Chapter 1
Dynamic Econometric Input-Output Modeling: New Perspectives

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1.1 Introduction

One of the first research strategies based on input-output (IO) modelling that had as an objective a fully fledged macro-econometric IO model is the 'Cambridge Growth Project' (Cambridge DAE 1962). The focus of extending the IO model towards a full macroeconomic model was on the endogenization of parts of final demand (usually exogenous in the static IO model) and the modelling of demand components depending on (relative) prices. Another milestone of this work on the Cambridge Growth Project was the macroeconomic multisectoral model of the U.K. economy (Barker 1976; Barker and Peterson 1987). Almost at the same time, U.S. based research group known as INFORUM (Inter-industry Forecasting at the University of Maryland) developed a macroeconomic closed IO model, which is first described in Almon et al. (1974). Since then, this model family has spread worldwide and developed into an international model by linking similar national models via bilateral trade matrices (Almon 1991; Nyhus 1991). Both the Cambridge Multisectoral Dynamic Model of the British economy (MDM) as well as the INFORUM models incorporate econometric specifications that take into account economic theory but cannot be directly derived from maximization or minimization calculus of representative agents. At the regional level, different types of econometric IO models have been developed by Geoffrey Hewings and his team at the Regional Economics Applications Laboratory (REAL, University of Illinois at Urbana-Champaign) based on the Washington Projection and Simulation Model (Conway 1990). Another important example of a recently developed econometric IO model is the (fully interlinked) Global Interindustry Forecasting System (GIN-

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FORS) model (Lutz et al. 2005), developed by Bernd Meyer and his team at the Institute of Economic Structures Research (GWS, Gesellschaft für Wirtschaftliche Strukturforschung).

The purpose of this paper is to bring to the attention of practitioners some, in our view, fruitful future directions for econometric IO modeling. Our suggestions on improving this branch of economic modeling comes from our observations that theoretical and empirical economic research of the last decades has developed completely new approaches that have not all found their representation in the econometric IO modeling strain. In this respect, we highlight the relevant developments in three subfields or schools of economics: neoclassical macroeconomics, agricultural economics, and post-Keynesian economics. Macroeconomics-related improvements have to do with an improved modeling of private consumption, production and trade, as briefly outlined below and discussed in some detail in the next two sections. Theoretical and empirical research in agricultural economics on observed data calibration seems to be a promising new addition to the econometric IO modeling. Another very important recent development in macroeconomic modeling includes the comprehensive integration of all the flows and stocks of the economy in the spirit of the post-Keynesian school of economic thought. These last two issues and their relevance for econometric IO modeling are discussed briefly in Sect. 1.4.

It is not difficult to realize that private consumption modeling should not be simplistic, because it constitutes the largest component (over 50%; close to 70% in the US) of aggregate demand (or national income) in virtually all individual economies around the world. Models based on the social accounting matrices (SAM) structure using average coefficients still dominate the modeling of the link between consumption and household income generation. That holds true for econometric IO as well as for computable general equilibrium (CGE) modeling. In both modeling families, also the concept of the representative consumer dominates and reactions of consumption of single goods to price and income changes follow simple linear approaches. In Sect. 1.2 we show how this part of an econometric IO model can be improved by introducing approaches that explicitly deal with household wealth, durables and nondurables as well as different household characteristics that have an influence at the level of consumption by commodity. The approaches presented all take into account the dynamics of structural change in society as well as in the economy.

In production theory, the important issues are imperfect competition and technical change. It is well known that both phenomena equally affect the wedge between costs and prices and, therefore, are rather difficult to disentangle. The IO model structure is fully compatible with flexible functional forms like the transcendental logarithmic (or translog) function (Jorgenson et al. 2013), which allow for a generic form of introducing different sources of technical change (i.e., total factor productivity (TFP), factor bias, embodied or induced). In Sect. 1.3 we discuss these generic forms and compare them with a more explicit treatment of technical change in an IO framework.

Another important issue, especially in the context of multi-regional modeling, is trade. As is well known, estimation of trade flows within the standard multiregional

IO framework is a challenging task mainly due to unavailability or incompleteness of the relevant data and the fact that interregional inter-sectoral flows can be quite volatile over time. Thus, in general, it is to be expected that trade flows may be one of the most important sources of uncertainty in multiregional IO modeling. It should be noted that within the traditional multiregional IO modeling, surprisingly very little attention, to the best of our knowledge, has been given to the full characterization of the IO price system. For example, multicountry IO price systems that explicitly model (changes in) exchange rates, which is a crucial factor for the analysis of open economies, seem to be largely lacking. In this respect, econometric IO modelling has gone much further, since the framework readily allows to incorporate all the real complexities of the pricing system of an economy. As an example, while prices per sector (or product) in the IO price model are identical for all intermediate and final users, in econometric IO models, prices are user-specific due to their proper account of margins, taxes and subsidies, and import shares that are all allowed to be different for each user (see e.g., Kratena et al. 2013). Trade flows of substitutes to domestic goods, as well as in terms of the country of origin and destination in most models, simply depend on the level of goods demand and relative prices. The standard workhorse in CGE modeling is still the Armington function (Armington 1969), which is calibrated to elasticity values found in two or three seminal papers. In this respect, we emphasize the necessity of new empirical work on the magnitude of Armington elasticities, and call for developing other alternatives to Armington approaches of trade modeling in IO models with clear links to the production side (for the first steps in this direction, see Kratena et al. 2013).

