	0.7		NA	1.1
Sum	2.0		18.7	16.7	3.3	1.2		13.9	7.2	55.1	23.0	156.4	297.4

**Industry 6: Mining**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA		1.9	0.7	0.1	0.2	0.3	0.8	0.3	0.6	0.1		5.2
J	0.4	NA	0.1	0.3	1.5	0.3	0.5	0.1		1.8		0.9	5.9
N	1.9		NA	0.2			0.1		0.3	0.1			2.7
E	1.3	0.1	1.6	NA	0.7	0.3	1.5	0.1	0.2	3.2	2.3	0.7	12.0
O	0.1		0.1		NA					0.2			0.4

(Continued)

**Table 15.8** Bilateral trade flows in the reference case (billion US\$)—cont'd

C	0.4	0.3	0.1	0.4	0.8	NA	0.3		0.1	0.9	0.2		3.7
I			0.1	0.1			NA		0.2	0.1		0.1	0.5
M	1.1		0.1	0.1			0.1	NA	0.1	0.2			1.8
V	0.1		0.1	0.1			0.1		NA				0.4
L	1.4	0.7	0.5	3.9	2.6	0.5	0.9		0.4	NA	1.1	0.8	12.9
B				0.6		0.1	0.1		0.1	0.4	NA		1.2
P	0.1			0.3			0.2			0.2	0.1	NA	1.1
Sum	6.8	1.2	4.5	6.5	5.8	1.4	4.2	1.1	1.9	7.7	3.9	2.7	47.8

**Industry 7: Agriculture**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA	0.1	5.7	2.7	0.3	0.6	1.8	4.3	5.9	4.0	0.2	0.4	25.8
J	11.8	NA	1.4	1.4	1.1	3.0	0.5		0.8	3.2	0.1	0.2	23.5
N	4.7		NA	0.3	0.1	0.1	0.1		0.4	0.4			6.2
E	11.3	0.1	1.4	NA	0.5	1.5	4.7	0.4	8.5	15.3	4.0	1.2	48.9
O	0.3			0.2	NA	0.1	0.1			0.5			1.2
C	1.5		1.3	0.2	0.1	NA			0.3	0.9			4.4
I	0.3		0.2	0.1			NA		0.4				1.1
M	8.3		0.6	0.2			0.1	NA	0.1	0.1			9.4
V	4.8		0.5	0.5		0.1	0.3	0.2	NA	0.3		0.2	6.8
L	16.3	0.2	0.7	4.1	9.5	2.7	1.2		0.4	NA	1.1	0.7	36.8
B	0.8		0.1	5.7		0.3	0.4		1.3	1.7	NA	0.2	10.5
P	1.7		1.3	1.4	0.5	0.2	0.2		0.2	3.1	0.1	NA	8.6
Sum	61.8	0.5	13.1	16.7	12.1	8.5	9.4	5.0	18.3	29.4	5.6	2.9	183.3

**Industry 8: Forestry**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA		17.2	0.9	0.1	0.2	0.5	0.8	0.3	2.1	0.1	2.3	24.6
J	4.1	NA	2.8	0.7	1.1	0.8	0.1			4.6	0.6	2.8	17.7
N	2.3		NA	0.1						0.2		0.2	2.8
E	2.0		0.9	NA		0.3	0.6		0.2	5.5	6.5	1.5	17.7
O	0.1		0.1	0.2	NA					0.3		0.2	0.9
C	0.1			0.1		NA				2.2	0.1	0.4	3.0
I							NA		0.1	0.2			0.3
M	0.8							NA	0.1			0.1	1.2
V	0.9			0.1			0.1		NA	0.1		0.1	1.3
L	1.0	0.1	0.3	1.7	0.6	0.7	0.2		0.1	NA	0.7	2.5	7.9
B	0.1			1.0						0.2	NA	0.1	1.4
P	0.3		0.1	0.7						0.4	0.1	NA	1.7
Sum	11.9	0.2	21.6	5.5	1.9	2.1	1.5	0.9	0.8	15.8	8.0	10.3	80.5

**Industry 9: Durables**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA	145.3	161.3	168.3	2.4	25.9	7.2	92.1	4.4	164.7	7.5	4.3	783.5
J	45.5	NA	1.2	34.9	2.1	13.1	1.5	0.8	0.4	59.0	2.3	2.0	162.6

*(Continued)*



**Table 15.8** Bilateral trade flows in the reference case (billion US\$)—cont'd

N	135.0	6.6	NA	12.8	0.2	1.4	0.3	3.2	0.1	5.6	0.3	0.2	165.7
E	132.1	87.6	8.5	NA	2.5	17.3	4.3	2.6	2.6	139.6	52.5	3.5	453.1
O	15.1	11.3	0.7	18.2	NA	1.2	0.2			12.6	0.1	0.3	59.7
C	9.9	25.2	0.7	20.8	0.4	NA	0.4			18.4	4.9	0.2	80.8
I	17.9	4.3	0.6	19.6	0.1	0.9	NA	1.4	0.6	6.3	0.2	0.2	52.2
M	114.2	11.4	1.5	15.2		0.4	1.3	NA	0.4	6.4	0.2	0.4	151.5
V	15.2	11.8	0.8	10.7		0.8	3.0	2.1	NA	8.7	0.7	1.3	55.1
L	130.6	223.6	4.7	302.6	12.2	45.8	3.4	1.5	0.9	NA	15.2	9.4	749.9
B	5.0	2.7	0.6	82.1		0.8	0.1	0.3		11.8	NA	0.3	103.6
P	21.8	20.9	1.3	40.7	1.6	2.4	0.8	0.5	0.8	16.2	1.6	NA	108.7
Sum	642.2	550.6	181.9	726.0	21.6	109.9	22.4	104.4	10.2	449.4	85.6	22.2	2,926.4

**Industry 10: Non-durables**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA	18.2	67.8	63.3	2.7	15.8	4.0	15.5	11.9	54.0	2.7	6.2	262.2
J	27.3	NA	3.5	30.4	5.5	23.6	1.2	0.2	0.6	29.6	0.6	3.3	125.8
N	44.2	0.6	NA	7.5	0.6	0.9	0.2	0.2	0.6	3.5	0.2	0.2	58.6
E	54.5	15.6	6.4	NA	6.9	13.9	7.1	1.4	5.1	87.3	36.8	8.5	243.4
O	5.8	1.6	0.5	8.3	NA	1.6	0.2		0.1	5.3		0.8	24.2
C	6.4	9.6	1.2	7.3	2.2	NA	1.0		0.8	20.2	3.0	1.2	52.8
I	4.5	0.5	0.5	5.0	0.2	0.4	NA	0.3	1.4	1.4	0.2	0.2	14.7
M	37.4	0.6	0.4	6.1	0.4	0.2	0.2	NA	0.7	1.6	0.1	0.1	47.8
V	27.4	0.6	1.0	10.6	0.5	1.4	3.1	2.5	NA	4.4	0.3	1.8	53.6
L	43.4	42.6	4.3	174.9	16.5	39.2	3.5	0.4	1.2	NA	24.8	12.6	363.4
B	4.8	0.3	0.3	57.0	0.3	3.4	0.9		0.2	8.7	NA	0.7	76.7
P	5.8	3.4	0.6	15.8	2.0	1.5	0.9	0.2	0.9	10.9	0.4	NA	42.4
Sum	261.4	93.6	86.4	386.2	37.9	101.9	22.2	20.8	23.4	226.8	69.2	35.7	1,365.5

**Industry 11: Transportation**

	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA	7.3	2.4	41.9	3.7	2.7	0.5	1.7	2.3	25.5	5.6	6.6	100.1
J	12.6	NA	1.8	18.7	1.7	1.5	0.3	1.4	1.5	11.0	3.0	3.6	57.0
N	3.3	1.1	NA	4.3	0.4	0.3	0.1	0.3	0.3	2.0	0.6	0.7	13.3
E	59.3	22.0	6.8	NA	6.4	12.2	1.8	4.5	6.3	46.5	12.9	11.6	190.3
O	2.8	1.0	0.3	4.0	NA	0.3	0.1	0.2	0.2	2.2	0.5	0.5	12.1
C	2.4	0.7	0.3	7.3	0.3	NA	0.1	0.2	0.3	3.8	0.6	0.8	16.8
I	1.9	0.7	0.2	3.6	0.2	0.4	NA	0.1	0.2	1.8	0.4	0.5	10.2
M	1.9	0.8	0.3	4.1	0.2	0.3		NA	0.3	1.4	0.5	0.4	10.1
V	2.8	1.1	0.3	4.6	0.3	0.3	0.1	0.2	NA	2.2	0.5	0.5	13.0
L	13.4	6.2	1.7	23.6	1.3	3.1	0.8	1.1	1.4	NA	2.9	2.8	58.3
B	5.2	1.7	0.6	7.8	0.5	0.8	0.1	0.4	0.5	4.2	NA	1.1	22.9
P	5.4	2.5	0.7	8.7	0.5	1.2	0.3	0.4	0.5	4.7	1.1	NA	25.9
Sum	111.0	45.0	15.3	128.5	15.6	23.0	4.3	10.5	13.8	105.3	28.5	29.1	530.0

*(Continued)*

**Table 15.8** Bilateral trade flows in the reference case (billion US\$)—cont'd

Industry 12: Services													
	U	J	N	E	O	C	I	M	V	L	B	P	Sum
U	NA	4.9	3.6	49.2	1.9	0.5	1.0	0.5	1.8	21.7	3.2	6.0	94.2
J	12.4	NA	0.3	23.0	1.0	0.5	0.2	0.2	0.6	6.3	1.8	1.8	48.0
N	6.4	0.4	NA	11.6	0.3	0.1	0.3	0.1	0.2	6.3	0.8	1.3	27.8
E	79.8	20.0	10.5	NA	4.7	2.1	2.1	1.1	2.9	52.8	10.3	11.1	197.4
O	2.2	0.5	0.2	3.8	NA		0.1		0.1	1.5	0.3	0.3	9.0
C	2.2	0.9	0.1	4.3	0.2	NA			0.1	1.4	0.4	0.4	10.1
I	2.5	0.3	0.4	3.7	0.1		NA		0.1	2.1	0.3	0.5	10.1
M	3.7	0.9	0.2	7.9	0.3	0.1	0.1	NA	0.3	1.7	0.5	0.4	16.2
V	3.1	0.7	0.3	4.5	0.2	0.1	0.1	0.1	NA	1.6	0.3	0.4	11.4
L	25.8	5.7	4.1	39.5	1.4	1.0	1.2	0.5	1.0	NA	3.0	3.9	87.1
B	7.4	2.1	1.1	14.2	0.4	0.2	0.2	0.1	0.3	5.2	NA	1.1	32.4
P	23.3	2.5	2.4	20.5	0.7	0.4	0.7	0.3	0.6	9.9	1.4	NA	62.8
Sum	168.9	39.0	23.0	182.3	11.2	5.1	6.0	3.0	8.0	110.4	22.4	27.2	606.6

The row sums in Table 15.8 show the total value of imports of the good by each region; the sum of the 'U' row in panel 5, for example, shows that total US imports of crude oil from all of its trading partners were worth \$96.2 billion. The column sums show the total value of exports of the good from each region; the sum of the 'P' column of panel 5 shows that total crude oil exports from OPEC were worth \$156.4 billion. The value in the lower right corner of each panel shows the total US dollar value of trade in the good; in panel 5, the value is \$297.4 billion.

