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FOREST POLICY MODELLING IN AN ECONOMY-WIDE FRAMEWORK

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Onil Banerjee[1] *and Janaki Alavalapati*[2]

[1]CSIRO ECOSYSTEM SCIENCES, 41 BOGGO ROAD, DUTTON PARK, QLD 4102, AUSTRALIA. ONIL@RMGEO.COM
[2]PROFESSOR AND HEAD, DEPARTMENT OF FOREST RESOURCES AND ENVIRONMENTAL CONSERVATION, COLLEGE OF NATURAL RESOURCES AND ENVIRONMENT, VIRGINIA TECH, BLACKSBURG, VA 24061, USA. JRRA@VT.EDU

Abstract

Computable general equilibrium (CGE) models are extensively used in agricultural economics and macroeconomic studies to assess the impacts of policy and programs. By providing a theoretically consistent mathematical representation of an economic system, these models effectively capture the linkages among sectors of the economy. This chapter provides an overview of CGE modelling in forest economics. As an illustration, a dynamic recursive CGE model is presented and applied to assess the regional economic impacts of Brazil's forest concessions policy in the Amazon. A comprehensive discussion on innovations in CGE analysis concludes the chapter. These innovations include institutional advancements, model validation techniques, systematic sensitivity analysis to address parameter uncertainty, and integration of ecosystem services.

Keywords

Computable general equilibrium model, dynamic model, input-output, land-use change, forest concessions, deforestation, Brazil

Introduction

The input-output (I-O) approach is by far the most commonly used technique in assessing economy-wide impacts of a policy or project. This approach rests on the idea that the economy is a system of interdependent industrial sectors and emphasizes incorporation of intersectoral linkages (Dixon, Parmenter, Powell and Wilcoxen, 1992; Shoven and Whalley, 1992). However, a closer look at the underlying assumptions of I-O models raises serious concerns about the validity of the information derived from these models (Alavalapati, Adamowicz and White, 1998). The I-O models' assumptions that prices of inputs and outputs are fixed, fixed amounts of inputs are required to produce a unit of output, there are no constraints on the supply of inputs and final demand for output is exogenous are likely to generate biased estimates (Alavalapati et al., 1998). These concerns have prompted economic modellers and policy analysts to develop an alternative interindustry, computable general equilibrium (CGE) approach, to assess economy-wide impacts of a policy, project or program.

Although CGE models have their foundation in the I-O framework developed by Wassily Leontief, they represent a theoretically consistent mathematical representation of an economic system. These models are formalized by a system of equations explaining demand for commodities, intermediate and factor inputs, equations relating prices and costs and market clearing equations for factors and commodities (Dixon et al., 1992). Both demand and supply equations describe the behavior of utility-maximizing consumers and cost-minimizing producers, respectively. This system of equations is simultaneously solved to determine the economic equilibrium (Bandara, 1991). CGE models are an improvement over I-O frameworks because they endogenize the price and demand system, enable substitutability of goods and services in production and demand, include a realistic treatment of factor scarcity, institutions and the macroeconomic environment and allow agent behavior optimization with producers competing for scarce resources and consumer expenditures.

At the core of a CGE model is the social accounting matrix (SAM), which empirically describes the structure of production and transactions between sectors, institutions and factors of production for a representative base year. The SAM serves to organize data transparently and provide the statistical basis for the model (King, 1985). SAMs are constructed based on I-O tables, national accounts data, government surveys such as household expenditure surveys and agricultural census data. A CGE model may be a static one-period or dynamic multiperiod model. Static models are used for estimating the order of magnitude and direction of effect of a policy shock, and depending on the model closure, they may be short-run or long-run. Dynamic CGE (DCGE) models shed light on the economic transition path resulting from a policy shock, including the short-term costs and longer-term gains (Cattaneo, 1999). DCGE models involve a deeper treatment of investment behavior and enable the modeller to update key growth parameters such as population, labor force, factor productivity, world prices and government consumption. As such, CGE models are considered flexible and powerful in assessing economy-wide and distributional impacts of a policy change by effectively incorporating intersectoral dynamics (Buetre, Rodriguez and Pant, 2003).

This chapter focuses on discussing the mechanics and application of a CGE model to provide an economy-wide assessment of a forest policy. The next section briefly reviews the literature regarding CGE applications to forestry issues. A stylized version of a CGE model is presented in the third section. In the fourth section, an application of a DCGE is presented through a case study of a recent forest policy in Brazil. The last section discusses innovations in CGE analysis.

Review of CGE applications to forestry

CGE models are frequently used to study international trade, taxes, economic policy packages and climate change issues (Stenberg, Mahinda and Siriwardana, 2005). In the last two decades they have been increasingly applied to the study of forest sector policies. For example, Dee (1991) developed a model to evaluate the impact of increasing the minimum harvest age of trees and variations in stumpage and discount rates in Indonesia. Wiebelt (1994) studied macroeconomic policy impacts on forestry in Brazil. Alavalapati, Percy and Luckert (1997) analyzed the distributional effects of an increase in the stumpage price in Canada. Thompson, Van Kooten and Vertinsky (1997) considered forest management options when nontimber values are accounted for in the modelling framework. Alavalapati et al. (199[illegible]mulated land-use restrictions on a resource-dependent economy in Canada. Dufournaud, Jerrett, Quinn and Maclaren (2000) assessed the economics of an export ban and an increase in royalties and export taxes. Gan (2004) investigated potential impacts of trade liberalization on China's forestry sector, while AuQ379 Gan (2005) considered the socioeconomic impacts of forest certification. Stenberg and Siriwardana (2007) examined the economic effects of selective logging, stumpage taxes, set-aside areas and secure forest land tenure on the Philippine economy, integrating a CGE model and a forestry submodel. Ochuodho, Lantz, Lloyd-Smith and Benitez (2012) recently applied a CGE model to estimate economic impacts of climate change adaptation in Canadian forests.

