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A Description of the Hybrid Bottom-Up CGE Model SCREEN with an Application to Swiss Climate Policy Analysis

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1 Introduction

Optimum and equilibrium seeking modeling approaches have been successfully applied to analyze energy-economy interactions and to elaborate rational policies. The first category, *optimum seeking approaches*, comprises mathematical programming models that typically maximize an economy-wide utility function within a one-sector economic representation under a set of technological constraints. Such models have been useful in energy planning as they include a detailed technological (bottom-up) representation and feature a comprehensive analysis of discrete technological choices in production. They lack, however, the necessary level of detail in their representation of the economy and either ignore sectoral differences or simply include them exogenously without resorting to microeconomic foundations. *Equilibrium seeking models*, by contrast, differentiate between various sectors of the economy and are based on microeconomic foundations. However, this kind of model adopts a top-down point of view, and usually lacks an accurate technological representation of the energy sector. It describes energy conversion at an aggregate level by means of continuous production functions that capture substitution possibilities through elasticities of substitution.

The need for a technologically detailed energy policy model and the strengths and weaknesses of different modelling approaches have recently been discussed by various researchers who employ different approaches to overcome the gap between top-down and bottom-up models (e.g. Jochem 1999, Müller 2000, Messner and Schrattenholzer 2000, Koopmans and Willem te Velde 2001, and Arıkan and Kumbaroglu 2001, among others).

The model introduced and applied in this paper, SCREEN (Sustainability Criteria for REgional ENergy policies, Frei 2001), overcomes the bottom-up – top-down dilemma by integrating bottom-up technological detail into the electricity sector of an equilibrium seeking framework according to the theory developed in Böhringer (1998). The scope of the SCREEN model meets the needs for studying pathways for a more sustainable development, which requires perspectives and instruments for the longer-term planning and assessment. For example, it may be used to study ecological tax reforms where typically energy is being taxed at a higher rate and labor at a lower rate as before, thus leading to production factor substitution effects and a so-called "double dividend" (i.e. creating extra jobs and at the same time reducing the adverse environmental impacts of energy use; Pearce 1991). For an investigation of the impacts of an ecological tax reform in Switzerland employing SCREEN see Frei (2001). Its comparably easier tractability is a distinguishing feature and advantage of SCREEN, as compared to much more sophisticated national models, such as GEM-E3 Switzerland (Bahn and Frei 2001).

In the empirical part of the paper, we employ the SCREEN model to study, relative to a business-as-usual scenario, the likely impacts caused by the introduction of a CO_2 tax in Switzerland by 2004, that aims to help achieving the CO_2 mitigation target of –10% in 2010 (compared to the reference year 1990) set in the Swiss CO_2 Act (CO_2-Gesetz 2000). Particularly, apart from total CO_2 emission development we will report on the induced changes in the electricity sector and of several macroeconomic indicators over the model horizon 2000-20.

The organization of the paper is the following: section 2 gives an introduction on the main features and the basic structure of SCREEN. Section 3 first provides a brief overview on the current CO_2 legislation in Switzerland, followed by a description of the two scenarios envisaged in the empirical application, and a presentation of the results obtained from the scenario analysis. Section 4 summarizes and concludes.

2 A primer to the SCREEN model

The model SCREEN, developed by our former colleague Frei (2001), has been developed and designed to model the consequences of today's energy policy decisions on the long-term evolution of energy technology mixes and on socio-economic and environmental indicators. It is a computable general equilibrium (CGE) type of model (Shoven and Whalley 1992, among others), formulated in the complementarity format[a] as a non-linear system of inequalities.

SCREEN disaggregates the (Swiss) economy into twelve sectors: (1) electricity; (2) fossil fuels; (3) agriculture, forestry, and fishery; (4) ore and metals; (5) chemicals; (6) other energy intensive industries; (7) equipment goods; (8) consumer goods; (9) building and construction; (10) telecommunications; (11) transport; and (12) services (for a more detailed account see Table 2-1).

Table 2-1. The production sectors in SCREEN

No.	Abbr.	Sector
1	ELE	Electricity, nuclear fuels, steam, hot water, compressed air
2	FOS	Fossil fuels
3	AGR	Agricultural, forestry, fishery products
4	MET	Ferrous and non-ferrous ore and metals other than radioactive
5	CHE	Chemical products
6	ENI	Other energy intensive industries (non-metallic minerals and mineral products; metal products except machinery and transport equipment; paper & printing products)
7	EQP	Equipment goods (electrical goods; transport equipment; other equipment goods industries)
8	CNG	Consumer goods industries (food, beverages and tobacco; textiles and clothing; timber and wooden furniture; leather and footwear; rubber and plastic products; other manufacturing products)
9	BLD	Building and construction
10	TLC	Telecommunications services
11	TRS	Transport (inland; maritime and air; auxiliary transport services)
12	SRV	Services (credit and insurance institutions; other market services; non-market services)

Source: adopted from Frei (2001)

In each sector *s* production is described by a nested structure as follows:

$E_s = f(ELE_s, FOS_s)$ (1.1)

$K_s/E_s = f(E_s, K_s)$ (1.2)

$L_s = f(L1_s, L2_s)$ (1.3)

$L_s/K_s/E_s = f(L_s, K_s/E_s)$ (1.4)

$Y_s = f(L_s/K_s/E_s, MAT_s)$ (1.5).

The function f *is* specified in constant-elasticity-of-substitution (CES) form[b], i.e.

$$f(i_1, i_2) = (\varphi_1\, i_1^{\rho} + \varphi_2\, i_2^{\rho})^{1/\rho} \quad (2)$$

where the pair (i_1, i_2) stands for the input pairs *(ELE, FOS)*, *(E, K)*, *(L, K/E)* and *(L/K/E, MAT)*; φ denotes the value shares of inputs, and the substitution elasticity is given as $\sigma = [1/(1\text{-}\rho)]$. Energy (*E*) is a CES aggregate of electricity (*ELE*) and fossil fuels (*FOS*). The energy aggregate comes together at the second level with capital (*K*) to produce a capital/energy bundle (*K/E*). *K/E* is then Cobb-Douglas (unitary elasticity of substitution) aggregated with labor (*L*) to yield a labor-capital-energy composite (*L/K/E*). Labor itself is a CES aggregate of two labor segments (*L1* and *L2*) of which the former includes non-monitored jobs and competitive wages, as opposed to the latter segment with monitored jobs and efficiency wages. Finally, *L/K/E* is combined in fixed proportions (zero elasticity of substitution, i.e. assuming a Leontief production function) with material inputs (*MAT*) to produce output (*Y*) (cf. Figure 2-1. Nesting structure of the CES functions characterizing the production sectors).