The model's 12 goods fall into three distinct categories in terms of the total dollar value of trade. Six sectors each account for less than \$100 billion: electricity (\$5 billion), natural gas delivered by utilities (\$12 billion), refined petroleum products (\$86 billion), coal (\$22 billion), non-fuel mining (\$48 billion) and forestry (\$80 billion). At the opposite extreme, two sectors each account for more than a trillion dollars: durables (\$2926 billion) and non-durables (\$1365 billion). The remaining four sectors fall in between: crude oil and natural gas (\$297 billion), agriculture (\$183 billion), transportation (\$530 billion) and services (\$607 billion). The overwhelming importance of durables is emphasized by the fact that shipments from Europe (column 'E') to developing countries (row 'L') — a single entry in the trade matrix for durables — are worth \$303 billion, or more than the total value of world trade in the six least-traded goods.

In order to evaluate subsequent simulations, it is useful to group the model's regions into three aggregates: (i) the NAFTA countries: the US, Canada, Mexico;<sup>45</sup> (ii) the other

<sup>45</sup> The NAFTA aggregate region is defined to be the US, Canada and Mexico whether or not NAFTA is actually in force.

potential participants in the FTAA: Brazil and the Rest of Latin America; and (iii) the Rest of the World: Japan, Europe, the Rest of the OECD, China, Eastern Europe and the Former Soviet Union, OPEC, and other developing countries. Table 15.9 shows the dollar value of trade flows within and between each of these aggregates.<sup>46</sup> As in the detailed bilateral trade matrices, the column indicates the source of each trade flow and the row indicates its destination. For example, the entry in the 'ROW' column and 'NAFTA' row for crude oil and natural gas (good 5) shows that the US, Canada and Mexico together import \$66 billion worth of crude oil and natural gas from the countries comprising ROW. The entry in the 'NAFTA' column and 'NAFTA' row, in contrast, shows the value of trade in crude oil and gas *among* the NAFTA countries. These aggregate regions will be used to assess the overall effects of NAFTA or the FTAA on the value of trade within the free trade area and between the trade area and the rest of the world.

#### **15.4.2.5 Immediate tariff reductions under NAFTA**

As discussed earlier, there is an empirical literature suggesting that tariff reform and increased international trade stimulate productivity growth. There are many mechanisms by which this could occur. Industries previously protected by high tariffs and now faced with increased competition would almost certainly undertake cost-cutting measures and shift toward global best practices in production. Lower trade barriers on durables would also allow a freer flow of new technology and embodied technical change.

To incorporate this effect, we assume that when tariffs are reduced, previously protected industries are able to make modest improvements in productivity in response. In particular, we assume they are able to reduce their costs by a percentage equal to half of the change in their tariff, or by 5%, whichever is smaller. For example, the Canadian tariff on durables is initially 4.14% so under this assumption trade reform would lead to a 2.07% improvement in the productivity of the Canadian durables sector. In contrast, the Mexican tariff on durables is initially 11.3% so the corresponding industry's productivity improvement would be limited to 5%.

The full set of productivity shocks used in this section is shown in Table 15.10. Under the NAFTA-p simulation, tariffs are reduced to zero on trade between the US, Canada and Mexico, and industries in those three countries receive the productivity improvements listed in Table 15.10. The FTAA-p simulation is similar to NAFTA-p, but also includes Brazil and the Rest of Latin America. In both cases, it is important to note that the productivity shocks are one-time changes in productivity levels, not changes in the rate of productivity growth. They are very modest effects in the sense that they correspond to at most 2–3 years of ordinary productivity improvements. On the other hand,

<sup>46</sup> Table 15.9 was computed by summing the corresponding flows in the detailed bilateral trade matrix.

**Table 15.9** Value of trade flows between regions in the reference case: column shows source and row shows destination (billions US\$; values <1 omitted)

	NAFTA	B&R	ROW
1 Electric Utilities			
NAFTA	2		
B&R			
ROW			3
2 Gas Utilities			
NAFTA	3		
B&R			
ROW			8
3 Refining			
NAFTA	7	3	9
B&R	2		4
ROW	7	1	54
4 Coal			
NAFTA	2		
B&R			1
ROW	3	1	14
5 Crude Oil and Gas			
NAFTA	31	6	66
B&R	1		16
ROW	3	1	174
6 Mining			
NAFTA	6	1	3
B&R			
ROW	6	5	26
7 Agriculture			
NAFTA	24	8	9
B&R	6	1	1
ROW	50	19	65
8 Forestry			
NAFTA	21	1	6
B&R	1		1
ROW	12	1	37
9 Durables			
NAFTA	507	14	580
B&R	38	4	66
ROW	383	15	1320
A Non-durables			
NAFTA	166	18	186
B&R	36	5	27
ROW	167	24	738

*(Continued)*

**Table 15.9** Value of trade flows between regions in the reference case: column shows source and row shows destination (billions US\$; values <1 omitted)—cont'd

	NAFTA	B&R	ROW
B Transportation			
NAFTA	10	3	110
B&R	6		17
ROW	121	14	248
C Services			
NAFTA	15	4	120
B&R	6		15
ROW	174	10	263

they do not include the effect of any adjustment costs or investment that might arise as the protected industries adapt. Thus, they allow us to gauge the importance of productivity changes over the medium to long run but are not a precise prediction.

Table 15.11 shows the effect of NAFTA-p on output, exports and capital stocks by sector and region in year 12. The results are percentage changes relative to the reference case. Entries with changes greater than or equal to 1% in magnitude are given in italics and those with changes less than 0.1% in magnitude are left blank. As would be expected, the reduction in tariffs leads to an increase in trade among NAFTA countries. Exports from the US, Canada and Mexico increase significantly.

**Table 15.10** Potential productivity gains, by country and industry (%)<sup>a</sup>

	Region											
	U <sup>N,F</sup>	J	N <sup>N,F</sup>	E	O	C	I <sup>F</sup>	M <sup>N,F</sup>	V <sup>F</sup>	L	B	P
Electric utilities									0.01			
Gas utilities												
Petroleum refining			1.98				1.73	2.42	2.36			
Coal mining								2.73	0.76			
Crude oil and gas extraction							2.43		1.76			
Other mining	0.19						0.79	3.98	1.49			
Agriculture			4.08				<i>5.00</i>	<i>5.00</i>	2.40			
Forestry and wood products			1.47				<i>5.00</i>	<i>5.00</i>	<i>5.00</i>			
Durable goods			0.77				<i>5.00</i>	4.35	<i>5.00</i>			
Non-durables			<i>5.00</i>				3.49	<i>5.00</i>	4.15			
Transportation									0.60			
Services									1.42			

Productivity gains that were capped at 5% are shown in italic.

<sup>N</sup>Member of NAFTA

<sup>F</sup>Member of the FTAA.

**Table 15.11** Changes in output, exports and capital stocks: NAFTA-p versus reference case (% change)

	US	Japan	Canada	Europe	ROECD	China	Brazil	Mexico	RLA	LDC	EEFSU	OPEC
<i>Panel 1: Industry output in 2015</i>												
Electric utilities	0.3		-0.2	0.1				1.0		0.1		0.1
Gas utilities	0.3		-0.4	0.1				0.3				0.1
Petroleum refining	0.8	0.1	2.1	0.2	-0.1	0.1	0.1	2.2	0.1	0.2		
Coal mining	0.3	-1.1	2.4					1.9	0.2	0.1		-0.3
Crude oil and gas extraction	0.2	-0.1	0.6					4.6				
Other mining	0.6	-0.1	2.3	-0.1	0.1			2.4	-0.1			
Agriculture	1.0		9.1	0.2	0.2	0.2	0.1	4.3	0.2	0.2		0.1
Forestry and wood products	0.6	0.1	5.0	0.2	0.1	0.1	0.1	2.4		0.2		0.3
Durable goods	0.6	0.1	2.1	0.1	0.1			5.0	-0.1	0.1		
Non-durables	1.0	0.2	11.4	0.2	0.2	0.2	0.1	5.5	0.1	0.2		0.2
Transportation	0.2	0.1	1.2	0.1		0.1	0.1	1.2	0.1	0.1		0.1
Services	0.1		-3.1			-0.1		-3.6	-0.1		-0.1	
<i>Panel 2: Exports in 2015</i>												
Electric utilities	-7.1		3.5	-1.2		1.4		40.0				
Gas utilities			0.4									
Petroleum refining	1.3		7.9	-0.1			-1.3	4.6			0.1	-0.1
Coal mining	-0.3		4.7		0.1	-0.4		0.0	1.1			
Crude oil and gas extraction	0.5		2.1	-0.4	0.3			7.4	0.8	-0.1		
Other mining	0.5		5.0		0.2			7.8		-0.3		

Agriculture	2.7	2.3	12.5	0.7	0.4	0.6	0.4	8.9	2.2	0.3	0.2	0.4
Forestry and wood products	2.5		11.5	1.6	0.9	0.8	1.3	10.9	1.6	0.6	0.5	1.0
Durable goods	2.4	0.2	6.9	0.1	0.4	0.2	0.2	8.6	1.1	0.2	0.2	0.3
Non-durables	5.3	0.8	18.5	0.5	0.5	0.5	0.6	11.9	2.6	0.5	0.3	0.6
Transportation	-0.2	-0.3	4.6	-0.4	-0.1	-0.2	0.1	5.5	1.1	-0.2	-0.1	-0.1
Services	-0.1	-0.4	1.0	-0.9	-0.2	-0.4	-0.1	1.1	0.5	-0.5	-0.3	-0.4
<i>Panel 3: Capital stocks in 2015</i>												
Electric utilities	0.3		-1.0			-0.1		-8.8	-0.1	0.1	-0.1	0.1
Gas utilities	0.3		-2.1			-0.1		-4.1	-0.1			0.1
Petroleum refining	0.2		-3.2		-0.1			-5.6	-0.1	0.1		
Coal mining	0.4	-0.2	2.3					1.5	0.2			
Crude oil and gas extraction	0.3	-0.1	0.1					7.1				
Other mining	0.4	-0.1	2.3					1.5	-0.1		-0.1	0.1
Agriculture	0.7	-0.1	1.4	0.1	0.2	0.2	0.1	4.8	0.1	0.3		0.2
Forestry and wood products	0.5	-0.1	3.5	0.2	0.3	0.1	0.1	-0.4		0.2		0.3
Durable goods	0.4		-4.4					1.3	-0.2	0.1	-0.1	
Non-durables	0.8	0.1	2.4	0.2	0.1	0.1	0.1	3.7		0.3		0.2
Transportation	0.3		1.4	0.1		0.1	0.1	2.4	0.1	0.1		0.1
Services	0.3	-0.1	-5.8		-0.1	-0.2		-10.8	-0.2		-0.1	

Exports of durables (panel 2) rise by 2.4% in the US, 6.9% in Canada and 8.6% in Mexico. Exports of non-durables increase even more because tariffs on non-durables are initially higher and hence fall more dramatically under a free trade agreement (the high tariffs on non-durables largely reflects the high levels of protection on textiles and apparel). Exports of non-durables rise by 5.3% in the US, 18.5% in Canada and 11.9% in Mexico.