A few modellers have addressed the interactions between land use and deforestation. Persson and Munasinghe (1995) assessed the impact of macroeconomic policy on deforestation and compared agent behavior under variable property rights arrangements. Cattaneo (2001, 2002) examined the relationship among economic growth, poverty and natural resource degradation in Brazil. Banerjee and Alavalapati (2010) considered both legal and illegal deforestation and forestry in their analysis of forest concessions in Brazil. Banerjee, Macpherson and Alavalapati (2012) evaluated the socioeconomic and land-use dynamics of ethanol expansion in Brazil. Huang, Alavalapati and Banerjee (2012) studied the economy-wide and welfare effects of bioenergy policies in the United States.

A stylized version of CGE

What follows is a stylized version of a static CGE model. Following Robinson, Yunez-Naude, Hinojosa-Ojeda, Lewis and Devarajan (1999), the model is organized into a series of building blocks, namely, price, quantity, income, expenditure and closure blocks.

Price equations

Prices in a CGE model may differ according to their origin and destination of use. The domestic import price P_i^m and the domestic export price P_i^e are a function of the world import price pw_i^m and the world export price PW_i^e in foreign currency, the exchange rate R and a tariff adjustment t_i^m on imports and a tariff adjustment t_i^e on exports (equations 1 and 2).[1] Interregional and international trade margins may also be included in the model specification. In single country or subnational models, the small country assumption is commonly made where world prices are taken as exogenous to reflect a country's often limited ability to affect world prices.

$$P_i^m = pw_i^m \left(1 + t_i^m\right) \cdot R \tag{1}$$

$$P_i^e = PW_i^e \left(1 + t_i^e\right) \cdot R \tag{2}$$

Equation 3 solves for the composite commodity price P_i^q, where composite goods supply Q_i is a CES aggregation of imported M_i and domestic D_i goods; P_i^d is the domestic goods price.

$$P_i^q = \frac{P_i^d \cdot D_i + P_i^m \cdot M_i}{Q_i} \tag{3}$$

Equation 4 describes output price P_i^x, which is a constant elasticity of transformation (CET) aggregation of goods supplied to both domestic and export markets.

$$P_i^x = \frac{P_i^d \cdot D_i + P_i^e \cdot E_i}{X_i} \tag{4}$$

Equation 5 explains the value-added price P_i^v, which is the output price P_i^x less both indirect taxes t^x and the cost of intermediate inputs based on I-O coefficients described by the coefficient matrix a_{ij}. Sectoral value added is the product of the value-added price and sectoral output, represented by payments from sectors to factors in the SAM.

$$P_i^v = P_i^x \cdot \left(1 - t_i^x\right) - \sum_j P_j^q \cdot a_{ji} \tag{5}$$

Capital used by different sectors is heterogeneous and therefore has a sector-specific price P_i^k as described in equation 6.

$$P_i^k = P_j^q \cdot b_{ji} \tag{6}$$

The capital coefficient matrix b_{ji} is the composition of capital by its activity of origin. In static CGE models, capital stock is fixed; therefore, investment is treated as another type of demand with no supply-side effects. Accounting for capital heterogeneity is important in dynamic modelling where the composition of capital investment affects future economic growth pathways (Robinson et al., 1999).

Equation 7 defines the aggregate price indicator *PINDEX* as the *GDP* deflator, which is the quotient of nominal *GDP*, *GDPVA* at market prices and real *GDP*, *RGDP*.

$$PINDEX = \frac{GDPVA}{RGDP} \tag{7}$$

This price index serves as the numeraire against which all changes in relative prices are measured. A numeraire is necessary because CGE models solve for changes in relative prices. Other indices or prices may be chosen as the numeraire, including the Consumer Price Index (CPI) or the exchange rate, respectively (Robinson et al., 1999).

Quantity equations

Equations 8 through 15 describe the supply side of the model, with equations 8 to 10 describing the production technology and factor demand. In CGE models, there are many ways to represent the structure of production. Options range from simple Leontief fixed shares specifications, to more complex configurations such as nested production structures, such as that presented in Figure 34.1.

At the top level, output is a fixed shares function of real value added and aggregate intermediate inputs. Real value added may be produced by a number of functional forms, including a Cobb-Douglas function of capital and labor or a constant elasticity of substitution (CES) function as in Figure 34.1. In other specifications, real value added may include land and other factors such as water. The level of domestic output X_i is given in equation 8.