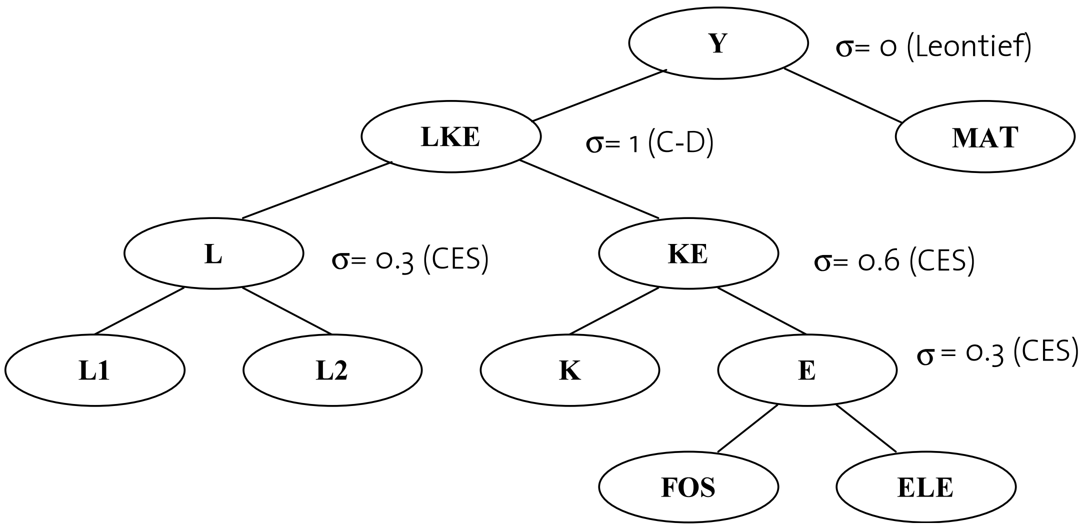


Figure 2-1. Nesting structure of the CES functions characterizing the production sectors

The energy sector is further disaggregated so as to absorb the output of a technologically detailed sub-sector that produces electricity. Seven alternative sources of power generation compete for market share in the bottom-up modeled electricity producing sub-sector: (1) gas-fired thermal power, (2) thermal power from biomass, (3) nuclear power, (4) hydro power, (5) power obtained from waste incineration, and power obtained from renewable sources: (6) wind turbines, and (7) photovoltaic systems (cf. Table 2-2). The technologies are defined as Leontief and hence use production factors in fixed, constant proportions. Technology-specific production (YT_{tec}), accordingly, is defined for each technology *tec* as

$$YT_{tec} = min(\alpha_{K,tec} K_{tec} , \alpha_{L,tec} L_{tec} , \alpha_{ELE,tec} ELE_{tec} , \alpha_{FOS,tec} FOS_{tec} , \alpha_{MAT,tec} MAT_{tec}) \quad (3)$$

where α denotes the Leontief coefficients. In the hybrid model, YT_{tec} enters as material input (part of *MAT*) into the production function of the electricity sector. Accordingly, a technology is defined by its specific physical input needs. Stationarity of the input coefficients is a strong assumption in the long run as it excludes the possibility of (technology-specific) technological progress. The model horizon has therefore been restricted to twenty years. Note that for analyses further into the future, technological progress could be incorporated by representing a technological improvement simply as a separate future technology.

Table 2-2. Electricity generation technologies covered in SCREEN

No.	Abbr.	Technology
	DEF	Generic default technology for SPF
1	GAS	Gas, thermal
2	NUC	Nuclear, fission
3	HYD	Hydro power
4	WST	Waste incineration
5	WIN	Wind turbines
6	SOL	Solar photovoltaic
7	BIO	Biomass, thermal
8	ELM	Electricity imports

Source: adopted from Frei (2001)

Foreign trade is implemented in the model by assuming a small open economy with negligible impact on world prices. That is, any import demand is met at exogenously fixed world prices and any export supply is sold at exogenously fixed world prices. The unit cost of an imported good, c_g^m, is accordingly determined as

$$c_g^m(p) = p^{fx} \cdot p_g^m \cdot (1 + t_g^m) \quad (4)$$

where pfx is the price of foreign exchange (i.e. the real exchange rate), p_g^m stands for the exogenous import price[c] of good g and t_g^m is the import tax rate. Similarly, the unit revenue from exports, rev_g^x, is determined as

$$rev_g^x(p) = \frac{p^{fx} \cdot p_g^x}{1+t_g^x} \quad (5)$$

where p_g^x stands for the (exogenous) export price[d] and t_g^x is the export tax rate. The gross import and export volumes emerge from relative price changes that are determined via equilibrium conditions described below.

Agents accounted for in the model are producers, consumers and a government. Consumers maximize utility by consuming commodities produced by the twelve sectors subject to endowments of primary factors. Producers maximize profits subject to available production technologies that transform primary and intermediate input factors into commodities. The government imposes taxes on production and collects social contributions both from employers and employees. There is no provision of a public good and the tax and social revenues are assumed to be redistributed in lump-sum fashion. The general equilibrium (GE) concept identifies zero profit, market clearance and income balance as the well-known three classes of conditions that correspond to the general first-order necessary conditions of the producers' profit maximizing and consumers' cost minimizing problems. These conditions, which characterize a competitive Arrow-Debreu equilibrium, are the core of the GE problem formulation. Economic theory tells that absolute prices are meaningless as the equilibrium is determined by relative prices only. Therefore, an index notation is used in the model formulation, describing the relative evolution compared to a benchmark situation. The adopted notation is such that $\bar{z}$ and $\hat{z}$, respectively, refer to benchmark and relative values of variable z , i.e. $\hat{z} = z/\bar{z}$. Below is a summary of the equilibrating constraints, derivation details can be explored in Frei (2001).

The 1990 social accounting matrix (SAM)[e] used in SCREEN has been constructed from various sources (see Frei 2001 for details, and Table a-1 in the appendix for the base-year value flows of the national economy). A new production account is currently in preparation that will soon allow an update of SCREEN.

2.1 Zero profit conditions

The first class of equilibrium conditions, zero profit, is based on profit maximization and implies that the marginal cost of a commodity or factor cannot be smaller than its market price. Zero profit is imposed on labor, sectoral production, technologies, foreign trade activities, and utility production.