The increase in trade raises the level of output of all industries in the US (panel 1), albeit by very small percentages in most cases. The corresponding capital stocks rise as well (panel 3). The output of almost all Canadian industries increases, as does the output of most Mexican industries. A notable exception is services (sector C) for both Canada and Mexico: output of services falls under NAFTA-p even though exports of services rise slightly in percentage terms due to the change in exchange rates (as well as increased demand for services in other countries that expand as a result of the policy). The reason is straightforward: the price of services rises, in part because the traded sectors grow and consume more labor, and in part because depreciation of the exchange rate raises the price of imported intermediate goods other than those whose tariffs have been cut. This effect is a recurring theme in the results and can be seen clearly in Figure 15.9, which

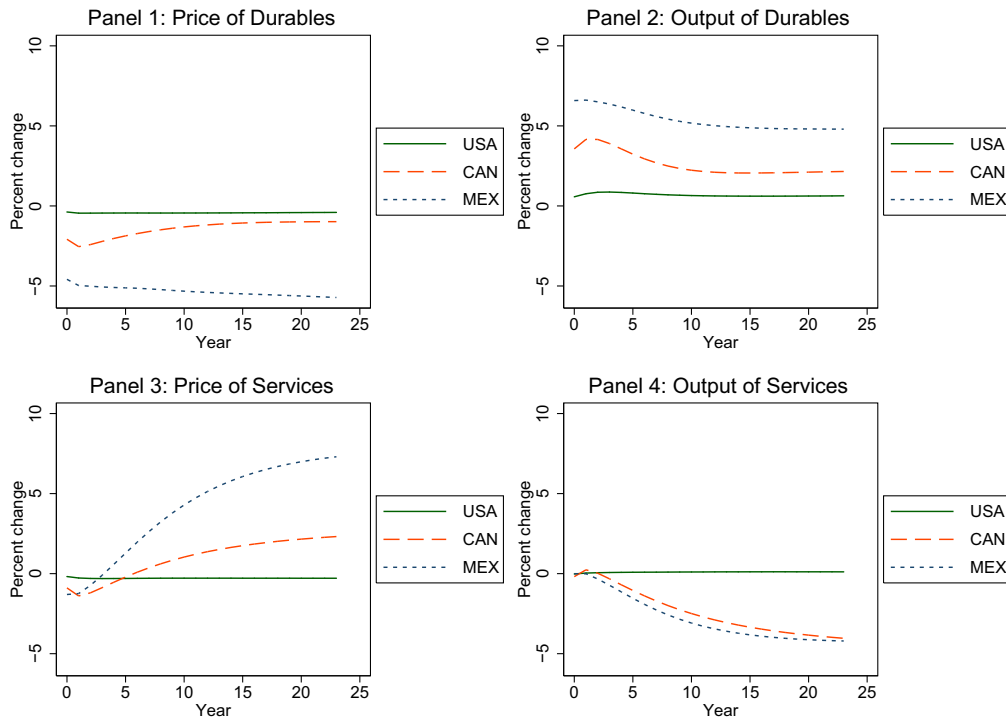


Figure 15.9 Selected industry prices and output: NAFTA-p versus reference case.



shows percentage changes from the reference case in selected industry prices and quantities over time for the US, Canada and Mexico.

The total value of the trade flows among NAFTA regions increases as shown in Table 15.12 (which also includes results for the FTAA, which will be discussed below). The value of trade in durables among NAFTA regions, for example, increases by \$16 billion, while the value of trade in non-durables increases by \$14 billion. Comparing the magnitudes of the within-NAFTA flows with those between NAFTA and the rest of the world shows that NAFTA clearly increases trade rather than just redirecting it. In fact, the increase in economic activity stimulated within NAFTA actually causes aggregate NAFTA imports of both durables and non-durables from the rest of the world to rise. Summing across goods and regions, NAFTA raises the total dollar value of trade flows in year 12 by \$50 billion.

The effects of NAFTA-p on trade and selected macroeconomic variables are shown in Figure 15.10. The reduction in tariffs in Canada and Mexico causes the demand for imports in those regions to increase, leading to depreciation of the two exchange rates relative to the US dollar.<sup>47</sup> The trade balances in the US, Canada and Mexico initially move toward deficit. The trade balances for Brazil and the Rest of Latin America (as well as most other regions, although they are omitted from the graph) move toward surplus as imports by the US, Canada and Mexico rise. Over time, however, the Canadian and Mexican trade deficits accumulate into increased stocks of foreign debt. The higher debt levels require larger interest payments, which consume an increasing share of each country's current account and eventually force the trade balance back toward surplus. This mechanism is made even stronger by the effect of exchange rates on each country's initial stocks of foreign debt. In particular, the depreciation of the Canadian and Mexican currencies relative to the US dollar increases the burden of servicing their US dollar denominated foreign debt.

The reduction in tariffs also has an important fiscal effect: by reducing government revenue it increases the fiscal deficit in each region. The effect is very small in the US because tariff revenue is a small part of the government budget but it is significant in Canada and Mexico. In the short run, the reduction in tariffs functions as a fiscal stimulus. This effect would be significantly different under alternative monetary and fiscal assumptions. For example, other taxes could be raised to compensate for the reduction in tariff revenue, or government spending could be cut. In addition, monetary policy could be altered — in these simulations the money supply has been held constant at its base case value. Either policy could reduce or eliminate the macroeconomic effects caused by the increase in the fiscal deficit.

<sup>47</sup> In G-Cubed, exchange rates are defined as the number of US dollars per unit of foreign currency. A decline in the exchange rate is a reduction in the number of dollars per unit of foreign currency and hence a depreciation of the currency.

**Table 15.12** Change in aggregate trade flows under NAFTA-p and FTAA-p: column shows source and row shows destination (billions US\$; values <0.1 billion omitted)

Good	Destination	NAFTA-p change from base			FTAA-p change from NAFTA-p		
		NAFTA	B&R	ROW	NAFTA	B&R	ROW
Electric utilities	NAFTA						
	B&R						-0.11
	ROW						
Gas utilities	NAFTA						
	B&R						
	ROW						
Petroleum refining	NAFTA	0.21					
	B&R				-0.11		-0.46
	ROW			0.18			
Coal mining	NAFTA						
	B&R						
	ROW						
Crude oil and gas extraction	NAFTA	0.14					
	B&R						-0.74
	ROW			0.42			-0.17
Other mining	NAFTA						
	B&R						
	ROW						
Agriculture	NAFTA	1.01	0.17	0.12		0.50	
	B&R				0.34	0.33	
	ROW	0.12		0.34	0.10	-0.59	0.20
Forest and wood products	NAFTA	1.13		0.24	0.24		
	B&R						
	ROW	0.16		0.20			
Durable goods	NAFTA	16.11		2.98	1.06		1.45
	B&R	-0.20		-0.18	-0.11	-0.20	-8.61
	ROW	1.27		3.15	-0.33	-0.32	-0.83
Non-durables	NAFTA	14.04	0.37	3.74	0.64	0.88	1.09
	B&R			0.37	1.39		-1.59
	ROW			2.40		-1.12	-0.14
Transportation	NAFTA	-0.28		-0.47		0.12	0.24
	B&R			-0.10	-0.56		-1.92
	ROW			0.50	-0.25	0.57	-0.22
Services	NAFTA	-0.55		-1.86			0.34
	B&R			-0.13	-0.65		-2.01
	ROW	0.54		0.59	-0.23	0.14	

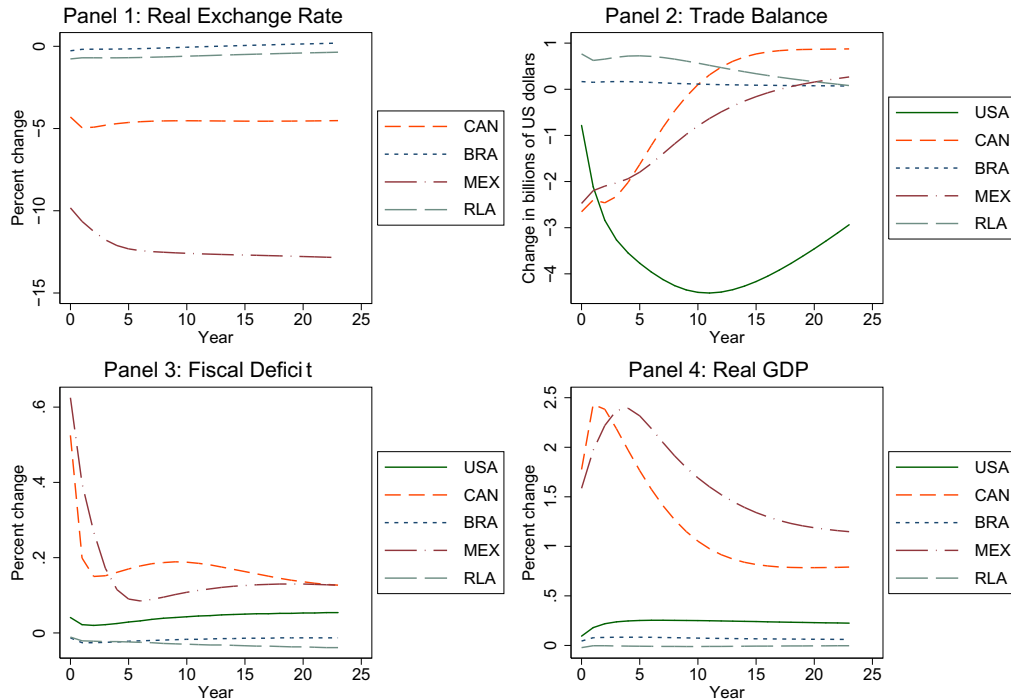


Figure 15.10 Trade accounts and macroeconomic variables: NAFTA-p versus reference case.