$$X_i = a_i^D \prod_f FDSC_{if}^{\alpha_{if}} \tag{8}$$

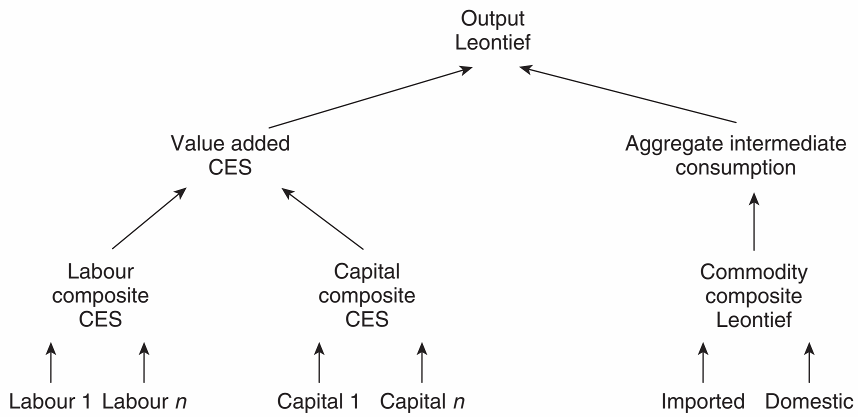


Figure 34.1 Structure of production.

where $FDSC_{if}$ is factor demand, a_{if} is a production function exponent and a_i^D is a production function shift parameter.

Firms are price takers and minimize costs subject to nested technological constraints. Sector output may be determined by combining value added with intermediate consumption through a Leontief production function. Labor and capital may be a CES aggregate of imperfectly substitutable types of labor and capital. Value added is a CES function of factors with firms employing factors until the value of the marginal factor product is equal to the factor price.

Factor demands are represented by equation 9. It is assumed that across all sectors, factors are paid the same average wage or rental rate WF_f. Factor market distortions may be simulated with the sector-specific $wfdist_{if}$ factor market distortion parameter. In the absence of distortions, this parameter is equal to one.

$$WF_f \cdot wfdist_{if} = P_i^v \cdot \alpha_{if} \cdot \frac{X_i}{FDSC_{if}} \tag{9}$$

Intermediate input demand INT_i in equation 10 is determined by fixed I-O coefficients, and each intermediate input is a CES aggregation of imported and domestic goods.

$$INT_i = \sum_j a_{ij} \cdot X_j \tag{10}$$

Similarly, imported goods M and domestic goods D are distinct from the composite good Q, with distinct sectoral prices. Any given sector may export and import a good simultaneously. The use of CET and CES functions insulates the domestic price system from large changes in world prices which could result in switching between exports and imports and vice versa. Equation 11 is a CET aggregate of exports and domestic sales where total domestic production X is either supplied to domestic markets D_i or foreign markets E_i and all have different prices.

$$X_i = a_i^T \left[\gamma_i E_i^{\rho_i^T} + (1-\gamma_i) \cdot D_i^{\rho_i^T} \right]^{1/\rho_i^T} \tag{11}$$

where a_i^T is the CET function shift parameter, γ_i is the CET function share parameter and ρ_i^T is the CET function exponent.

Equation 12 solves for export supply, which is a function of the export price and domestic price ratio.

$$E_i = D_i \cdot \left[\frac{P_i^e \cdot (1-\gamma_i)}{P_i^d \cdot \gamma_i} \right]^{1/\rho_i^T} \tag{12}$$

Where certain sectors are able to exert market power, equation 13 represents a downward-sloping world export demand function, where $econ_i$ is the export demand shift parameter, $pwse_i$ is the world price of export substitutes and η_i is the export demand price elasticity.

$$E_i = econ_i \cdot \left[\frac{PW_i^e}{pwse_i} \right]^{\eta_i} \tag{13}$$

CES aggregation functions describe domestic and import demand for goods and the import demand function, which is determined by the ratio of domestic to import prices (equations 14 and 15).

$$Q_i = a_i^C \left[\delta_i M_i^{-\rho_i^C} + (1-\delta_i) \cdot D_i^{-\rho_i^C} \right]^{1/\rho_i^C} \tag{14}$$

where a_i^C is a CES function shift parameter and δ_i is a CES function share parameter.

$$M_i = D_i \cdot \left[\frac{P_i^d \cdot \delta_i)}{P_i^m \cdot (1-\delta_i)} \right]^{1/1+\rho_i^C} \tag{15}$$

Income equations

Income equations track the flow of income from value added to institutions to agents. Factor income Y_f^F, described by equation 16, is distributed to households as household income Y_h^H by equations 17 and 18, where *DEPREC* is the cost of depreciation.

$$Y_f^F = \sum_i WF_f \cdot FDSC_{if} \cdot wfdist_{if} \tag{16}$$

$$Y_{cap \in h}^H = Y_l^F - DEPREC \tag{17}$$

$$Y_{lab \in h}^H = \sum_{f \neq 1} Y_f^F \tag{18}$$

Government tariff revenue *TARIFF*, indirect tax revenue *INDTAX* and income tax revenue *HHTAX* are given by equations 19 through 21, export subsidies *EXPSUB* by equation 22 and total government revenue *GR* by equation 23, where t_h^h is the household income tax rate.

$$TARIFF = \sum_i pw_i^m \cdot M_i \cdot t_i^m \cdot R \tag{19}$$

$$INDTAX = \sum_i P_i^x \cdot X_i \cdot t_i^x \tag{20}$$

$$HHTAX = \sum_h Y_h^H \cdot t_h^h \, h = cap, lab \tag{21}$$

$$EXPSUB = \sum_i PW_i^e \cdot E_i \cdot t_i^e \cdot R \tag{22}$$

$$GR = TARIFF + INDTAX + HHTAX - EXPSUB \tag{23}$$

Equation 24 is financial depreciation *DEPREC* and equation 25 is household savings *HHSA* Equation 26 is government savings *GOVSAV* calculated as government revenues net of government expenditures. Finally, equation 27 represents total savings *SAVING,* which is the sum of household and government savings, less depreciation, plus foreign savings *FSAV* converted to local currency units, where $depr^i$ is the rate of depreciation, mps_h is household marginal propensity to save, and GD_i is government final demand.