2.1.2 Zero profit for employment

A zero profit condition is imposed on the labor market in order to implement the concept of efficiency wages (Yellen 1984, Huang et al. 1998). The theory recognizes that a worker's productivity depends not only on human endowments, as is assumed in traditional neoclassical models, but also on the compensation they receive. The constraint is of the form

$$\hat{w} \cdot \frac{\overline{w}}{\overline{w}_u} - 1 \geq \frac{\varepsilon/\overline{w}_u}{q} \cdot \left(b \cdot \frac{L^*}{L^* - L} + \Delta \right) \tag{6}$$

where L is the actual employment level, L^* the level of full employment, w the efficiency wage and w_u the unemployment wage (i.e. the social contribution that is paid to the unemployed workers). ε is the workers' utility cost of supplying effort, q the probability of shirkers to be caught and fired, b the labor turnover rate, and Δ the discount rate. It is implicitly assumed that workers who want more than the efficiency wage are unemployed and that firms who pay less than the efficiency wage employ shirking workers.

2.1.3 Zero profit for production sectors

The zero profit condition for sectors implies that no sector earns a positive profit. For the Cobb-Douglas functional form the formulation is

$$\left(\frac{\hat{w}}{\hat{\eta}_L} \cdot (1 - \rho^L) \right)^{\theta_s^L} \cdot \left(\frac{\hat{r}}{\hat{\eta}_K} \right)^{\theta_s^K} \Pi_g \left(\hat{p}_g^{ag} \cdot (1 + t_g) \right)^{\theta_{s,g}} \geq \hat{p}_s \tag{7}$$

where p_s is the pre-tax producer price (at the factory gate) in sector s; p_g^{ag} is the pre-tax price of the so-called 'Armington good' (an artificial CES aggregate of domestic and imported goods, see 2.1.4) used as an input for production; t_g is an input-specific ad-valorem tax rate, r denotes the rental rate of capital K; θ stands for the benchmark value shares; ρ^L is an ad-valorem restitution rate on labor; and $\hat{\eta}_L$ and $\hat{\eta}_K$ are the factor efficiencies of labor and capital, respectively.

2.1.4 Zero profit for technologies

The differentiation of various electricity generating technologies necessitates the definition of an additional zero profit condition for technologies competing for market share in the electricity sector of the hybrid model. The zero profit formulation for technologies is

$$\sum_g \overline{c}_{g,s,tec} \cdot \hat{p}_g^{ag} \cdot (1 + t_g) + t_{tec}^{xc} + \overline{c}_{s,tec}^{trf} + r_{s,tec}^{ssc} \geq \hat{p}_s^{dsp} \qquad \text{for } s = \text{electricity} \tag{8}$$

where p_s^{dsp} is the dispatch price at marginal cost of the technology aggregate; $\bar{c}_{s,tec}^{trf}$ are benchmark transfers per unit of technology output; $r_{s,tec}^{ssc}$ is the short term scarcity rent of a technology; t_{tec}^{xc} is the technology-specific excise tax rate; p_g^{ag} again is the price of the Armington good; and $c_{g,s,tec}$ is the technology-specific unit cost. The first term in the above inequality, $\sum_g \bar{c}_{g,s,tec} \cdot \hat{p}_g^{ag} \cdot (1+t_g)$, is the short-term marginal cost of a technology.

2.1.5 Zero profit for foreign trade

The standard Armington formulation (Armington 1969), assuming that domestic and international goods are imperfect substitutes, is employed for specifying foreign trade activities. It allows to consider two-way trade and at the same time to avoid unrealistically high levels of specialization. That is, imported and domestic commodities are CES-aggregated in order to produce the 'Armington good'. The associated zero profit condition is of the form

$$\left[\theta_g^m \cdot \left(\hat{p}^{fx} \cdot \hat{p}_g^m\right)^{(1-\sigma_g^m)} + \left(1-\theta_g^m\right) \cdot \left(\hat{p}_g^{ds}\right)^{(1-\sigma_g^m)}\right]^{\frac{1}{1-\sigma_g^m}} \geq \hat{p}_g^{ag} \tag{9}$$

where θ_g^m is the value share of imports in the domestic consumption; p_g^{ds} is the price of the domestic sector output for domestic supply; and σ_g^m is the elasticity of substitution between the imported and the domestically produced good.

As a symmetric formulation to the Armington assumption, a constant-elasticity-of-transformation specification characterizes the splitting of domestic production between domestic and export markets, and the associated zero profit condition is of the form

$$\left[\theta_g^x \cdot \left(\hat{p}^{fx} \cdot \hat{p}_g^x\right)^{(1+\nu_g^x)} + \left(1-\theta_g^x\right) \cdot \left(\hat{p}_g^{ds}\right)^{(1+\nu_g^x)}\right]^{\frac{1}{1+\nu_g^x}} \geq \hat{p}_g^d \tag{10}$$

where θ_g^x is the value share of exports in the domestic production; p_g^d is the (shadow-) price for domestic sector-output; and ν_g^x is the elasticity-of-transformation that defines the sensitivity of the sector's market selection to relative price changes. The zero profit formulations for foreign trade do not include import and export taxes, as it is assumed that the rates of those taxes remain unchanged.

2.1.6 Zero profit for utility production

Households are treated as a production sector that consumes only goods and services, but no primary input factors. A Cobb-Douglas aggregation is employed in combining goods and services for utility production. The zero profit function for household utility may accordingly be specified as

$$\Pi_g \left(\hat{p}_g^{ag} \cdot (1 + \frac{t_g}{1 + \wp_g^{trf}}) \right)^{\theta_g^u} \geq \hat{p}^u \qquad (11)$$

where p^u is the price of utility (i.e. the consumer price index) and $\wp_g^{trf}$ is the rate that summarizes the benchmark transfers that come up from taxes and subsidies.

2.2 Market clearance conditions

The market clearance conditions ensure that, at equilibrium prices and activity levels, there is enough supply of a commodity to satisfy excess demand by consumers. These conditions are defined for labor markets, commodities, capacity markets, the balance of payments, and the utility good.