#### 15.4.2.6 Immediate tariff reductions under FTAA

Table 15.13 shows the effect of FTAA-p relative to NAFTA-p on output, exports and capital stocks by industry and region for year 12. The results are percentage changes relative to the NAFTA-p simulation; as before, entries with changes greater than or equal to 1% in magnitude are given in italics and those below 0.1% are left blank. The general nature of the results is highly analogous to those for NAFTA-p: the effect of the FTAA on Brazil (I) and the rest of Latin America (V) is very much like the effect of NAFTA-p on Canada and Mexico. The main difference is that the percentage changes tend to be larger in magnitude for Brazil and the Rest of Latin America. For most industries, output, exports and capital stocks all increase substantially. This can be seen graphically in Figure 15.11, which shows the effects of FTAA-p relative to NAFTA-p on selected industry prices and output for all regions. In general, prices fall significantly in Brazil and the Rest of Latin America, and output rises accordingly. As with NAFTA-p relative to the reference case, service sector output falls in Brazil and the Rest of Latin America; however, the magnitude is relatively small.

The value of trade flows between aggregate regions is shown in Table 15.12 above. The most notable result is a pronounced decline in imports of durables from non-

**Table 15.13** Changes in output, exports and capital stocks: FTAA-p versus NAFTA-p (% change)

	US	Japan	Canada	Europe	ROECD	China	Brazil	Mexico	RLA	LDC	EEFSU	OPEC
<i>Panel 1: Industry output in 2015</i>												
Electric utilities	0.1	0.1	0.1	0.2	0.1		0.6	0.1	-0.6	0.3		0.1
Gas utilities	0.1		0.2	0.1		0.7	1.1	0.1	-0.1	0.3		0.1
Petroleum refining	0.3	0.1	0.1	0.1	0.2	0.1	4.0	0.1	3.5	0.4	-0.1	-0.2
Coal mining			-0.2	-0.2			16.7		3.9	0.2		0.3
Crude oil and gas extraction	0.1	0.2		0.2	0.1		5.2	-0.1	3.2	0.2	-0.1	-0.1
Other mining		-0.2	-0.3	-0.1	-0.1	0.1	5.0	0.1	5.2	0.3	0.1	0.1
Agriculture	0.2	-0.1	0.5	0.1	0.1	0.1	9.5	0.1	5.5	0.2		0.1
Forestry and wood products	0.3	0.3	0.3	0.3	0.2	0.1	8.3	0.1	8.9	0.4	0.1	0.2
Durable goods	0.1		0.2	0.2	0.1	0.1	6.4	0.2	5.3	0.2		0.1
Non-durables	0.3	0.2	0.3	0.3	0.1	0.1	9.6	0.2	8.2	0.2	0.1	0.1
Transportation				0.1		0.1	3.5	0.1	3.8	0.2		0.1
Services	0.1	0.1	0.1	0.2	0.1	0.1		0.1	-1.2	0.4		0.2
<i>Panel 2: Exports in 2015</i>												
Electric utilities	-3.8		-0.5	-2.4		-1.4		-28.6		-10.0	-2.6	-9.1
Gas utilities										-0.6		
Petroleum refining	-0.6	0.5	-1.0	-0.2	0.7	-0.5	5.3		14.6	-0.1	-1.6	-1.1
Coal mining	-1.0		-0.5						16.1			
Crude oil and gas extraction			-0.2	0.1			100.0	-0.2	11.3		-1.0	-0.1
Other mining	-0.9		-0.6	0.3	-0.3		7.0		22.3	-0.2	-0.3	

Agriculture	1.0		1.7	1.4	0.3	0.6	10.4	0.4	22.4	0.2	0.6	
Forestry and wood products	0.9	5.3	0.5	0.6	0.4	0.4	11.0	0.4	22.2	0.1	0.6	0.5
Durable goods	0.1	-0.2	0.2	-0.3	0.1	0.1	11.1	0.3	12.1	-0.3		-1.0
Non-durables	0.8	0.3	0.5	0.2	0.1	0.2	10.1	0.6	24.6	0.1	0.3	0.1
Transportation	-0.7	-0.4	-0.8	-0.6	-0.2	-0.2	5.8	-0.1	19.0	-0.4	-0.1	-0.1
Services	-0.4	-0.2	-0.5	-0.3	-0.2	-0.2	4.4	-0.2	11.3	-0.2		
<i>Panel 3: Capital stocks in 2015</i>												
Electric utilities	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.3	-2.2	0.5	0.1	0.3
Gas utilities	0.2	0.1	0.2	0.2	0.1		-0.5	0.2	-1.8	0.3	0.1	0.2
Petroleum refining	0.1	0.1	0.2	0.1	0.2		-0.1	0.2	-1.3	0.3		
Coal mining	0.1	0.1	-0.1	0.1		0.1	6.0	0.2	4.9	0.3	0.1	0.3
Crude oil and gas extraction	0.2	0.1		0.2	0.2	0.1	0.4	-0.1	1.2	0.3	-0.2	-0.1
Other mining	0.1		-0.2	0.1	-0.2	0.1	9.0	0.3	3.7	0.3	0.1	0.1
Agriculture	0.1	-0.1	0.4	0.1	0.2	0.1	7.3	0.4	3.8	0.5		0.3
Forestry and wood products	0.4	0.2	0.5	0.4	0.3	0.2	6.2	0.2	3.0	0.5	0.1	0.3
Durable goods	0.2	0.1	0.3	0.3	0.2	0.1	1.6	0.4	-3.5	0.3	0.1	0.4
Non-durables	0.2	0.1	0.3	0.2	0.1	0.1	8.1	0.3	3.2	0.3	0.1	0.2
Transportation	0.1	0.1	0.1	0.2	0.1	0.1	6.3	0.2	3.8	0.3	0.1	0.1
Services	0.3	0.2	0.3	0.3	0.3	0.1	-0.7	0.4	-4.6	0.8	0.1	0.5

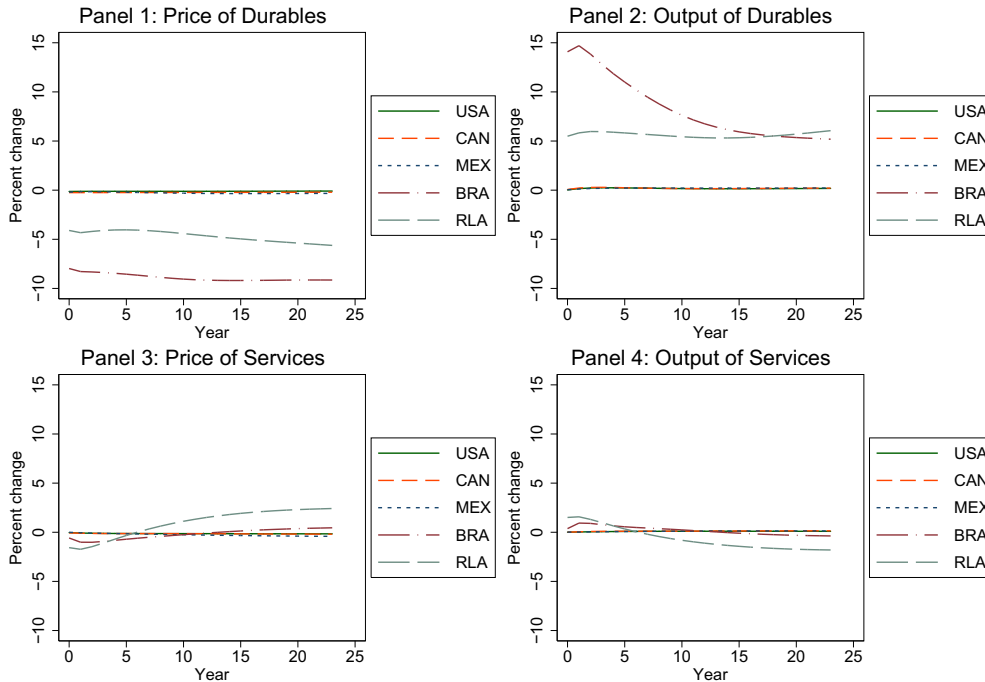
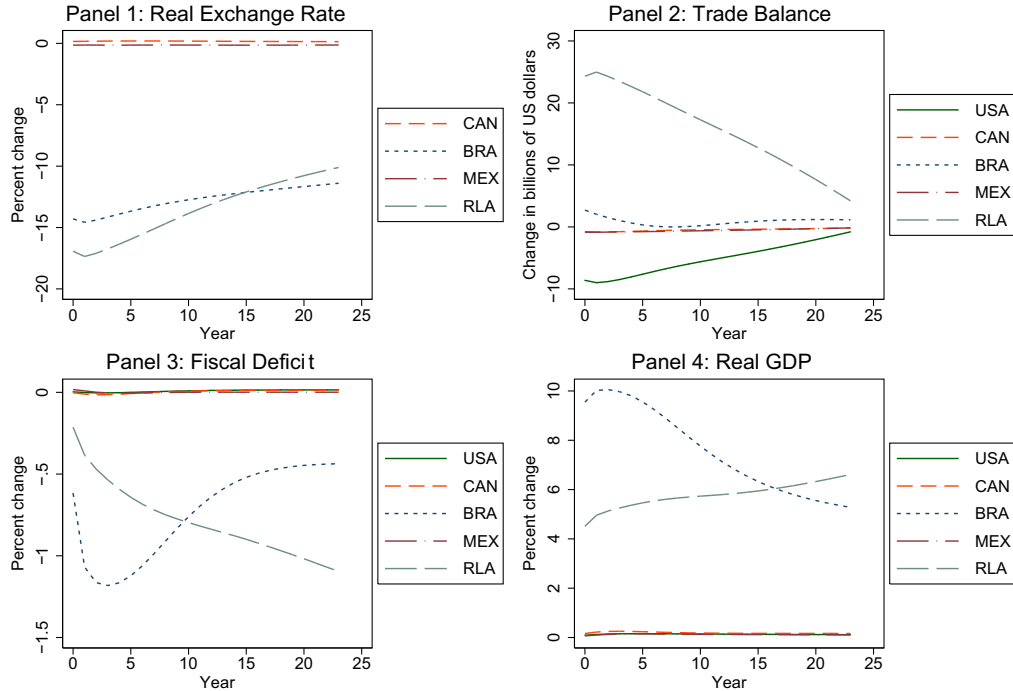


Figure 15.11 Changes in industry prices and output: FTAA-p versus NAFTA-p.