$$DEPREC = \sum_i depr^i \cdot P_i^k \cdot FDSC_{il} \tag{24}$$

$$HHSAV = \sum_h Y_h^H \cdot \left(1 - t_h^H\right) \cdot mps_h \tag{25}$$

$$GOVSAV = GR - \sum_i P_i^q \cdot GD_i \tag{26}$$

$$SAVING = HHSAV + GOVSAV + DEPREC + FSAV \cdot R \tag{27}$$

Expenditure equations

Expenditure equations represent the demand for goods and services. Private consumption C_i is a function of household demands calculated by fixed expenditure shares β_{ih}^H in equation 28. Other options exist for representing household demand, such as CES or linear expenditure system (LES) functional forms. In an LES, households allocate their income to consume a minimum level of subsistence goods and services above which they purchase goods and services according to a linear relationship between income and consumption. LES functions differ from CES functions in that LES functions have nonunitary income elasticities for all pairs of goods (Annabi, Cockburn and Decaluwé, 2006) which enables flexible substitution possibilities in response to changes in relative prices (Decaluwé, Lemelin, Robichaud and Maisonnave, 2010).

Government demand *gdtot* in equation 29 is determined by fixed government expenditure shares β_i^G of real spending.

$$P_i^q \cdot C_i \cdot D_i = \sum_h \left[\beta_{ih}^H \cdot Y_h^H \cdot \left(1 - mps_h\right) \cdot \left(1 - t_h^H\right) \right] \tag{28}$$

$$GD_i = \beta_i^G \cdot gdtot \tag{29}$$

Changes in inventories DST_i are represented in equation 30 as fixed shares $dstr_i$ of sectoral production. Aggregate fixed nominal investment *FXDINV* in equation 31 is total investment *INVEST* less inventory accumulation. Fixed nominal shares $kshr_i$ in equation 32 are used to convert aggregate fixed investment to real sectoral investment DK_i. The capital composition matrix b_{ij} in equation 33 transforms investment by sector of destination into demand for capital goods by sector of origin ID_i.

$$DST_i = dstr_i \cdot X_i \tag{30}$$

$$FXDINV = INVEST - \sum_i P_i^q \cdot DST_i \tag{31}$$

$$P_i^k \cdot DK_i = kshr_i \cdot FXDINV \tag{32}$$

$$ID_i = \sum_j b_{ij} \cdot DK_j \tag{33}$$

Equations 34 and 35 solve for nominal and real *GDP*. Nominal *GDP* is the sum of nominal value added, indirect taxes and tariffs, net of export subsidies.

Real *GDP* is determined from the expenditure side, where imports are valued in world prices and exclude tariffs, while nominal *GDP* is calculated from the value-added side.

$$GDPVA = \sum_i P_i^v \cdot X_i + INDTAX + TARIFF - EXPSUB \tag{34}$$

$$RGDP = \sum_i (CD_i + GD_I + ID_i + DST_i + E_i - pw_i^m \cdot M_i \cdot R \tag{35}$$

Macroeconomic closure equations

Market clearing equations and macroeconomic closures represent the system constraints that the model must satisfy. In the competitive market economy system developed here, prices adjust to clear each market. Equation 36 defines the market clearing condition for product markets and equation 37 specifies the equilibrium condition for factor markets where factor supply fs_f is exogenous. Factors may be sector-specific or mobile.

$$Q_i = INT_i + CD_i + GD_i + ID_i + DST_i \tag{36}$$

$$\sum_i FDSC_{if} = fs_f \tag{37}$$

Equation 38 describes the balance of payments closure. To establish the balance of payments, foreign savings are the difference between total imports and total exports. Because foreign savings are defined exogenously, the exchange rate is the equilibrating variable and works through changes in the relative prices of tradable to nontradable goods. The model in effect solves for stability between the real exchange rate and the balance of trade. Alternative balance of payment closures is possible; for example, the exchange rate may be fixed with foreign savings acting as the equilibrating variable. Another closure option would be to fix the price index with the exchange rate, in which case foreign savings would adjust to balance the account.

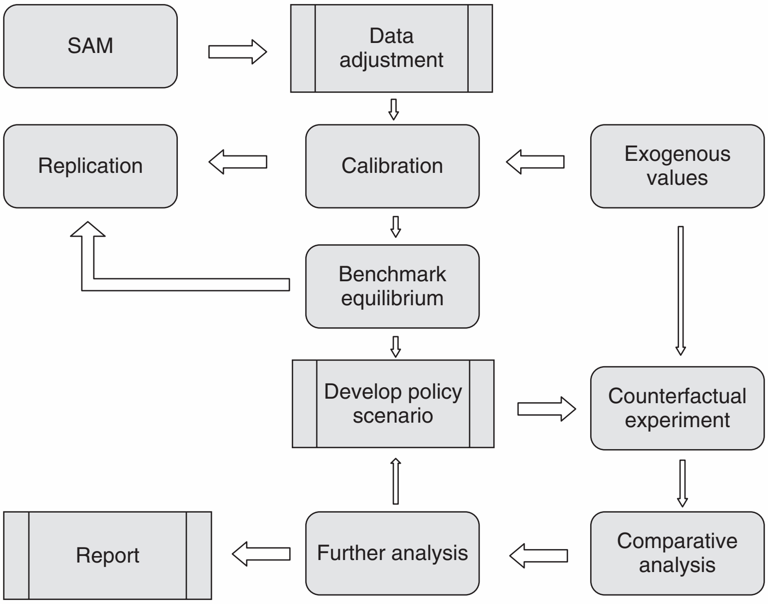


Figure 34.2 CGE workflow diagram with modifications.
Source: Shoven and Whalley (1992).