2.2.1 Market clearance for labor markets

Labor market clearance conditions imply that the supply of labor is at least as high as its demand. For the hybrid case with a Cobb-Douglas production function characterizing top-down sectors and an activity analysis representation characterizing the bottom-up formulated power supply sector, the condition for labor market clearance is

$$L \geq \sum_{s \in SPF} \frac{\bar{L}_s^D}{\hat{\eta}_L} \cdot \hat{y}_s \quad \frac{\hat{p}_s}{\frac{\hat{w}}{\hat{\eta}_L} \cdot (1 - \rho^L)} + \sum_{tec, s \notin SPF} \frac{\bar{c}_{s,tec}^L}{\hat{\eta}_L} \cdot y_{tec,s} \qquad (12)$$

where $\bar{L}_s^D$ is the sector-specific benchmark demand for labor; y_s represents the output of top-down sectors; $y_{tec,s}$ stands for the technology-specific output of the bottom-up electricity sector; and $\bar{c}_{s,tec}^L$ is the technology-specific benchmark unit expenditure for labor. The set *SPF* stands for 'Smooth Production Function' and covers the top-down sectors (i.e. all sectors except electricity). The case with CES production functions is formulated analogously.

2.2.2 Market clearance for commodities

Due to the artificially introduced Armington good, there are two market clearance conditions for commodities. First, the domestic sector output for domestic supply is absorbed as input in the Armington good. The associated market clearance condition can be written as

$$\hat{y}_g \cdot \left(\frac{\hat{p}_g^{ds}}{\hat{p}_g} \right)^{\nu_g^x} \geq \hat{y}_g^{ag} \cdot \left(\frac{\hat{p}_g^a}{\hat{p}_g^{ds}} \right)^{\sigma_g^m} \qquad (13)$$

where y_g and y_g^{ag} are respectively the output levels of the domestically produced good for domestic supply and of the Armington good. Second, the total supply of the Armington good satisfies the domestic demand consisting of the final demand of households, y^u, the intermediate demand of top-down and bottom-up sectors, and the technology-specific investment demand, $I_{s,tec}$:

$$\bar{y}_g^a \cdot \hat{y}_g^a \geq \bar{d}_g^{hh} \cdot \hat{y}^u \frac{\hat{p}^u}{\hat{p}_g^a \cdot \left(1 + \frac{t_g}{1 + \wp_g^{trf}}\right)} + \sum_{s \in SPF} \bar{d}_{s,g} \cdot \hat{y}_s \frac{\hat{p}_s}{\hat{p}_g^{ag} \cdot (1 + t_g)}$$
$$+ \sum_{tec,\, s \notin SPF} \bar{c}_{g,s,tec} \cdot y_{tec,s} + \sum_{tec,\, s \notin SPF} \frac{p_{g,tec}^I}{\tau_{tec}^{av}} I_{s,tec} \qquad (14)$$

where τ_{tec}^{av} stands for the average annual availability of a technology and $p_{g,tec}^I$ denotes the technology-specific price of an investment good.

2.2.3 Market clearance for capacity markets

The capacity supply in the electricity sector is bounded from above to reflect the technology-specific capacity restrictions in the short-term, i.e.

$$K_{tec,s} \geq y_{tec,s} \qquad \text{for } s = \text{electricity} \qquad (15)$$

where $K_{tec,s}$ represents the available capital stock of a specific technology *tec*.

2.2.4 Market clearance for the balance of payments

Exports and remittances from abroad determine the supply of foreign exchange and, similarly, imports determine the demand for foreign exchange. Hence the real exchange rate that equilibrates the demand and supply of foreign exchange depends on the levels of imports (m_g), exports (x_g) and transfers (*TRF*). The associated market clearance formulation is

$$\sum_g \bar{x}_g \cdot \hat{x}_g \cdot p_g^X + \overline{TRF} \geq \sum_{g \in SPF} \bar{m}_g \cdot \hat{y}_g^{ag} \cdot p_g^m \left(\frac{\hat{p}_g^{ag}}{\hat{p}^{fx} \cdot \hat{c}_g^m}\right)^{\sigma_g^m} + \sum_{g \notin SPF} y_g^m \cdot \hat{p}_g^m$$
$$+ \frac{1}{\hat{p}^{fx}} \cdot \left(\beta^{sav} \cdot PP^{hh} \quad \sum_s I_{tec,s} \sum_g \frac{p_{g,tec}^I}{\tau_{tec}^{av}} \cdot \hat{p}_g^{ag} \cdot (1 + t_g)\right) \qquad (16)$$

where β^{sav} is the fraction of household savings and PP^{hh} stands for the purchasing power of households (total consumption expenditure of households, described as an income balance equation).

2.2.5 Market clearance for the utility good

The market clearance condition for the 'utility good' is obvious:

$$\bar{y}^u \cdot \hat{y}^u \cdot \hat{p}^u \geq \left(1 - \beta^{sav}\right) \cdot PP^{hh} \quad . \tag{17}$$

2.3 Income balance conditions

The income balance conditions ensure that the sum of savings and expenditures equals total disposable income. Hence, the disposable income of households is computed as

$$PP^{hh} = L \cdot w + K \cdot r + REV + TRF \cdot p^{fx} \tag{18}$$

where *REV* stands for the total tax revenue defined as

$$REV = \sum_g \frac{t_g}{\left(1+\wp_g^{trf}\right)} \cdot \hat{p}_g^a \cdot \bar{d}_g^{hh} \cdot \hat{y}^u \cdot \frac{\hat{p}^u}{\hat{p}_g^{ag} \cdot \left(1 + \frac{t_g}{1+\wp_g^{trf}}\right)}$$

$$+ \sum_g \hat{p}_g^{ag} \cdot \left(\begin{array}{l} \sum_{s \in SPF} t_g \cdot \bar{d}_{g,s} \cdot \hat{y}_s \cdot \frac{\hat{p}_s}{\hat{p}_g^{ag}\left(1+t_g\right)} + \sum_{tec, s \notin SPF} t_g \cdot \bar{c}_{g,s,tec} \cdot y_{s,tec} \\ + \sum_{tec, s \notin SPF} t_g \cdot \frac{p_{g,tec}^I}{\tau_{tec}^{av}} \cdot I_{s,tec} \end{array} \right)$$

$$+ \sum_g t_g \cdot y_g^m \cdot \hat{p}^{fx} \cdot \hat{p}_g^m + \sum_{s \notin SPF} t_{tec}^{xc} \cdot y_{tec,s} \tag{19}$$

2.4 Dynamic specifications

In addition to the equilibrium conditions, there are technology- and sector-specific constraints that determine the investment behavior. The evaluation of the technology-specific expected return on capital that conditions the investment decision is based on the relation

$$r_s + r_{s,tec}^{lsc} \geq \frac{\tau_{tec}^{av}}{\tilde{p}_{tec}^I} \cdot \left[r_s^K + r_{s,tec}^{ssc} \cdot \frac{y_{tec}}{K_{tec}} \right] - \delta_{tec} - \zeta_{tec} \tag{20}$$

where $r^{lsc}_{s,tec}$ is the long-term scarcity rent of a technology, τ^{av}_{tec} is the expected technology-specific plant availability (load factor), $\tilde{p}^{I}_{tec}$ is the price of the technology-specific investment composite good, δ_{tec} stands for the depreciation rate of the technology-specific capital stock, and ζ_{tec} is the specific adjustment cost.