FTAA countries by Brazil and the Rest of Latin America. The effects on trade and macroeconomic variables are shown in Figure 15.12. The productivity improvements in Brazil and the Rest of Latin America cause several dramatic changes. Production costs fall by enough in the Rest of Latin America that exports boom and the trade balance and current account move sharply toward surplus. The economies of Brazil and the Rest of Latin America both expand enough to raise tax revenue above its value in the NAFTA-p simulation — despite the decrease in tariff revenue — and shift the corresponding fiscal deficits toward surplus (i.e. the magnitudes of the fiscal deficits fall). Consumption rises substantially and the price of new investment goods drops. Real investment rises and the GDP of both economies is about 6% larger in the long run.

#### 15.4.2.7 Anticipated tariff reductions under FTAA

The final simulation was an anticipated implementation of the FTAA: the agreement was announced in the first year of the simulation but took effect in the fifth year. To distinguish it from the previous FTAA simulation, this version will be denoted FTAA5-p where the '5' indicates that implementation of the agreement is anticipated 5 years in advance. The effects of the anticipated FTAA will be equal to the differences between the



**Figure 15.12** Trade accounts and macroeconomic variables: FTAA-p versus NAFTA-p.

FTAA5-p simulation and a counterfactual NAFTA simulation, NAFTA5-p, in which NAFTA was announced 5 years before its implementation.<sup>48</sup>

When the FTAA is announced in advance, Figure 15.13 shows that very large anticipatory changes occur in exchange rates, trade accounts and macroeconomic variables. The key mechanism by which this occurs is the real exchange rate, which can be shown to be the price to foreigners of a given country’s domestic assets. When the FTAA is implemented, real exchange rates for Brazil and the Rest of Latin America will drop sharply for the reasons discussed in the previous section. Investors anticipating the fall will be less willing to hold Brazilian and Latin American assets in advance, even at the beginning of the simulation. As a result, exchange rates for Brazil and Latin America deteriorate immediately. Financial capital flows out of those regions and into the US and other large economies, whose trade balances deteriorate as a result. Investment, labor demand, GDP and consumption all decline in Brazil and the Rest of Latin America

<sup>48</sup> This approach is used for the same reason that other FTAA simulations are compared to analogous NAFTA runs: the model’s internal structure does not currently allow the size of a free trade area to change in the middle of a simulation. In the two simulations discussed in this section, either NAFTA or the FTAA is adopted immediately but remains dormant for 5 years. During that time, tariffs on imports from trade area partners remain the same as tariffs on other imports. This approximates an anticipated introduction of the FTAA.

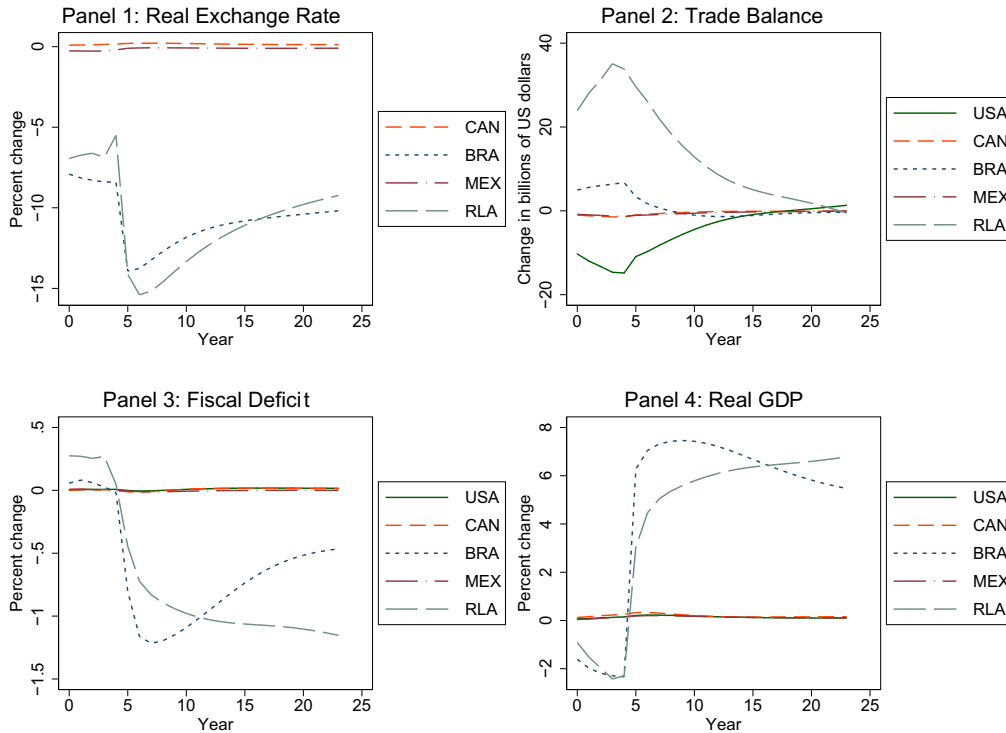


Figure 15.13 Trade accounts and macroeconomic variables: FTAA 5-p versus NAFTA5-p.

during the period of anticipation and then rebound after implementation. By year 12, output levels, exports and capital stocks become similar to those from the unanticipated FTAA, as can be seen in Table 15.14.

**15.4.2.8 Effect of trade agreements on carbon emissions**

Finally, Figure 15.14 shows the effect of each of the simulations on total carbon dioxide emissions from key regions. In keeping with the modest effects of NAFTA and the FTAA on industry output and GDP, the effect on carbon emissions is relatively small; in most cases, the change is 1–2% of emissions in the reference case. The only exception is the FTAA5-p experiment, which causes emissions to change by more than 3% in some years.

**15.4.2.9 Summary**

The overall effects of the FTAA are highly analogous to NAFTA, but smaller in magnitude. Countries reducing their tariffs see imports rise, exchange rates fall, trade balances move toward deficit, capital inflows increase and foreign debt levels rise. Trade increases significantly between member countries and the largest changes arise in



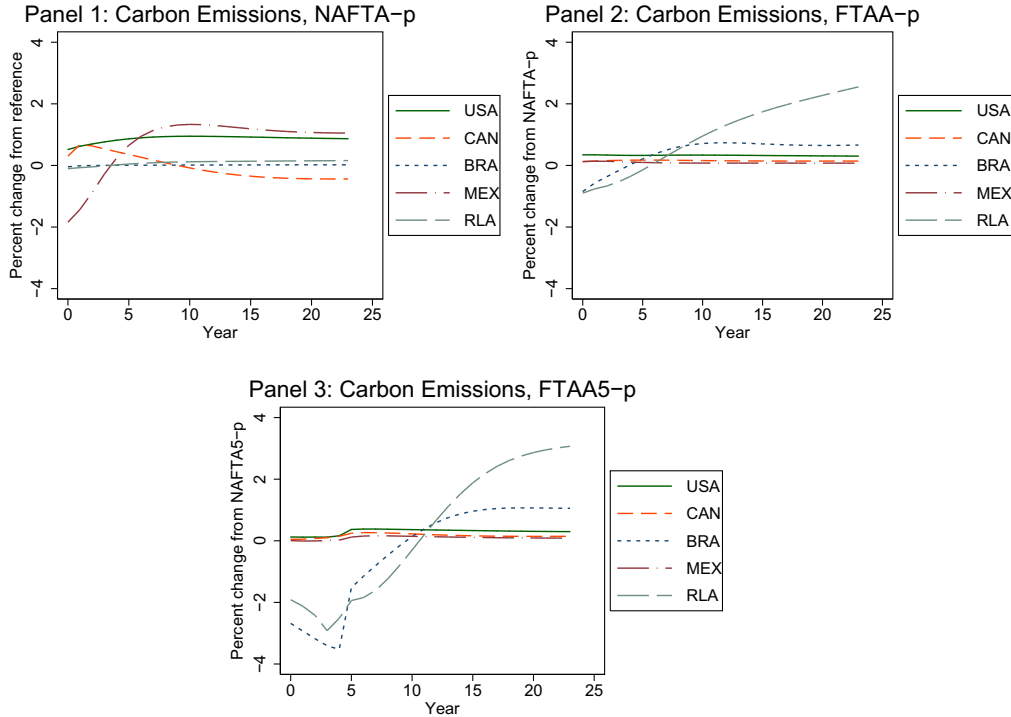
**Table 15.14** Change in output, exports and capital stocks: FTAA 5-p versus NAFTA-p (% change)

	US	Japan	Canada	Europe	ROECD	China	Brazil	Mexico	RLA	LDC	EEFSU	OPEC
<i>Panel 1: Industry output in 2015 under FTAA5-p</i>												
Electric utilities	0.1	0.1	0.2	0.2		0.1	0.9	0.2	-0.8	0.4		0.2
Gas utilities	0.1		0.2	0.1			1.1		0.3	0.3		0.2
Petroleum refining	0.3	0.1	0.1	0.2	0.1	0.1	3.9	0.1	3.2	0.4	-0.1	-0.1
Coal mining				-0.2	0.1		16.7		3.6	0.3		
Crude oil and gas extraction	0.1	0.1		0.3	0.1	0.1	4.0		2.7	0.3	-0.1	
Other mining		-0.2	-0.2		-0.1	0.1	5.5	0.1	7.6	0.3		0.1
Agriculture	0.2	-0.1	0.5	0.1	0.1	0.1	9.8	0.1	5.9	0.2		0.1
Forestry and wood products	0.2	0.1	0.3	0.3	0.2	0.1	9.6	0.1	11.0	0.3	0.1	0.2
Durable goods	0.2	0.1	0.2	0.2	0.1	0.1	7.6	0.3	6.5	0.3		0.1
Non-durables	0.3	0.2	0.2	0.3	0.1	0.1	9.9	0.2	8.6	0.2	0.1	0.1
Transportation				0.1		0.1	4.2	0.1	4.1	0.2		0.1
Services	0.1	0.2	0.2	0.3	0.1	0.1	-0.7	0.2	-2.3	0.6	0.1	0.3
<i>Panel 2: Exports in 2015 under FTAA5-p</i>												
Electric utilities	-3.7		-0.5	-1.2		-1.4		-16.7		-5.0	-1.3	-9.1
Gas utilities										-0.6		
Petroleum refining		0.5	-0.8	-0.1	0.7		5.3		13.6	0.1	-1.3	-0.8
Coal mining	-0.6		-0.5		0.1		0.0		15.1			
Crude oil and gas extraction	0.5		-0.1	0.1	0.3		100.0	-0.1	9.9	0.1	-0.9	
Other mining	-0.6		-0.2	0.3	-0.3		6.3		19.5	-0.1		
Agriculture	1.1	2.3	1.9	1.4	0.2	0.6	10.0	0.4	22.3	0.2	0.6	0.2
Forestry and wood products	1.3	5.3	0.4	0.8	0.4	0.4	10.6	0.4	23.8	0.2	0.6	0.5