$$pw_i^m \cdot M_i = PW_i^e \cdot E_i + FSAV \tag{38}$$

Finally, equation 39 represents the aggregate savings *SAVING* and investment *INVEST* balance and is a neoclassical savings-driven closure where aggregate investment is the endogenous sum of the components of savings. Once again, alternative closures are possible such as the investment-driven closure, in which aggregate investment is fixed while a component of savings such as the marginal propensity to save or foreign savings is endogenous.

$$SAVING = INVEST \tag{39}$$

Once we have a system of equations in place, empirical analysis can proceed with a basic SAM (see Figure 34.2). The model is calibrated with base SAM data to estimate various model parameters and shares. Successful calibration to the base year of SAM replicates the benchmark equilibrium. Next, counterfactual scenarios are developed and exogenous values are specified to introduce the policy shock. The counterfactual experiment is conducted and a counterfactual equilibrium is established. This counterfactual is compared with the benchmark equilibrium to evaluate the impact of the policy shock on the economy. Results of this analysis may provide insight into further policy counterfactuals and additional scenarios may be implemented.

An illustration of CGE analysis through a case study of Brazil's forest policy

In this section we explore the regional economic impacts of Brazil's implementation experience with forest concessions in the Amazon. In 2006, Brazil's Public Forest Management Law

(PFML; Law 11.284/2006) was passed to regulate the management of public forests for sustainable use and conservation. Prior to this law, Brazil lacked a mechanism to enable the legal harvest of timber on public land. Almost all timber harvesting was conducted on private land or illegally on public land. The law's principal mechanism for developing the natural forestry sector is through establishing forest concessions on public land (Banerjee, Macpherson and Alavalapati, 2009).

The DCGE model developed in Banerjee and Alavalapati (2010), based on the International Food Policy Research Institute's Standard CGE Model in GAMS (Lofgren, Harris, Robinson, Thomas and El-Said, 2002; Robinson and Thurlow, 2004), was applied in this analysis. This model has a regional dimension, representing Brazil's administrative areas, namely, the north, northeast, center west, south and southeast.[2] The underlying data source for the model and its calibration is based on the SAM developed in Banerjee and Alavalapati (2009, 2010). The SAM, with a base year of 2003, has 14 sectors/commodities and has significant forest sector detail, including natural forest management, forest plantations and both legal and illegal deforestation activities. There are three types of labor based on skill level and low, middle and high household income categories.

One salient feature of this model is its ability to track illegal and legal deforestation activities and land use. Although rates of deforestation have been on the decline in Brazil, deforestation remains an important feature of the rural economy, affecting all economic sectors, especially agriculture and forestry. The production structure of the deforestation sector and the customization of the SAM required to represent deforestation are described in detail in Banerjee and Alavalapati (2010). Key assumptions in the treatment of this sector are as follows:

1. Illegal deforestation produces less timber per unit area than the legal deforestation sector and pays less for access to forestland.
2. The illegal deforestation sector does not pay taxes; instead, it pays fines based on assumptions on probabilities of apprehension and rates of collection.
3. The difference between an illegal and legal sector's expenditure to produce a unit of forest product output is considered to be the level of above-normal profits earned for operating illegally. This profit is allocated to labor.

Finally, while the stylized model presented earlier was a static model, the model applied in this analysis is a recursive dynamic model enabling the accrual of investment and growth in factor stocks. In both the baseline and the policy shock scenarios, labor supply is updated based on the estimated labor force growth rate. Capital stocks are updated endogenously based on the previous period's allocation of investment and the rate of capital depreciation. Total factor productivity growth is updated based on OECD (2006) projections while the average capital to output ratio is derived from Morandi and Reis (2004).

The stock of agricultural land is also updated each year. Because the deforestation sectors clear forestland, the quantity of forestland cleared in 1 year is used to update the factor supply of agricultural land in the subsequent year and is thus made available to the agricultural and forest plantation sectors. Equation 40 demonstrates the updating of the agricultural land stock based on the previous period's level of deforestation using the stock of agricultural land in the north as an example.

$$QFS_{agriland\ north,a,t+1} = QFS_{agriland\ north,a,t} + QF_{forestland\ north,legal\ deforestation\ north,t} + QF_{forestland\ north,illegal\ deforestation\ north,t} \quad (40)$$

where:

$QFS_{f,a,t}$ = Quantity of factor *f* demanded by activity a in time *t*;
$QFS_{f,a,t}$ = Quantity of factor supply for activity a in time *t*.

Policy scenario design

The policy scenario developed here follows from the observed rate of growth in forest concessions. Since the PFML was passed, approximately 350,000 ha were made available for harvest as forest concessions in the Amazonian states of Rondônia and Pará. Between 2007 and 2012, forest concessions have been implemented at a rate of 70,000 ha per year.