Section 1.4 concludes and summarizes the discussed perspectives for future econometric IO modeling.

1.2 Private Consumption, Income and Socio-economic Characteristics of Households

In this section we discuss the complex relationship between consumption and income that has been a major field of macroeconomic research during the last decades (for an overview of the debate, see e.g., Meghir and Pistaferri 2010). The SAM multiplier model as well as the standard CGE model both use a static link between income and consumption. The standard formulation of consumption in the CGE model with a static consumption function and a linear expenditure system for splitting up the consumption vector does *not* take into account the huge body of literature on macroeconomic consumption functions of the last decades. A line of development reaches from the Keynesian consumption function used in Miyazawa (1976) to the model of permanent income. As empirical research has discovered some puzzles about the dependence of consumption on income dynamics (Hall 1978) inconsistent with the predictions of the permanent income hypothesis, the 'buffer-stock model' of consumption emerged. Carroll (1997) has laid down the basis of the buffer-stock model, starting from the empirical puzzles that the permanent income hypothesis has not been able to resolve. One of the main starting points for Carroll in developing this model was the desired characteristic of a *concave* consumption function, due to a non-constant marginal propensity of consumption (MPC) along the process of income growth and wealth accumulation. This idea dates back to the work of Keynes himself, as Carroll and Kimball (1996) have shown. In general, the MPC should increase with higher income uncertainty (the main innovation of the buffer-stock model) and decrease with higher levels of wealth. Several empirical tests of the buffer-stock model have been carried out. Japelli et al. (2008) and Luengo-Prado and Sorensen (2004) are two prominent examples. The two main issues in this empirical testing were, in general, the income sensitivity of consumption and the empirical proof of a non-constant MPC. As far as the first point is concerned, the difference between permanent and transitory income shocks by the founders of the Permanent Income Hypothesis has been crucial. The MPC out of transitory income should only be significantly different from zero for households with binding liquidity constraints. This can be part of the households—in that case household heterogeneity needs to be introduced—or all households in situations of high liquidity demand, e.g., for debt deleveraging.

Whereas in the original version of the buffer-stock model income uncertainty was the main saving motive, in a new version households save for the purchase of durables, as described in Luengo-Prado (2006). Consumers maximize the present discounted value of expected utility from consumption of nondurable commodity and from the service provided by the stocks of durable commodity, subject to the budget and collateralized constraints. The consideration of the collateralized constraint is formalized in a down payment requirement parameter, which represents the fraction of durables that a household is not allowed to finance.

$$\max_{(C_t,K_t)} V = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U\left(C_t, K_t\right) \right\} \tag{1.1}$$

Specifying a constant relative risk aversion (CRRA) utility function yields:

$$U\left(C_t, K_t\right) = \frac{C_t^{1-\rho}}{1-\rho} + \varphi \frac{K_t^{1-\rho}}{1-\rho}, \tag{1.2}$$

where φ is a preference parameter and $\rho > 0$ implies risk aversion of consumers.

The budget constraint in this model without adjustment costs for the durables stock is given by the definition of assets, A_t:

$$A_t = (1+r)\left(1-t_r\right) A_{t-1} + YD_t - C_t - \left(K_t - (1-\delta) K_{t-1}\right). \tag{1.3}$$

The sum of C_t and $(K_t - (1-\delta)K_{t-1})$ represents total consumption, i.e., the sum of nondurable and durable expenditure (with depreciation rate of the durable stock, δ). The gross profit income rA_{t-1} is taxed at the rate t_r. These taxes, therefore, reduce the flow of net lending of households that accumulates to future assets. Disposable household income that excludes profit income, YD_t, is given as the balance of net wages $(1-t_S-t_Y)w_tH_t$ and net operating surplus accruing to households $(1-t_Y)\Pi_{h,t}$, plus unemployment benefits transfers with UN_t as unemployed persons and br as the benefit replacement rate, measured in terms of the after tax wage rate, plus other transfers Tr_t:

$$YD_t = (1 - t_S - t_Y)\, w_t H_t + (1 - t_Y)\, \Pi_{h,t} + brw_t\, (1 - t_S - t_Y)\, UN_t + Tr_t. \quad (1.4)$$

The following taxes are charged on household income: social security contributions with tax rate t_S, which can be further decomposed into an employee and an employer's tax rate (t_{wL} and t_L) and income taxes with tax rate t_Y. The wage rate w_t is the wage per hour and H_t are total hours demanded by firms. Wage bargaining between firms and unions takes place over the employee's gross wage, i.e.,$w_t\,(1-t_L)$.