(Continued)

**Table 15.14** Change in output, exports and capital stocks: FTAA 5-p versus NAFTA-p (% change)—cont'd

	US	Japan	Canada	Europe	ROECD	China	Brazil	Mexico	RLA	LDC	EEFSU	OPEC
Durable goods	0.5	0.1	0.3		0.2	0.2	10.9	0.4	11.3		0.2	-0.2
Non-durables	1.0	0.4	0.5	0.2	0.1	0.3	9.8	0.7	24.4	0.1	0.3	0.2
Transportation	-0.6	-0.4	-0.8	-0.5	-0.2	-0.1	5.3	-0.1	18.4	-0.3	-0.1	
Services	-0.3	-0.1	-0.4	-0.2	-0.1		2.7		8.0			0.2
<i>Panel 3: Capital stocks in 2015 under FTAA5-p</i>												
Electric utilities	0.3	0.1	0.3	0.3	0.2	0.1	-1.8	0.5	-3.5	0.6	0.1	0.5
Gas utilities	0.2	0.1	0.3	0.2	0.2	0.1	-2.1	0.4	-2.9	0.4	0.1	0.3
Petroleum refining	0.2	0.1	0.3	0.2	0.2	0.1	-1.4	0.4	-2.2	0.4	0.1	0.1
Coal mining	0.2	0.2		0.2	0.2	0.1	4.5	0.2	4.2	0.4	0.1	0.5
Crude oil and gas extraction	0.3	0.2	0.1	0.3	0.2	0.1	-1.5		0.4	0.4	-0.1	
Other mining	0.2	0.1	-0.1	0.2		0.1	8.7	0.3	3.2	0.4	0.1	0.2
Agriculture	0.2		0.4	0.1	0.2	0.1	7.0	0.5	3.4	0.5		0.3
Forestry and wood products	0.4	0.3	0.5	0.5	0.3	0.2	7.6	0.2	4.4	0.5	0.2	0.4
Durable goods	0.3	0.2	0.4	0.4	0.3	0.1	-0.1	0.5	-5.1	0.5	0.1	0.7
Non-durables	0.3	0.2	0.3	0.3	0.2	0.1	7.6	0.3	3.1	0.4	0.1	0.2
Transportation	0.2	0.1	0.1	0.2	0.1	0.1	7.0	0.2	3.9	0.3	0.1	0.2
Services	0.3	0.3	0.4	0.4	0.3	0.2	-3.1	0.6	-6.5	1.1	0.2	0.8



**Figure 15.14** Carbon emissions.

the most heavily traded sectors: durables and non-durables. The effects are most pronounced for non-durables because the initial tariffs are highest. Liberalization is good for importers and exporters, as would be expected. Non-traded sectors, particularly services, are hurt by the expansion of exporting industries which draw in labor and raise wages (even though, in percentage terms, exports of services rise slightly).

For several of the FTAA countries the agreement would have a significant fiscal impact by reducing an importance source of government revenue. Unless another tax is increased to compensate for the reduction in tariff revenue, the FTAA raises the country's fiscal deficit. providing a short-term stimulus but crowding out some private investment in the long run.

Allowing for industries to respond to liberalization by adopting modest productivity improvements sharply increases the overall gain from liberalization and reduces the fiscal drag causes by the drop in tariff revenue (tax revenue from other sources rises). Both GDP and consumption rise significantly in liberalizing economies. In addition, productivity effects tend to reduce the changes in trade flows caused by liberalization because the difference in relative prices between foreign and domestic goods is smaller. This effect is particularly noticeable with durables imported by Brazil and the rest of Latin America.

The FTAA and NAFTA are not analogous in one respect. NAFTA increases overall trade rather than just redirecting it away from non-NAFTA countries. The effect of the FTAA, however, is closer to trade redirection than to trade creation. The difference stems from the relative effects of the agreements on the US. NAFTA does more to stimulate the US economy and thus has a larger effect on the US demand for imports.

Finally, the effect of both NAFTA and the FTAA on carbon emissions are very small. Neither agreement has much effect on energy consumption. The effect on criteria air pollutants would be small as well.

## 15.5 CONCLUSION

G-Cubed bridges three areas of research — econometric general equilibrium modeling, international trade theory and modern macroeconomics — to provide a versatile multi-country, multisector, intertemporal general equilibrium model that can be used for a wide variety of policy analyses. It distinguishes between financial and physical capital, tracking financial capital by currency and physical capital by region and sector where it is installed. Investment, saving and international asset markets are driven by agents solving intertemporal optimization problems and having expectations driven by foresight (although not always perfect foresight). All budget constraints are imposed, including those applying to regions as a whole: all trade deficits must eventually be repaid by future trade surpluses.

This combination of features allows the model to be used for a wide range of applications. Its industry detail allows it to be used to examine environmental and tax policies, which tend to have their largest direct effects on small segments of the economy. Intertemporal modeling of investment and saving allows it to trace out the transition of the economy between the short run and the long run. Slow wage adjustment and liquidity-constrained agents improves the empirical accuracy with which the model captures the transition.

To date, G-Cubed has been used in nearly 80 studies covering topics ranging from climate and energy policy to pandemic influenza. Its core strengths are: (i) scenario analysis, where scenarios are made up of different shocks that might confront the world economy or an individual country, and (ii) policy evaluation, especially where dynamic adjustment towards a long-run equilibrium is important. It has also occasionally been used as a forecasting model although it was not designed for that purpose.

G-Cubed continues to evolve and there a number of areas where research is underway to improve it. One project currently underway is an analysis of the effects of alternative fiscal closures on the consequences of imposing a carbon tax in the US. A second project, also underway, is further disaggregation of the energy sectors, which will allow analysis of a wider range of primary energy inputs will include explicit treatment of alternative energy generation technologies. A third project focuses on the

role of infrastructure. This is particularly important for better understanding the determinants of economic growth especially in developing countries. It will also be critical when using the model to evaluate large fiscal consolidation programs in heavily indebted industrial economies over future years. A fourth area where more work is underway is improved estimation of G-Cubed's dynamic adjustment parameters. Although many of the intratemporal parameters of the model are estimated, the key dynamic parameters are largely calibrated. A number of alternative approaches are possible to improve this. Perhaps the most attractive, particularly in adapting the core model to be used as a forecasting tool is to further develop the approach in Pagan et al. (1998). In that approach, the impulse response functions from G-Cubed are combined with vector autoregression techniques on a time series data set. The result is a dynamic system with the medium- and long-term properties of G-Cubed as well as the dynamics found in high frequency macro data.

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## REFERENCES

- Abel, A.B., 1979. *Investment and the Value of Capital*. Garland, New York.
- Abel, A.B., Blanchard, O.J., 1983. An intertemporal model of saving and investment. *Econometrica* 51, 675–692.
- Adkins, L.G., Garbaccio, R.F., 2002. The effects of the proposed FTAA on global carbon emissions: a general equilibrium analysis. Presented at the Second World Congress of Environmental and Resource Economists, Monterey.
- Allsop, C., Davies, G., McKibbin, W., Vines, D., 1996. Monetary and fiscal stabilisation of demand shocks within Europe. *Rev. Int. Econ.* 5 (Suppl), 55–76.
- Allsop, C., McKibbin, W., Vines, D., 1999. Fiscal consolidation in Europe: Some empirical issues. In: Hughes-Hallett, A., Hutchison, M., Hougaard Jensen, S. (Eds.), *Fiscal Aspects of European Monetary Integration*. Cambridge University Press, Cambridge, pp. 288–319.
- Anderson, K., McKibbin, W., 2000. Reducing coal subsidies and trade barriers: Their contribution to greenhouse gas abatement. *Environ. Dev. Econ.* 5, 457–481.
- Armington, P.S., 1969. The geographic pattern of trade and the effects of price changes. *IMF Staff Papers* 16, 179–199.
- Asian Development Bank, 1997. *Emerging Asia: Changes and Challenges*. Asian Development Bank, Manila.
- Auerbach, A.J., Kotlikoff, L.J., 1987. *Dynamic Fiscal Policy*. Cambridge University Press, Cambridge.