The forecast baseline projects the Brazilian economy to the year 2030 in the absence of the PFML. In the policy scenario, it is assumed that forest concessions are established in the northern administrative region at a rate of 70,000 ha per year beginning in 2008 and implemented in the model as a forestland shock until 2030. The difference between the policy scenario and the forecast baseline scenario is the impact of the PFML on the Brazilian economy.

A balanced model closure is used in this analysis because it is the preferred closure for examining the probable economic impacts of policy shocks (Lofgren et al., 2002). A flexible real exchange rate is chosen for the balance of payments closure, while the government closure fixes direct tax rates enabling flexible government savings. The domestic price index is chosen as the numeraire. The model is implemented in the general algebraic modelling system (GAMS) and solved as a mixed complementarity problem using the PATH solver.

Results of CGE analysis

The results presented here are the deviation between the forecast baseline and policy scenario with regards to average annual growth rates (AAGR). All macroeconomic indicators grew faster as a result of the implementation of forest concessions, including gross domestic product (GDP), private and government consumption, fixed investment, exports and imports (difference in AAGR of 0.004%, 0.004%, 0.002%, 0.006%, 0.002%, 0.002% and 0.001%, respectively). Household consumption for low-, mid- and high-income households grew faster (difference in AAGR of 0.004%, 0.005% and 0.005%, respectively). Equation 41 summarizes the movement of these macroeconomic indicators, where *C* is consumption, *I* is investment, *G* is government consumption, *X* are exports and *M* are imports. Although the rate of growth of imports increased, GDP still grew faster as a result of the implementation of forest concessions.

$$GDP\uparrow = C\uparrow + I\uparrow + G\uparrow + X\uparrow - M\uparrow \quad (41)$$

All economic activities increased output in the baseline with the exception of plantations in the southeast and legal and illegal deforestation in the northeast. The policy shock resulted in slower growth in forestry in the northeast, southeast and south (–0.015%, –0.007% and –0.004%, respectively; Table 34.1). Forest plantation activity grew slower in the north, northeast, southeast, south and center west (–0.331%, –0.296%, –0.309%, –0.293% and –0.349%, respectively). Legal deforestation grew slower in the center west (–0.012%), while illegal deforestation contracted even further than that in the baseline. The policy shock resulted in slower though positive growth in the price of agriculture, forestry, deforestation, sawmilling and food processing (difference in

Table 34.1 Difference in AAGR of economic sectors (%).

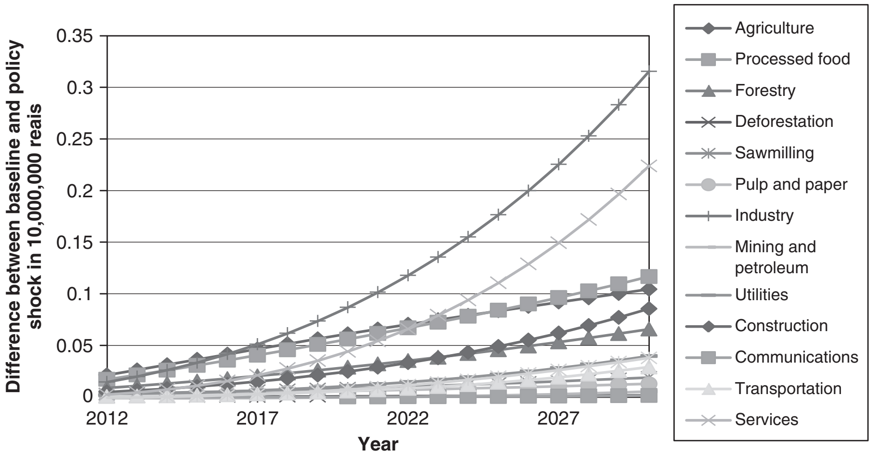
Activity	Difference in AAGR	Activity	Difference in AAGR
Agriculture north	0.051	Plantations south	–0.293
Agriculture northeast	0.033	Plantations center west	–0.349
Agriculture southeast	0.005	Deforestation north	1.417
Agriculture south	0.022	Deforestation northeast	0.175
Agriculture center west	0.002	Deforestation center west	–0.012
Food processing	0.010	Illegal deforestation north	0.076
Forestry north	2.163	Illegal deforestation northeast	0.055
Forestry northeast	–0.015	Illegal deforestation center west	–0.099
Forestry southeast	–0.007	Industry	0.002
Forestry south	–0.004	Mining and petroleum	–0.002
Forestry center west	0.068	Utilities	0.003
Sawmilling	0.036	Construction	0.005
Pulp and paper	0.098	Communications	–0.005
Plantations north	–0.331	Transportation	0.002
Plantations northeast	–0.296	Services	0.002
Plantations southeast	–0.309	Public administration	0.001

AAGR of –0.0052%, –0.1430%, –0.0496%, –0.0364% and –0.0013%, respectively), while pulp and paper product prices fell faster (–0.0008%).

Figure 34.3 depicts the difference between the baseline and policy shock for output of domestically produced goods. Industrial commodities and services were the largest gainers, though beginning from an already large base. The increased growth rate of agriculture was tracked by that of the processed food sector. Construction and forest-sector commodity output also grew faster.