Financial assets of households are built up by saving after durable purchasing has been financed, and the constraint for lending is:

$$A_t + (1 - \theta)\, K_t \geq 0. \quad (1.5)$$

This term represents voluntary equity holding, $Q_{t+1} = A_t + (1-\theta)K_t$, as the equivalent of the other part of the durable stock (θK_t) needs to be held as equity. The consideration of the collateralized constraint is operationalized in a down payment requirement parameter θ, which represents the fraction of durables purchases that a household is not allowed to finance. One main variable in the buffer stock-model of consumption is 'cash on hand', X_t, measuring the household's total resources:

$$X_t = (1 + r_t)\,(1 - t_r)\, A_{t-1} + (1 - \delta)\, K_{t-1} + YD_t \quad (1.6)$$

Total consumption is then defined as:

$$CP_t = C_t + K_t - (1 - \delta)\, K_{t-1} = r_t\,(1 - t_r)\, A_{t-1} + YD_t - (A_{t-1} - A_t)\,, \quad (1.7)$$

where the last term represents net lending, so total consumption is the sum of durable and nondurable consumption, or the difference between disposable income and net lending.

The model solution works via deriving the first-order conditions and yields an intra-temporal equilibrium relationship between C_t and K_t as one solution of the model, when the constraint is not binding. For all other cases, where the collateral constraint is binding, Luengo-Prado (2006) has shown that this relationship can be used to derive policy functions for C_t and K_t and formulate both as functions of the difference between cash on hand and the equity that the consumer wants to hold in the next period.

This model describes a clear *alternative* to the static model of consumption in the standard CGE model and introduces *dynamics* into the model. It allows for deriving demand for different types of durables and total non-durables as the main macroeconomic consumption functions. As an empirical application of this model, the non-linear functions for durable and nondurable consumption, depending on wealth (in this case the durable stock), cash on hand, and the down payment (θ) have been estimated for 14 EU countries[1] for which the data situation covers the main variables of the model. The non-linearity of the functions should deal with: (i) non-constant MPC (in this case with respect to cash on hand), (ii) smoothing of nondurable consumption with respect to shocks in savings requirements for the down payment. Both characteristics yield estimation results that can be, in a second step, built into an econometric IO model of the EU-27 (for details, see Kratena and Sommer 2014) that incorporates five different groups of household income (quintiles). For this purpose, the estimation results are used to calibrate the model at the level of the five quintiles of income, which are characterized by different values for the durable stocks per household. Therefore, the model contains growth rates for $C_{dur,t}$ and $C_{nondur,t}$ for each quintile (q). Once the full model is set up with the integrated consumption block, the property of 'excess sensitivity' can be tested. Excess sensitivity describes the empirical fact that the growth rate of consumption (partly) reacts to the lagged growth rate of disposable (or labour) income. This issue has been raised by Hall (1978) and confronted the Permanent Income Hypothesis with contradictory empirical findings.

The full econometric IO model (Kratena and Sommer 2014) is run until 2050, so that endogenous disposable household income is generated. Then excess sensitivity is tested by setting up the regressions that Hall (1978) proposed to test the influence of transitory income shocks on consumption. That means regressing the growth rates for $C_{dur,t}$ and $C_{nondur,t}$ for each quintile (q) on lagged disposable income growth (without profit income) for each quintile, generated by the full model. Profit income is not included, because it is endogenous and depends on equity built up, which in turn is the result of inter-temporal optimization. Luengo-Prado (2006) also carries out excess sensitivity tests with her calibrated model, based on U.S. household survey data and confronts similar results with U.S. stylized macroeconomic facts. The excess sensitivity coefficients, i.e., the MPC with respect to lagged income change, found by Luengo-Prado (2006) are 0.16 (nondurables) and 0.26 (durables). The results from the econometric IO model solution until 2050 (Table 1.1) clearly reveal that for the 5th and partly for the 4th quintile, durable and nondurable consumption do not statistically significantly depend on transitory income shocks. The MPC is higher in general for lower income households and for situations with higher liquidity constraints (higher θ). The 'low θ scenario' corresponds to a financial regime, where the relationship debt to durable stock does not significantly decrease, i.e., no major debt deleveraging by households occurs. The 'high θ scenario' corresponds to debt deleveraging so that the relationship debt to durable stock in the long-run decreases to its values before 2002, i.e., before the main expansion of household debt began.