There are also differences between sector returns on capital as a consequence of partial capital mobility. The evaluation of the sector-specific expected return on capital is based on the relation

$$\hat{r}_s^{\mu^I} \cdot \sum_{tec} \bar{I}_{s,tec} \cdot \sum_g \frac{p^I_{g,tec}}{\tau^{av}_{tec}} \cdot \hat{p}^{ag}_g \cdot (1+t_g) \geq \sum_{tec} I_{s,tec} \cdot \sum_g \frac{p^I_{g,tec}}{\tau^{av}_{tec}} \cdot \hat{p}^{ag}_g \cdot (1+t_g) \qquad (21)$$

which is an ad-hoc implementation of partial capital mobility assuming that any amount of capital needed is available at a given interest rate.

Finally, the dynamics of the model is based on a year-by-year iterative update of the capital stock:

$$K_{year,s,tec} = K_{year-1,s,tec} \cdot (1 - \delta_{tec}) + I_{year-1,s,tec} \qquad (22)$$

where δ_{tec} is the rate of depreciation of the capital stock. Thus, it is implicitly assumed that current investment is put fully into operation at the beginning of the following year.

3 Empirical application of the SCREEN model: the case of Swiss carbon mitigation policy

3.1 Swiss climate mitigation policy – the Swiss CO_2 Act

In a worldwide rather outstanding CO_2 Act (CO_2-Gesetz 2000) Switzerland has committed itself to reduce its overall CO_2 emissions by –10% until 2010, as compared to the reference year 1990. This is on top of the obligations within the framework of the Kyoto Protocol, under which Switzerland is obliged to reduce its greenhouse gas (GHG) emissions by –8% (UNFCCC 1997). The 10% reduction target is subdivided into an 8% reduction target for transportation fuels and a 15% reduction for fuels for stationary use.

The achievement of the GHG mitigation target according to the CO_2 Act is supposed to be supported by *voluntary measures* taken by industry and other GHG-reducing activities (cf. Aebischer et al. (2001)). In case the appropriate GHG mitigation trajectory is not reached by the year 2004, a CO_2 tax will be introduced. Among the other GHG-reducing activities there is a performance-related *heavy-duty transport levy* (LSVA), the 1999 Energy Act (EnG 1999), and the action programme "EnergieSchweiz" (BFE 2001; successor programme of "Energie 2000"). Under the umbrella “EnergieSchweiz” all activities in the area of energy efficiency improvements and the promotion of renewables will be coordinated.

In case it turns out that with the voluntary and additional other measures it cannot realistically be expected that the targets stipulated in the CO_2 Act are actually going to be reached, a CO_2 tax will be introduced whose level is dependent on the degree of the deviation from the target CO_2 mitigation trajectory. Particularly, the CO_2 tax may be differentiated for transport fuels and fuels used in stationary equipment. Furthermore, the CO_2 Act caps the CO_2 tax at a level of 210 Swiss Francs (CHF) per ton of CO_2 (US$ 126 or EUR 140, based on assumed exchange rates of CHF 1 = US$ 0.6 and CHF 1 = EUR 0.67, resp.), equivalent to approximately CHF 0.5 (US$ 0.3 or EUR 0.33, resp.) per liter of petrol. The tax revenues will be redistributed among the population (criteria: per head) and among the industries (criteria: sum of wages paid) on a pro rata basis, according to the actual split of the tax burden.

3.2 Scenarios considered

In our illustrative empirical analysis we have calibrated SCREEN with data for Switzerland. Two cases are considered: a business-as-usual scenario “Trend” (section 3.2.1) and a scenario “CO_2 Act” (section 3.2.2). In the latter scenario an energy tax is introduced that is sufficiently high to ensure the achievement of the –10% target stipulated in the CO_2 Act (as well as diminishing reductions in emissions beyond 2010). In line with Frei (2001) we have taken the values from the latest available SAM (1990) for the definition of the base year 2000. Note that although this approach will not allow us to make any assessments in absolute levels, it is of little importance for exploring policy implications based on relative changes. Besides, CGE models are designed to study the economy-wide repercussions of policy measures in a coherent framework, and are not the right choice for forecasting. The models has been programmed in a hybrid LaTeX-GAMS code and results are obtained with the mixed complementarity problem solver PATH (Ferris and Munson 1999).

3.2.1 Scenario “Trend” (business-as-usual)

The scenario “Trend” describes a moderate business-as-usual development of the Swiss economy. Particularly for the energy sector we assume that fossil fuel and electricity import prices remain stable, and that nuclear power plants remain in operation for a total lifetime of 50 years. The ongoing electricity market liberalization in Europe leads to an expected price decrease of –10% by 2005, mainly due to overcapacities and competitive pressure, while the sector’s restructuring (e.g. through rationalization of labor, capacity reductions, mergers & aquisitions) leads to price increases in later years (the price index is assumed to rise to 110% by 2015). Finally, factor efficiency of capital and labor is assumed to rise by 1.5% per annum.

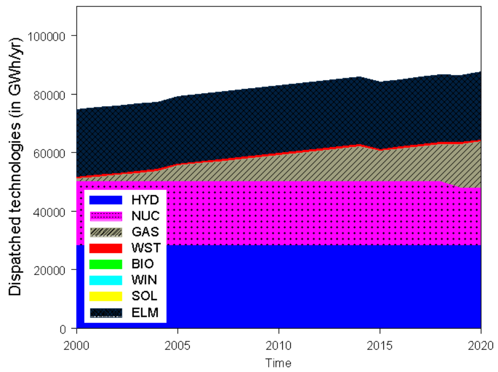
3.2.2 Scenario "CO_2 Act"

In the "CO_2 Act" scenario we have introduced an incremental carbon tax on primary energy[f] in 2004 that is just sufficient to achieve the carbon dioxide mitigation target stipulated in the Swiss CO_2 Act (i.e. a reduction in CO_2 emissions by –10% in 2010 compared to 1990, or about –15.6% compared to 2000). Among the various options in SCREEN for defining the tax restitution mechanism we have chosen the one in which the energy tax revenues are used to lower the cost of labor.