- Australian Government, 2008. Carbon Pollution Reduction Scheme: Australia's Low Pollution Future. White Paper. Government Printing Office, Canberra.
- Bagnoli, P., McKibbin, W., Wilcoxon, P., 1996. Future projections and structural change. In: Nakicenovic, N., Nordhaus, W., Richels, R., Toth, F. (Eds.), *Climate Change: Integrating Economics and Policy: CP 96-1*. International Institute for Applied Systems Analysis, Laxenburg, pp. 181–206.
- Ballard, C.L., Fullerton, D., Shoven, J.B., Whalley, J., 1985. A General Equilibrium Model for Tax Policy Evaluation. National Bureau of Economic Research, Chicago, IL.
- Batini, N., Callen, T., McKibbin, W., 2005. The global impact of demographic change. In: IMF Working Paper WP/06/9. International Monetary Fund, Washington, DC.
- Berklemens, L., Davis, L., McKibbin, W., Stoeckel, A., 2001. Economic Impacts of an Australia – United States Free Trade Area. Centre for International Economics, Canberra.
- Blanchard, O., 1985. Debt, deficits, and finite horizons. *J. Polit. Econ.* 93, 223–247.
- Bovenberg, A.L., Goulder, L.H., 1996. Optimal environmental taxation in the presence of other taxes: general-equilibrium analyses. *Am. Econ. Rev.* 86, 985–1000.
- Bryant, R., McKibbin, W., 2004. Incorporating demographic change in multi-country macroeconomic models. In: Onofri, P. (Ed.), *The Economics of an Ageing Population: Macroeconomic Issues*. Edward Elgar, Cheltenham, pp. 349–408.
- Bryant, R., McKibbin, W., 1998. Issues in modeling the global dimensions of demographic change. In: *Brookings Discussion Paper in International Economics 141*. Brookings Institution, Washington, DC.
- Burniaux, J.-M., Truong, T.P., 2002. GTAP-E: an energy-environmental version of the GTAP model. In: GTAP Technical Paper 16. Center for Global Trade Analysis, Purdue University, West Lafayette, IN.
- Burniaux, J.-M., Martin, J.P., Nicoletti, G., Oliveira Martins, J., 1992. GREEN: A multi-sector, multi-region general equilibrium model for quantifying the costs of curbing CO<sub>2</sub> emissions: A technical manual. In: Working Paper 116. OECD, Paris.
- Cagliarini, A., McKibbin, W., 2009. Relative price shocks and macroeconomic adjustment. In: Fry, R., Jones, C., Kent, C. (Eds.), *Inflation in a Era of Relative Price Shocks*. Reserve Bank of Australia, Sydney, pp. 305–333.
- Callen, T., McKibbin, W., 2003. The impact of Japanese economic policies on the Asia region. In: Callen, T., Ostry, J. (Eds.), *Japan's Lost Decade: Policies for Economics Revival*. International Monetary Fund, Washington DC, pp. 251–271.
- Campbell, J., Mankiw, N.G., 1990. Permanent income, current income and consumption. *J. Bus. Econ. Stat.* 8, 265–279.
- Catinat, M., Italianer, A., 1988. Completing the Internal Market: Primary Microeconomic Effects and their Impact in Macroeconometrics Models. Commission of the European Communities, Brussels.
- Chand, S., 1999. Trade liberalization and productivity growth: time series evidence from Australian manufacturing. *Econ. Rec.* 75 (228), 28–36.
- Congressional Budget Office, 1993a. Budgetary and Economic Analysis of the North American Free Trade Agreement. US Government Printing Office, Washington, DC.
- Congressional Budget Office, 1993b. The Economic Effects of Reduced Defense Spending. 52 pages. US Government Printing Office, Washington, DC.
- Deardorff, A.V., Stern, R.M., 1985. *The Michigan Model of World Production and Trade: Theory and Applications*. MIT Press, Cambridge, MA.
- Diao, X., Somwaru, A., 2000. A Dynamic Evaluation of the Effects of a Free Trade Area of the Americas – An Intertemporal, Global General Equilibrium Model. *Journal of Economic Integration*. Volume 16, Number 1, March 2001. Pages 21–47.
- Dixon, P.B., Parmenter, B.R., Sutton, J., Vincent, D.P., 1982. *ORANI: A Multisectoral Model of the Australian Economy*. North-Holland, Amsterdam.
- Doornik, J.A., 2007. *Object-Oriented Matrix Programming Using Ox*, third ed. Timberlake Consultants Press, London.
- Faruquee, H., 2003. Debt, deficits, and age-specific mortality. *Rev. Econ. Dynam.* 6, 300–312.
- Feldstein, M., Horioka, C., 1980. Domestic savings and international capital flows. *Econ. J.* 90, 314–329.

- Flavin, M.A., 1981. The adjustment of consumption to changing expectations about future income. *J. Polit. Econ.* 89, 974–1009.
- Frankel, J.A., Romer, D., 1999. Does trade cause growth? *Am. Econ. Rev.* 89, 379–399.
- Gagnon, J., Masson, P., McKibbin, W., 1996. German unification: what have we learned from multi-country models. *Econ. Model.* 13, 467–497.
- Gilbert, J., 2001. *Free Trade in the Americas from a North–South Perspective*. CEPII, Paris.
- Gordon, R.H., Bovenberg, A.L., 1994. Why is Capital so Immobile Internationally? Possible Explanations and Implications for Capital Taxation. *American Economic Review*, 1996, volume 86, number 5, December, pages 1057–1075.
- Goulder, L.H., 1992. *An Intertemporal General Equilibrium Model for Analyzing US Energy and Environmental Policies: Model Structure*. Stanford University, Stanford, CA.
- Goulder, L.H., Summers, L.H., 1989. Tax policy, asset prices and growth: A general equilibrium analysis. *J. Publ. Econ.* 38, 265–296.
- Haber, G., Neck, R., McKibbin, W.J., 2001. Monetary and fiscal policy rules in the European Economic and Monetary Union: A simulation analysis. In: Choi, J.J., Wrase, J. (Eds.), *European Monetary Union and Capital Markets*. Elsevier, Amsterdam, pp. 195–217.
- Hall, R.E., 1978. Stochastic implications of the life-cycle hypothesis: Theory and evidence. *J. Polit. Econ.* 86, 971–987.
- Hayashi, F., 1979. Tobin's marginal  $q$  and average  $q$ : A neoclassical interpretation. *Econometrica* 50, 213–224.
- Hayashi, F., 1982. The permanent income hypothesis: Estimation and testing by instrumental variables. *J. Polit. Econ.* 90, 895–916.
- Henderson, D.W., McKibbin, W., 1993. A comparison of some basic monetary policy regimes for open economies: implications of different degrees of instrument adjustment and wage persistence. *Carnegie-Rochester Conf. Ser. Publ. Pol.* 39, 221–318.
- Hertel, T.W. (Ed.), 1997. *Global Trade Analysis: Modeling and Applications*. Cambridge University Press, Cambridge.
- Ho, M.S., 1989. *The Effects of External Linkages on US Economic Growth: A Dynamic General Equilibrium Analysis*. PhD Dissertation. Harvard University, Cambridge, MA.
- International Monetary Fund, 2004. *World Economic Outlook*. International Monetary Fund, Washington, DC.
- Johansen, Leif, 1960. *A Multi-Sectoral Study of Economic Growth*. North-Holland, Amsterdam.
- Jorgenson, D.W., Wilcoxon, P.J., 1990. Intertemporal general equilibrium modeling of us environmental regulation. *J. Pol. Model.* 12, 314–340.
- Kim, J., Lau, L., 1994. The role of human capital in the economic growth of the East Asian newly industrialized countries, paper presented at the Asia-Pacific Economic Modeling Conference, Sydney.
- Lee, J.W., McKibbin, W., Park, Y., 2006. Transpacific trade imbalances: Causes and cures. *World Econ.* 29, 281–304.
- Lee, J.W., McKibbin, W.J., 2004. Globalization and disease: The case of SARS. *Asian Econ. Paper.* 3, 113–131.
- Lucas, R.E., 1967. Optimal investment policy and the flexible accelerator. *Int. Econ. Rev.* 8, 78–85.
- Manchester, J., McKibbin, W., 1994. The macroeconomic consequences of the savings and loan debacle. *Rev. Econ. Stat.* 76, 579–584.
- Manchester, J., McKibbin, W., 1995. The global macroeconomics of NAFTA. *Open Econ. Rev.*, 203–223.
- Martin, W., Winters, L.A., 1995. The Uruguay round and the developing economies. In: *World Bank Discussion Papers 307*. World Bank, Washington, DC.
- McKibbin, W., 1986. *The International Coordination of Macroeconomic Policies*. PhD Dissertation. Harvard University, Cambridge, MA.
- McKibbin, W., 1994. Dynamic adjustment to regional integration: Europe 1992 and NAFTA. *J. Jpn. Int. Econ.* 8, 422–453.
- McKibbin, W., 1996. Military spending cuts and the global economy. In: Gleditsch, N., Bjerkholt, O., Cappelen, A., Smith, R., Dunne, J. (Eds.), *The Peace Dividend, Contribution to Economic Analysis*. North-Holland, Amsterdam, pp. 465–489.

- McKibbin, W., 1997. Which monetary policy regime for Australia? In: Reserve Bank of Australia (Ed.), *Monetary Policy and Inflation Targeting*. Reserve Bank of Australia, Canberra, pp. 166–173.
- McKibbin, W., 1998a. Regional and multilateral trade liberalization: The effects on trade, investment and welfare. In: Drysdale, P., Vines, D. (Eds.), *Europe, East Asia and APEC: A Shared Global Agenda?* Cambridge University Press, Cambridge, pp. 195–220.
- McKibbin, W. 1998b. Unilateral versus multilateral trade liberalization: The importance of international financial flows. In: US ITC (Ed.), *The Economic Implications of Liberalizing APEC Tariff and Non-Tariff Barriers to Trade: US International Trade Commission Publication 3101*, pp. 10–41–10–66.
- McKibbin, W., 1999. Modelling the crisis in Asia. In: Arndt, H., Hill, H. (Eds.), *Southeast Asia's Economic Crisis: Origins, Lessons, and the Way Forward*. Institute of Southeast Asian Studies, Singapore, pp. 119–127.
- McKibbin, W., 2000. Forecasting the world economy with dynamic intertemporal general equilibrium multi-country models. In: Abelson, P., Joyeux, R. (Eds.), *Economic Forecasting*. Allen & Unwin, London, pp. 50–73.
- McKibbin, W., 2002. Macroeconomic policy in Japan. *Asian Econ. Paper*. 1, 133–165.
- McKibbin, W., 2006a. Global energy and environmental impacts of an expanding China. *China World Econ.* 14, 38–56.
- McKibbin, W. 2006b. The global macroeconomic consequences of a demographic transition. *Asian Econ. Paper*. 5, 92–141. Also published in G-20 Workshop on Demographic Challenges and Migration. Australian Government Printing Service, Canberra, pp. 11–44.
- McKibbin, W., 2008. China and the global environment. In: Eichengreen, B., Park, Y.C., Wyplosz, C. (Eds.), *China, Asia and the New World Economy*. Oxford University Press, Oxford, pp. 18–50.
- McKibbin, W., Bok, T., 1995. The impact on the Asia–Pacific region of fiscal policy in the United States and Japan. *Asia Pac. Econ. Rev.* 1, 25–40.
- McKibbin, W., Bok, T., 2001. The European Monetary Union: Were there alternatives to the ECB? A quantitative evaluation. *J. Pol. Model.* 23, 775–806.
- McKibbin, W., Chanthapun, W., 2009. Exchange rate regimes in the Asia–Pacific region and the global financial crisis. In: *Asia Development Bank Working Paper Series on Regional Cooperation 36*. Asian Development Bank, Manila.
- McKibbin, W., Huang, Y., 2000. Rapid economic growth in China: implications for the world economy. In: Drysdale, P., Song, L. (Eds.), *China's Entry to the WTO: Strategic Issues and Quantitative Assessments*. Routledge, London, pp. 194–216.
- McKibbin, W., Le, H.-G., 2004. Which exchange rate regime for Asia? In: DeBrouwer, G., Kawai, M. (Eds.), *Exchange Rate Regimes in East Asia*. Routledge Curzon, London, pp. 385–416.
- McKibbin, W., Martin, W., 1998. The East Asia crisis: Investigating causes and policy responses [background paper for the World Bank Report *East Asia: The Road to Recovery*]. In: *Brookings Discussion Paper in International Economics 142*. Brookings Institution, Washington, DC.
- McKibbin, W., Nguyen, J., 2004. Modelling global demographic change: results for Japan. In: *Brookings Discussion Papers in International Economics 162*. Brookings Institution, Washington DC.
- McKibbin, W., Sachs, J., 1991. *Global Linkages: Macroeconomic Interdependence and Cooperation in the World Economy*. Brookings Institution, Washington DC.
- McKibbin, W., Salvatore, D., 1995. The global economic consequences of the Uruguay Round. *Open Econ. Rev.* 6, 111–129.
- McKibbin, W., Sidorenko, A., 2006. *Global macroeconomic consequences of pandemic influenza*. Lowy Institute Analysis February.
- McKibbin, W., Singh, K., 2003. Issues in the choice of a monetary regimes in India. In: Jha, R. (Ed.), *Indian Economic Reforms*. Palgrave-Macmillan, London, pp. 11–50.
- McKibbin, W., Stoeckel, A., 2010a. The global financial crisis: Causes and consequences. *Asian Econ. Paper*. 9, No. 1, pp. 54–86.
- McKibbin, W., Stoeckel, A., 2010b. Modeling the Global Financial Crisis. *Oxf. Rev. Econ. Pol.* 25, No. 4, pp. 581–607.