The implementation of forest concessions had a positive growth impact for the Brazilian economy, which was expected, because forest concessions were modelled as an increase in the land endowment, enabling increased forest sector output in the north. One of the strengths of the CGE approach highlighted in this case study is its ability to shed light on sectoral linkages and regional impacts. For example, while overall the impact of the policy was positive, forest concessions resulted in slower growth in Brazil's northeast, southeast and southern forestry sectors. Forest plantation activities also grew slower in all regions. This result is largely explained by the increase in output and greater competitiveness of the forest sector in the north as well as increased forest product output through deforestation in the north and northeast.

In the baseline scenario, legal forestry in the north and center west contracted. Legal forestry expanded in all other regions. With forest concessions implemented in 2008, the opposite became true, with a positive policy impact in the north and center west and negative impacts



AuQ381 *Figure 34.3* Difference between baseline and policy shock domestic commodity production.

in other regions. This is an indication of forestland scarcity, which was offset to a degree by an increase in the forestland endowment. Greater growth in the north and center west was accompanied by expansion in the sawmilling and pulp and paper sectors, which use forest products as intermediate inputs.

Illegal deforestation grew in the north and center west and contracted in the northeast in the baseline. Forest concessions caused a contraction in illegal deforestation in all regions. This contraction in illegal deforestation is a function of the increasing scarcity of forestland on which firms may operate illegally and the reduced returns to agricultural land. Greater growth of legal deforestation in the north and northeast produced agricultural land, allowing the sector to expand in these regions, while reduced growth in illegal deforestation in the center west slowed growth in this region.

Thus, in contrast to partial equilibrium approaches, the CGE approach highlights the interdependencies among economic sectors as well as regions. Constraints on resources (capital, labor and land) result in some sectors contracting while others expand. All sectors in the economy compete for scarce resources. Those sectors with comparative advantage are able to pull resources from less productive sectors. This also holds true for capital investment, in which sectors with above-average rates of return capture a greater share of investment. The dynamic among forestry, forest plantations, deforestation and agriculture is revealed in this analysis, with forestry in the north outcompeting forestry in most other regions. In the case of agricultural land, higher returns to agriculture draw land out of forest plantation production and into agriculture. A general equilibrium approach is required to shed light on this competitive dynamic.

Innovations in CGE analysis

Since Jones's (1965) seminal publication on 'The Structure of Simple General Equilibrium Models' in the *Journal of Political Economy*, several advancements have been made in CGE modelling. Specific institutions have been created to facilitate interaction among CGE modellers, policymakers and other end-users, to share experiences and innovations, and to provide modelling support and advice. The Global Trade Analysis Project (GTAP) at Purdue University is one of the largest such institutions. GTAP aims to improve quantitative analysis in an economy-wide framework by developing a common language for economic analysis through development of software and data, training and annual conference events. The Centre of Policy Studies (CoPS), based at Monash University in Australia, is another institution that does significant economic research and policy analysis for government and the private sector globally. The CoPS has developed a number of widely used models, including ORANI, MONASH and TERM, and offers training courses in CGE modelling worldwide. The CoPS has also developed GEMPACK, a CGE modelling software program, enabling accurate and efficient solution of CGE models, which provides powerful analytical tools to facilitate analysis and interpretation of results (Harrison and Pearson, 1996).

The Partnership for Economic Policy (PEP) was instituted in 2002 and now has over 8,000 members worldwide. PEP aims to ensure greater participation of local expertise in the analysis of issues related to poverty and socioeconomic development, using CGE models as one analytical approach. PEP's mandate is to produce evidence-based policy advice, develop analytical tools and build capacity in policy analysis. Finally, EcoMod is a global economic modelling network with over 3,000 members and offers training, support and advisory services to clients. EcoMod aims to promote advanced modelling and statistical techniques in economic policy and decision making through research, training, conferences and workshops.

Advances have also been made with regard to model validation, which is important to assure policymakers and other users that model results are credible. Validation refers to (1) verifying that solutions were computed correctly and (2) demonstrating that an explanation of results is an accurate reflection of the mechanics of the model. Validation may also be extended to demonstrating model consistency with history, as well as its effectiveness as a forecasting tool. Many procedures exist for validating a CGE (see Dixon and Rimmer, 2013); we present three of the more common approaches.

Testing model sensitivity to parameter inputs (e.g. shock and elasticity parameters) is one test of the robustness of a model and enables confidence intervals to be constructed around model results (e.g. welfare measures) and is referred to as systematic sensitivity analysis (SSA) (Alavalapati, Adamowicz and White, 1999). Monte Carlo analysis is one approach to SSA where a model is solved iteratively with the parameter of interest randomly selected from a sample distribution. For large models, however, this can make model solution cumbersome. The Guassian Quadrature approach provides a good alternative which estimates an approximate parameter distribution, thereby saving considerable computing time (Hertel, Hummels, Ivanic, and Keeney, 2004). Tools for conducting SSA have been built into the CGE modelling software, GEMPACK, facilitating their application significantly (Horridge and Pearson, 2011).

Demonstrating that results are consistent with the workings of the model may be achieved through telling a qualitative story, and quantitatively through back-of-the-envelope (BOTE) calculations. Telling a qualitative story simply seeks to explain model results in broad descriptive terms in a way which demonstrates that model results are supported by assumptions on how the economy behaves (Dixon and Rimmer, 2013). A quantitative BOTE may then help explain a particular model feature that reproduces key aspects of the results. BOTE models may be as simple as containing only one domestically produced good which is consumed domestically and exported, an imported good and one type of capital and labor. The specification of the BOTE depends on the application (see Dixon and Rimmer, 2013, for examples).