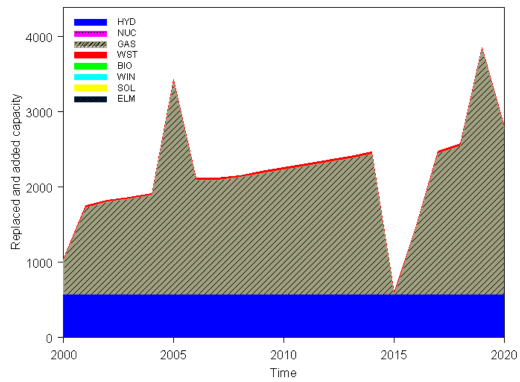
3.3 Empirical results

The "Trend" scenario shows an increase in real GDP over the model horizon 2000-2020 of +38% and in employment of +9% (Figure 3.1 f). Compared to the base year, CO_2 emissions are predicted to rise by around 46%. Growth in electricity demand and the widening gap in generation capacity due to the decommissioning of nuclear power stations towards the end of the model horizon is met by domestically generated electricity from gas-fired power stations (cf. Figures 3.1 ab).

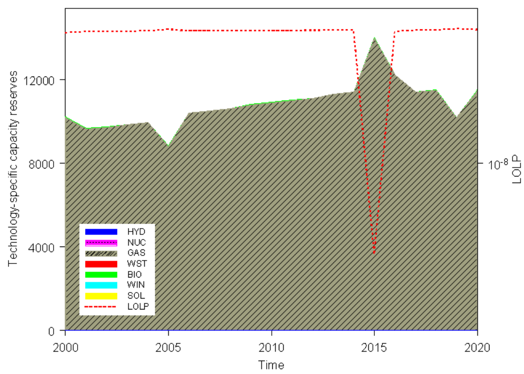
The results of the scenario "CO_2 Act", in comparison to the "Trend" scenario, depict a slight reduction in the employment level and in real GDP growth, and a flatter trajectory in the real exchange rate after 2004. Total CO_2 emissions are curbed by –15% in 2010 and –25% in 2020, respectively, as compared to the year 2000 (note that CO_2 emissions have been roughly 5% higher in 2000 than they have been in 1990). The tax implied by the CO_2 Act increases the price of natural-gas using technologies, which makes them relatively less attractive. This summarizes the primary effect concerning the power producing technology mix depicted in Figures 3.1 a-d and 3.2 a-d, respectively. Besides, no new technologies penetrate the market (in a model run up to 2040 we found that bioenergy technologies gain a certain share after 2035). Finally, it is worth to mention that the electricity consumption in the "CO_2 Act " is about 9% lower in 2020 than in the "Trend" scenario. In line with a similar study undertaken by Bahn and Frei (2000), using the CGE model GEM-E3 Switzerland, we find that the macroeconomic impacts turn out to be very modest.



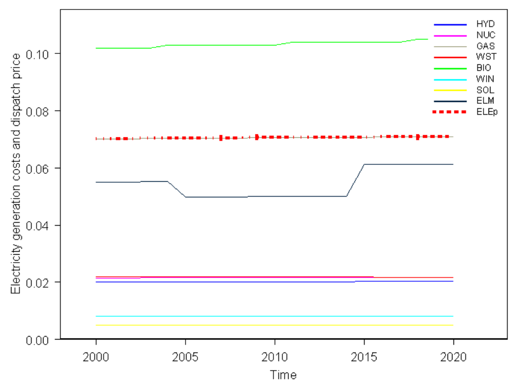
(a) technology mix



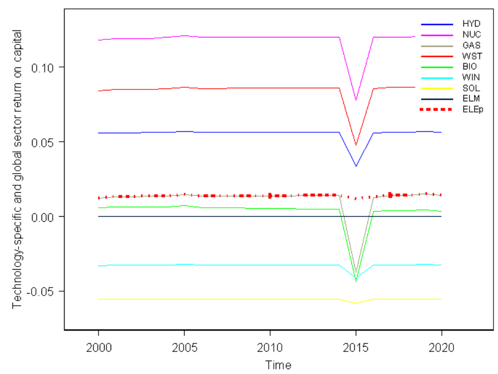
(b) capacity changes (in GWh/yr)



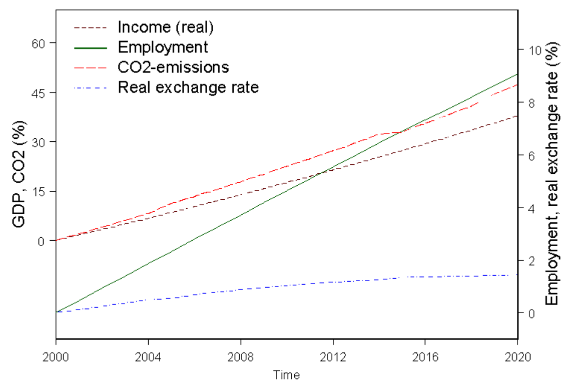
(c) capacity reserves (in GWh/yr)



(d) electricity generating costs, dispatch price (in CHF/yr)

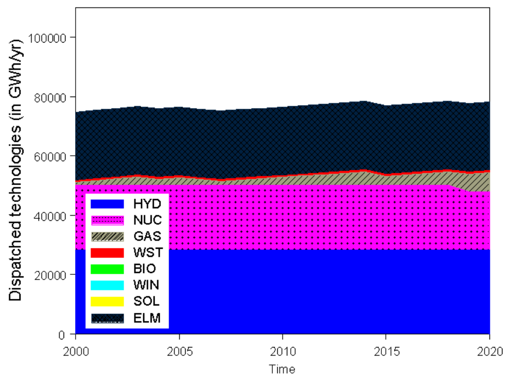


(e) return on capital

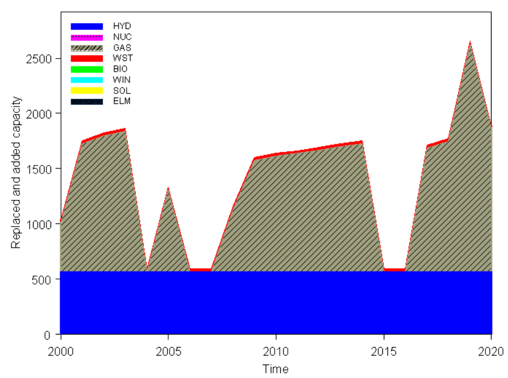


(f) macroeconomic indicators, CO_2 emissions (in %)