- McKibbin, W., Stoeckel, A., 2012. Global Fiscal Consolidation. *Asian Economic Papers*, 11, No. 1, pp. 124–146.
- McKibbin, W., Tan, K., 2009. Learning and the International Transmission of Shocks. *Econ. Model.* 31 (3), 463–477.
- McKibbin, W., Tang, K.K., 2000. Trade and financial reform in China: Impacts on the world economy. *World Econ.* 23, 979–1003.
- McKibbin, W., Thurman, S., 1995. The impact on the world economy of reductions in military expenditures and military arms exports. In: Klein, L., Lo, F., McKibbin, W. (Eds.), *Arms Trade: Economic Implications in the Post Cold War Era*. United Nations University Press, New York, pp. 129–171.
- McKibbin, W., Vines, D., 2000. Modelling reality: The need for both intertemporal optimization and stickiness in models for policymaking. *Oxf. Rev. Econ. Pol.* 16, 106–137.
- McKibbin, W., Wilcoxon, P.J., 1993. The global consequences of regional environmental policies: an integrated macroeconomic multisectoral approach. In: Kaya, Y., Nakicenovic, N., Nordhaus, W.D., Toth, F.L. (Eds.), *Costs, Impacts and Benefits of CO<sub>2</sub> Mitigation*. International Institute for Applied Systems Analysis, Laxenburg, pp. 247–272.
- McKibbin, W., Wilcoxon, P., 1994. The global costs of policies to reduce greenhouse gas emissions. In: *Final Report on US Environmental Protection Agency Cooperative Agreement CR818579-01-0*. Brookings Institution, Washington, DC.
- McKibbin, W., Wilcoxon, P., 1997. The economic implications of greenhouse gas policy. In: English, H., Runnalls, D. (Eds.), *Environment and Development in the Pacific: Problems and Policy Options*. Addison Wesley, London, pp. 8–34.
- McKibbin, W., Wilcoxon, P., 1999a. The theoretical and empirical structure of the G-Cubed model. *Econ. Model.* 16, 123–148.
- McKibbin, W., Wilcoxon, P., 1999b. Environmental policy and international trade. In: Mahendrarajah, S., Jakeman, A., McAleer, M. (Eds.), *Modelling Change in Integrated Economics and Environmental Systems*. Wiley, New York, pp. 339–368.
- McKibbin, W., Wilcoxon, P., 2000. The role of international permit trading in climate change policy. *Oxf. Energ. Forum* 41, 4–6 (May).
- McKibbin, W., Wilcoxon, P., 2002a. The role of economics in climate change policy. *J. Econ. Perspect.* 16, 107–129.
- McKibbin, W.J., Wilcoxon, P.J., 2002b. *Climate Change Policy after Kyoto: A Blueprint for a Realistic Approach*. Brookings Institution, Washington, DC.
- McKibbin, W., Wilcoxon, P., 2004. Estimates of the costs of Kyoto–Marrakesh versus the McKibbin–Wilcoxon blueprint. *Energ. Pol.* 32, 467–479.
- McKibbin, W., Wilcoxon, P., 2007. A credible foundation for long term international cooperation on climate change. In: Aldy, J., Stavins, R. (Eds.), *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*. Cambridge University Press, Cambridge, pp. 185–208.
- McKibbin, W., Wilcoxon, P., 2009a. The economic and environmental effects of border adjustments for climate policy. In: Brainard, L., Sorkin, I. (Eds.), *Climate Change Trade and Competitiveness: Is a Collision Inevitable?* Brookings Trade Forum 2008/09. Brookings Institution, Washington, DC, pp. 1–35.
- McKibbin, W., Wilcoxon, P., 2009b. Uncertainty and climate change policy design. *J. Pol. Model* 31, 463–477.
- McKibbin, W., Woo, W., 2004. Quantifying the international economic impact of China's WTO membership. *China World Econ.* 12, 3–19.
- McKibbin, W., Pagan, A., Robertson, J., 1998. Some experiments in constructing a hybrid model for macroeconomic analysis. *Carnegie Rochester Ser. Publ. Pol.* 49, 113–142.
- McKibbin, W., Ross, M., Shackleton, R., Wilcoxon, P., 1999a. Emissions trading, capital flows and the Kyoto protocol. *Energ. J.* 287–333. (Special Issue: The Costs of the Kyoto Protocol: A Multi-model Evaluation). Reprinted from: *Economic Impact of Mitigation Measures*. Intergovernmental Panel on Climate Change, Geneva.
- McKibbin, W., Shackleton, R., Wilcoxon, P., 1999b. What to expect from an international system of tradeable permits for carbon emissions. *Resource Energ. Econ.* 21, 319–346.

- McKibbin, W., Wang, Z., Coyle, W., 2001. The Asian financial crisis and global adjustments: Impacts on US agriculture. *Jpn. Econ. Rev.* 52, 471–490.
- McKibbin, W., Lee, J.-W., Cheong, I., 2004. A dynamic analysis of the Korea–Japan free trade area: simulations with the G-Cubed Asia-Pacific model. *Int. Econ. J.* 18 (no 1), 3–32.
- McKibbin, W., Pearce, D., Stegman, A., 2007. Long term projections of carbon emissions. *Int. J. Forecast.* 23, 637–653.
- McKibbin, W., Wilcoxon, P., Woo, W., 2008. China can grow and still help prevent the tragedy of the CO<sub>2</sub> commons. In: Garnaut, R., Song, L., Woo, W.T. (Eds.), *China's Dilemma: Economic Growth, the Environment and Climate Change*. Asia Pacific Press, Brookings Institution Press and Social Sciences Academic Press, Washington, DC, pp. 190–225.
- McKibbin, W., Pearce, D., Stegman, A., 2009a. Climate change scenarios and long term projections. *Climatic Change* 97, 23–47.
- McKibbin, W., Morris, A., Wilcoxon, P., Cai, Y., 2009b. *Consequences of Alternative US Cap and Trade Policies: Controlling Both Emissions and Costs*. Brookings Institution, Washington, DC.
- McKibbin, W., Morris, A., Wilcoxon, P., 2009c. A Copenhagen collar: Achieving comparable effort through carbon price agreements. In: *Climate Change Policy: Recommendations to Reach Consensus*. Brookings Institution, Washington, DC, pp. 26–34.
- McKibbin, W., Morris, A., Wilcoxon, P., 2009d. Expecting the unexpected: Macroeconomic volatility and climate policy. In: Aldy, J., Stavins, R. (Eds.), *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*. Cambridge University Press, Cambridge, pp. 185–208.
- McKibbin, W., Morris, A., Wilcoxon, P., 2010. *Comparing Climate Commitments: A Model Based Analysis of the Copenhagen Accord*. Brookings Institution, Washington, DC.
- Monteagudo, J., Watanuki, M., 2001. *Regional Trade Agreements for MERCOSUR: The FTAA and the FTA with the European Union*. CEPII, Paris.
- Neck, R., Haber, G., McKibbin, W., 2005. Global macroeconomic policy implications of an enlarged EMU. In: Breuss, F., Hochreiter, E. (Eds.), *Challenges for Central Banks in an Enlarged EMU*. Springer, New York, pp. 235–257.
- Neck, R., Haber, G., McKibbin, W., 2000. Macroeconomic impacts of European Union membership of Central and Eastern European economies. *Atl. Econ. J.* 28, 71–82.
- Nguyen, J., 2011. *Modelling the Macroeconomic Effects of Population Ageing in Japan and the International Economy*. PhD Dissertation. The Australian National University, Canberra.
- Papageorgiou, D., Choski, A.M., Michaely, M., 1990. *Liberalizing Foreign Trade in Developing Countries: The Lessons of Experience*. World Bank, Washington, DC.
- Shoven, J.B., Whalley, J., 1984. Applied general equilibrium models of taxation and international trade: An introduction and survey. *J. Econ. Lit.* 22, 1007–1051.
- Stoekel, A., McKibbin, W., Tang, K.K., 2000. Productivity, risk and the gains from trade liberalisation. In: *Pelham Papers 9*. Melbourne Business School, Melbourne.
- Strutt, A., Anderson, K., 1999. *Estimating Environmental Effects of Trade Agreements with Global CGE Models: A GTAP Application to Indonesia*. OECD, Paris.
- Treadway, A., 1969. On rational entrepreneurial behavior and the demand for investment. *Rev. Econ. Stud.* 3, 227–239.
- Tsigas, M., Gray, D., Hertel, T., 2002. *How to Assess the Environmental Impacts of Trade Liberalization*. Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana.
- Uzawa, H., 1969. Time preference and the Penrose effect in a two class model of economic growth. *J. Polit. Econ.* 77, 628–652.
- Weil, P., 1989. Overlapping families of infinitely-lived agents. *J. Publ. Econ.* 38, 183–198.
- Wilcoxon, P.J., 1988. *The Effects of Environmental Regulation and Energy Prices on US Economic Growth*. PhD Dissertation. Harvard University, Cambridge, MA.
- Yaari, M.E., 1965. Uncertain lifetime, life insurance, and the theory of the consumer. *Rev. Econ. Stud.* 32, 137–150.