The diversity of thematic areas to which CGE models are applied has increased considerably in the last decade. For example, there is a growing interest from policymakers and practitioners to consider policy impacts on ecosystem services – the benefits nature contributes to human well-being (Costanza et al., 1997; Daily, 1997; Millenium Ecosystem Assessment, 2005; Perrings, 2006; Kumar, 2010). Some ecosystem service values are traded in the market (e.g. carbon credits for climate change mitigation). Other ecosystem services are not traded in the marketplace and are therefore not captured in regular accounting frameworks. These services include regulating services such as erosion and natural disaster mitigation, the provision of habitat and gene pools and cultural and aesthetic values, to mention a few examples.

The System of Environmental and Economic Accounts (SEEA) was developed to hybridize economic data with environmental information in a common accounting framework such that the contribution of the environment to the economy as well as the impact of economic activity on the environment may be assessed in a quantitative way (Dube and Schmithusen, 2003). SEEA provides a promising framework for the accounting of ecosystem service supply and a platform for their integration with CGE models as it follows the United Nations' system of national accounts (European Commission et al., 2012). This framework is the first international statistical standard for environmental-economic accounting.

Significant advances have been made in regional CGE modelling, with increasing demand for evidence-based analysis to inform policies across regions. This demand has been driven in part by the transformative impacts of globalization and technical progress leading to regionally differentiated outcomes and a need to understand the underlying processes (Giesecke and Madden, 2013). Significant regional detail can be included in these models, from region-specific technologies, tastes and constraints, to regionally differentiated policies and policy shocks.

A regional model may be a single region which models an economy with little detail beyond what occurs beyond the regional border; a top-down model which disaggregates results by region through decomposition; a bottom-up model which models each region as a separate economy with a robust specification of interregional trade and factor flows subject to national and regional resource constraints; and finally, a hybrid top-down bottom-up model, such as the model presented in the Brazilian case study, which maintains a standard structure, though incorporates bottom-up detail as required by the nature of the inquiry. Bottom-up models enable deeper treatment of issues such as factor mobility, trade and transport, trans-boundary factor ownership, migration, interregional investment, transport margins, regionally differentiated treatment of taxes and the impact of regional and national government policy (Giesecke and Madden, 2013).

The development and application of DCGE has seen significant advances. Many CGE models are comparatively static and have been used to ask 'what if' questions (Dixon and Rimmer, 2009). Static models roughly distinguish between a short term, where capital is immobile between regions, and a long term, where capital stocks are interregionally mobile. Assumptions with regards to labor are made as appropriate to the particular region being modelled. Dynamic models are increasing their presence due to the additional economic insight they provide. Dynamic models portray the transition path of an economy, which permits a more robust specification of investment behavior, the potential to introduce lags such as sticky wages and interregional labor migration, as well as the ability to customize the policy or environmental shock through time for greater realism.

Understanding the past can help us better understand the future; that is, the relative importance of drivers of change can inform future policy development by highlighting those factors that were more important in driving economic outcomes (Giesecke and Madden, 2013). Historical modelling is one form of dynamic modelling and can shed light on how preferences and technologies as well as policies, trade and foreign demand have evolved over time (Dixon and Rimmer, 2009). This form of modelling occurs in two steps – first as a historical simulation and then a decomposition simulation. The power of this approach lies in its ability to provide information on the individual contributions of the historical movement of variables of interest, including those pertaining to policy and economic structure (Giesecke and Madden, 2013).

Economic forecasting is another emerging area for CGE modelling, providing forecasts for industries, employment and regional economies. Baseline forecasts use information derived from historical simulations; thus, the forecasts are consistent with historical trends, often supplemented by expert opinion (Dixon and Rimmer, 2009). Baseline forecasts also serve as the business-as-usual case used as a reference by which the impact of a policy change is evaluated. The net welfare impact of a policy or investment program depends heavily on the baseline forecast used (Wittwer and Banerjee, in review).

For the consideration of particular policy options, sometimes greater detail in agent behavior may be required, which has led to the integration of new theoretical constructs into the CGE model itself – for example, the TERM H_2O model, which incorporates a water accounting and trading framework within the CGE (Wittwer, 2012) or theories of lagged wage adjustment. Alternatively, CGE models may be linked with microsimulation models to enable more robust analysis of household level effects, particularly where understanding policy impacts on poverty and inequality are of interest (Ferreira Filho and Horridge, 2006; Agenor, Chen and Grimm, 2004; Savard, 2005; Bouet, Estrades and Laborde, 2013).

Notes

1 Notational convention: Upper case variables are exogenous; lower case variables are endogenous. The subscript *i* refers to commodities, and the subscript *j* refers to activities. The superscripts *m* and *e* are for imports and exports, respectively; *d* represents domestic, *x* is output, *v* is value added, *q* is composite commodity and *k* is for capital.

2 Brazil's administrative regions are north, northeast, southeast, south and center west. The northern region is composed of the states of Rondônia, Acre, Amazonas, Roraima, Pará, Amapá and Tocantins. The northeastern region includes Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia. The southeast includes Minas Gerais, Espírito Santo, Rio de Janeiro and São Paulo. The south includes Paraná, Santa Catarina and Rio Grande do Sul. The center west includes Mato Grosso do Sul, Mato Grosso, Goiás and the Distrito Federal.

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