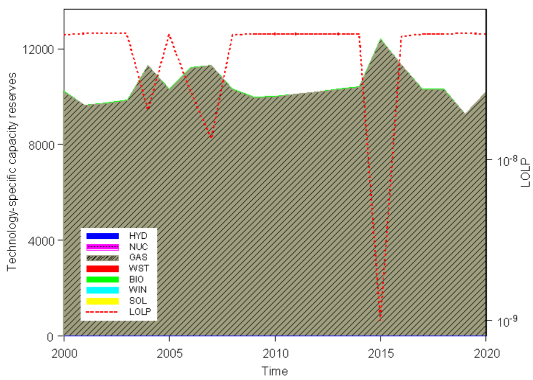
Figure 3.1 a-f. Results for the Scenario “Trend”, 2000-20



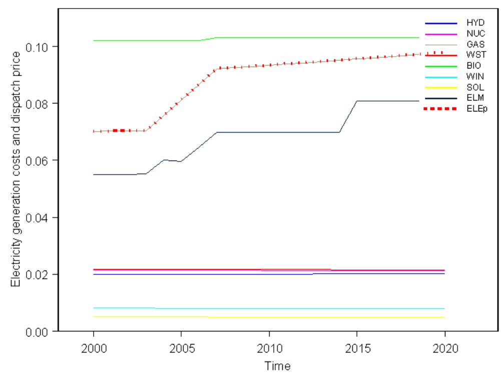
(a) technology mix



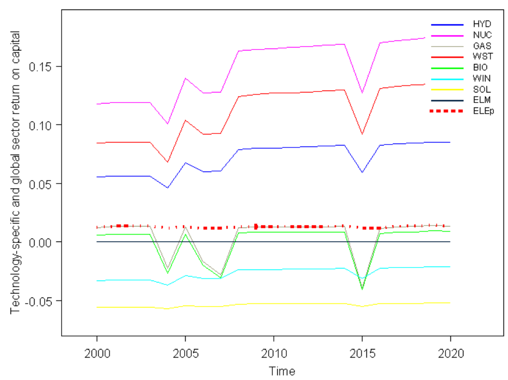
(b) capacity changes (in GWh/yr)



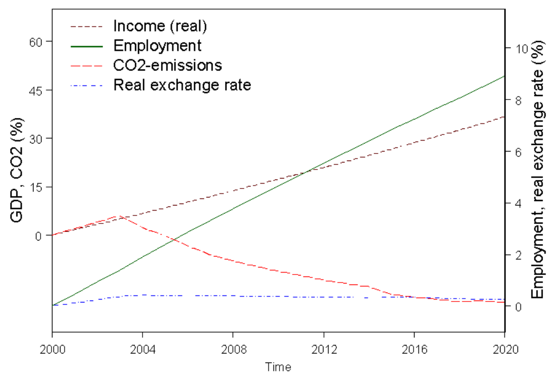
(c) capacity reserves (in GWh/yr)



(d) electricity generating costs, dispatch price (in CHF/yr)



(e) return on capital



(f) macroeconomic indicators, CO_2 emissions (in %)

Figure 3.2 a-f. Results for the Scenario "CO_2 Act", 2000-20

4 Summary and conclusions

In this paper we have introduced the hybrid computable general equilibrium model SCREEN. It integrates the technological detail of a bottom-up model with the merits of a top-down general equilibrium approach. Computationally, the model is solved year by year for Arrow-Debreu equilibria. The model in its current implementation is backward looking, and has been designed for studying the medium- to longer-term changes induced by energy and climate policies aimed at fostering sustainable development, a notion that inherently requires a more strategic way of thinking by policy-makers. Its strength lies particularly in the tractability of inter-linkages, and the detailed modeling both of the electricity sector and the labor market.

We have also shown how the SCREEN model can be used empirically for the analysis of relative changes in the bottom-up activities in the power generation sector within a CGE framework. In particular, we have analyzed two alternative scenarios for the development of the electricity sector and the macro-economy of Switzerland. The first scenario is a business-as-usual trend scenario, while in the second scenario a linearly increasing carbon tax on fossil fuels has been introduced in such a way that the CO_2 mitigation target set in the Swiss CO_2 Act (–10% by 2010 compared to 1990) can actually be achieved. The results indicate that the share of natural gas in electricity generation is reduced remarkably over the time horizon of the model, due to lower (re-)investment in natural-gas using technologies, whereas national employment and real GDP are hardly affected. The real exchange rate levels off, and CO_2 emissions decrease at diminishing rates by approx. –16% relative to 2000 (and approx. –10% relative to 1990) levels until the year 2020.

We can identify several avenues for future refinements of SCREEN: (1) an update of the SAM; (2) the inclusion of rational expectations; (3) a more detailed modeling of future energy technologies, (4) the disaggregation of other sectors of the economy; (5) the use of elasticities of substitution that are based on econometric estimates for Swiss data; and (6) the inclusion of the option to use flexible mechanisms for reductions in CO_2 emissions.

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Appendix

Table a-1. Benchmark Social Accounting Matrix (SAM) for Switzerland, 1990

	AGR	FOS	ELE	MET	CHE	ENI	EQP	CNG	BLD	TLC	TRS	SRV	HH	EXP	TOT
AGR	1290.4		0.1	3.4	38.7	57.6	30.3	8470.8	175		3.2	2392.1	4221	347.8	17030.5
FOS	72.6	1348.1	23.4	71.6	219.1	478.6	204.6	223.4	266.1	41.3	549.8	955.5	5119.3	568.8	10142.2
ELE	139.4	41.3	1193.8	286.6	396	522.7	297.2	379.5	133.7	61.6	210.8	1550.7	2643.2	1364.8	9221.2
MET	121.6	60.7	199.4	8054.9	388.6	185.6	7897.5	711.5	2091.4	20.6	169.6	827	3947.7	6709.8	31385.8
CHE	332.8	49.9	160.9	408	8590.7	929	1636.9	1798.8	758.2	17.2	44.2	2392.3	3043	18409.6	38571.5
ENI	270.4	6.5	22.4	997.8	818.1	5928.6	1884.2	1459.2	5371.3	272.9	426.3	7664.5	3051.1	2925.2	31098.5
EQP	317.1	84	284.1	648.7	623.8	681.4	24982	926.5	2181	453.8	933.1	9955.5	48361.6	45964.9	136397.5
CNG	1365	5.2	13.7	216.9	563.5	410.9	3017.7	7448.2	2400.9	129	180.1	6835	35078.3	10833.2	68497.8
BLD	559.8	107.5	349.3	117.1	106.6	212.7	582.2	981.3	1971.8	287.7	752.3	9658.6	35410.5	360.5	51457.9
TLC	24.2	12.9	43.4	103.9	293.4	164.7	818.2	332.8	377.3	1392.5	241.8	2986	3690.9	769	11251
TRS	97.7	72	48.3	699	815	925.7	1259.3	1563	828.6	431.6	2905.3	4153.3	5600.2	4665.4	24064.5
SRV	1034.2	240.7	665.1	2407.7	4021	3064.6	13174.8	7114.6	6701.4	273.5	2502	50870.2	177663.9	22130	291863.7
L	2092.7	176.8	1398.1	5201.9	5622.5	6388	23553.4	10133.5	17940.2	4946.9	10415.7	108810.2			196679.8
K	7021.3	405.9	3797.2	2584	3945	3492.7	9834.8	4235.4	6786.7	1867.6	3647.6	69907.4			117525.6
TRF	-1031.8	7.7	47.5	405.8	229.3	502.9	2515.2	1761.5	2592.2	113.1	-1985.8	5520.1		2947.5	13625.2
IMP	3323.1	7523.1	974.6	9178.6	11900.2	7152.6	44709.3	20957.7	882	941.7	3068.4	7385.2			117996.6
TOT	17030.5	10142.2	9221.2	31385.8	38571.5	31098.5	136397.5	68497.8	51457.9	11251	24064.5	291863.7	327830.7	117996.6	
$\bar{x}^s$	347.8	568.8	1364.8	6709.8	18409.6	2925.2	45964.9	10833.2	360.5	769	4665.4	22130			115049
$\bar{y}_s$	14739.2	2611.5	8199.2	21801.5	26442	23442.8	89173.1	45778.5	47983.6	10196.2	22981.8	278958.3			592307.7
$\overline{ag}_g$	17714.5	9565.8	7809	24270.3	19932.6	27670.2	87917.5	55903	48505.1	10368.9	21384.8	264213.5			595255.2
s_{1s}	1.0%	42.9%	41.9%	22.1%	44.2%	28.0%	27.1%	20.0%	22.2%	44.1%	40.4%	32.8%			30.0%
s_{2s}	99.0%	57.1%	58.1%	77.9%	55.8%	72.1%	72.9%	80.0%	77.9%	55.9%	59.6%	67.2%			70.0%
(Labour demand normalised to unity benchmark wage rate in the secondary sector:)															
$\bar{d}_s^{L1}$	20.3	32.9	257.6	687.1	1060.5	965.3	3500.5	1258.8	2374.7	932.2	1888.9	17878.8			30857.6
$\bar{d}_s^{L2}$	2010.6	43.8	357.2	2426.1	1338.2	2488.3	9411.6	5047.9	8346.3	1180.7	2784.4	36579.9			72015.1
$\bar{d}_s^{L}$	2031.0	76.7	614.9	3113.2	2398.7	3453.6	12912.0	6306.7	10721.1	2112.9	4673.3	54458.7			102872.7
(Labour demand normalised to effective employment figures:)															
$\bar{d}_s^{L1}$	690	1069	8364	22307	34425	31339	113652	40869	77103	30264	61320	580454			1002739
$\bar{d}_s^{L2}$	68268	1421	11598	78767	43442	80787	305574	163887	270991	38330	90387	1187607			2340176
$\bar{d}_s^{L}$	68957	2490	19962	101074	77868	112126	419226	204756	348094	68594	151708	1768061			3342915
$\overline{VA}_{mp}(L_1)$	82.1	133.0	1040.9	2775.8	4284.3	3899.7	14141.8	5085.6	9593.9	3766.2	7631.3	72230.3			124664.8
$\overline{VA}_{mp}(L_2)$	2010.6	43.8	357.2	2426.1	1338.2	2488.3	9411.6	5047.9	8346.3	1180.7	2784.4	36579.9			72015.1
$\overline{VA}_{mp}(L)$	2092.7	176.8	1398.1	5201.9	5622.5	6388.0	23553.4	10133.5	17940.2	4946.9	10415.7	108810.2			196679.9
$\overline{VA}_{mp}(K)$	7021.3	405.9	3797.2	2584	3945	3492.7	9834.8	4235.4	6786.7	1867.6	3647.6	69907.4			117525.6
$\overline{VA}_{mp}$	9114	582.7	5195.3	7785.9	9567.5	9880.7	33388.2	14368.9	24726.9	6814.5	14063.3	178717.6		2947.5	317153

Units are millions of Swiss francs (MCHF) per year in base-year francs. An agent's expenditures are characterised by the associated column, its revenues in the associated row. The row TRF represents benchmark transfers between agents. Derived variable benchmarks: The sector output at supply market prices, $\bar{y}_s$, the Armington aggregate volumes at supply market prices, $\overline{ag}_g$, the labour segment shares, s_{1s} and s_{2s}, the employment specified for the two segments, $\bar{d}_s^{L1}$ and $\bar{d}_s^{L2}$, as well as the total $\bar{d}_s^{L}$, the corresponding payrolls, $\overline{VA}_{mp}(L_1)$, $\overline{VA}_{mp}(L_2)$, $\overline{VA}_{mp}(L)$, and the GDP, $\overline{VA}_{mp}$.

Source: Frei (2001)

Endnotes

[a] The complementarity format (Cottle and Pang 1992) allows to keep the general equilibrium conditions in their most general form. The model is formulated as a nonlinear program corresponding to the three classes of equilibrium conditions associated with an Arrow-Debreu general equilibrium: market clearance, zero profit and income balance. Each of the three fundamental unknowns prices, activity levels and incomes is linked to an equilibrium condition as implied by Walras' law. This complementarity relation motivates the formulation of the problem in complementarity format. A particular advantage as compared to traditional approaches is the simultaneous and explicit treatment of equalities/inequalities as well as decision variables.

[b] Nested CES functions are better at preserving local calibration information and have clear advantages for equilibrium analysis as justified in a comparative study on the performance of various functional forms for use in applied general equilibrium analysis (Perroni and Rutherford 1996).

[c] C.I.F. price, i.e. including cost, insurance and freight up to the port of destination named in the contract of sale.

[d] F.O.B. (free on board) price, i.e. including export taxes and the cost of boarding to a ship at the port of shipment named in the contract of sale.

[e] In contrast to national accounting matrices, which puts less emphasis on households, a social accounting matrix details the revenues and expenditures of the households.

[f] It should be noted that SCREEN currently does not allow to impose separate taxes on heating fuels and on transportation fuels, so that we have been unable to study the impact of fuel-specific taxes on the achievement of the –8% and –15% individual targets, respectively, contained in the CO_2 Act.

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