[1]These countries include Austria, Belgium, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Italy, Lithuania, Poland, Portugal, Romania, and Slovakia.

Table 1.1 Excess sensitivity of consumption with respect to lagged disposable income (without profit income), EU 14 (2005–2050)

	1st quintile	2nd quintile	3rd quintile	4th quintile	5th quintile
	Sensitivity, low θ				
dlog(C_{dur})	0.45***	0.38***	0.30**	0.21	0.14
	(0.15)	(0.16)	(0.16)	(0.16)	(0.16)
dlog(C_{nondur})	0.94***	0.76***	0.58***	0.38***	−0.03
	(0.41)	(0.20)	(0.15)	(0.12)	(0.13)
	Sensitivity, high θ				
dlog(C_{dur})	0.44***	0.40**	0.33***	0.26**	0.20
	(0.13)	(0.14)	(0.14)	(0.14)	(0.14)
dlog(C_{nondur})	1.02***	0.86***	0.69***	0.49***	0.09
	(0.37)	(0.18)	(0.14)	(0.12)	(0.09)

Note: ** and *** indicate significance at the 5%, and 1% level, respectively

This specification of the buffer-stock model that has already been built into a dynamic econometric IO model indirectly yields the following properties that make it significantly different from the standard consumption model (SAM based and linear expenditure system) applied in econometric IO and CGE modeling: (i) a non-constant MPC, (ii) a concave consumption function across household income groups, and (iii) different sensitivity of different household types in their consumption reaction on transitory income changes. This version of the buffer-stock model is data-intensive and introduces cross-section data (i.e., household heterogeneity) that are combined with time series estimation results.

A different way of ending up with a buffer-stock model that exhibits the desired properties (non-constant MPC, concave consumption function, different sensitivity of different household types), is a direct estimation of consumption functions, incorporating income, wealth and debt for different household groups. Early examples of these empirical explorations into the validity of the buffer-stock model are Japelli et al. (2008) and Luengo-Prado and Sorensen (2004). Recently, models that take into account household heterogeneity with respect to the impacts of debt deleveraging and wealth shocks have gained ground. Mian et al. (2013) show that poorer households and households with a higher debt burden react more to wealth shocks in their consumption than other households. Their specification also takes into account concavity in the consumption function with respect to the level of wealth. Eggertson and Krugman (2012) develop a theoretical model with two different household types (savers and debtors), where debt deleveraging has strong macroeconomic impacts as it reduces consumption of the debtors, which depends more on transitory income. The results presented in Table 1.1 and the findings of Mian et al. (2013), as well as of Eggertson and Krugman (2012), strongly encourage going into the direction of a model with different household groups, where the consumption of richer households is simply determined by a constant growth rate, whereas for the other groups of households, income, wealth and debt limits play a major role.

As far as the demand for nondurables at the commodity level is concerned, the alternative to the linear expenditure system could be a flexible functional form, like the widely used Almost Ideal Demand System (AIDS), starting from the cost function for $C(u, p_i)$, describing the expenditure function (for C) as a function of a given level of utility u and prices of consumer goods, p_i (see Deaton and Muellbauer 1980). The AIDS model is represented by the well-known budget share equations for the i nondurable goods in each period:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log\left(\frac{C}{P}\right) \quad \text{for } i = 1 \ldots n, \tag{1.8}$$

with price index, P_t, defined by $\log P_t = \alpha_0 + \sum_i \alpha_i \log p_{it} + 0.5 \sum_i \sum_j \gamma_{ij} \log p_{it}$, $\log p_{jt}$ often approached by the Stone price index, $\log {P_t}^* = \sum_k w_{it} \log p_{it}$.

This model has been estimated by combining time series (panel data) information from 1995 to 2012 for 27 EU countries with individual data from the 2004/2006 household surveys for 6 EU countries (namely, Austria, France, Italy, Slovakia, Spain, and the UK). This cross section model introduces heterogeneity of households at the level of commodities. Several socio-economic characteristics of households can be introduced as additional variables, complementing income and prices. These variables include age group dummies for the household head, dummies if the household head is retired, unemployed, and is the owner of the house. Further, household size and population density are taken into account.

The expressions for the expenditure elasticity (η_i) and the compensated price elasticity (ε_{ij}^C) within the AIDS model for the quantity of each consumption category C_i can be written as (the details of these derivations can be found in, e.g., Green and Alston 1990)[2]:

$$\eta_i = \frac{\partial \log C_i}{\partial \log C} = \frac{\beta_i}{w_i} + 1 \tag{1.9}$$

$$\varepsilon_{ij}^C = \frac{\partial \log C_i}{\partial \log p_j} = \frac{\gamma_{ij} - \beta_i w_j}{w_i} - \delta_{ij} + \eta_i w_j, \tag{1.10}$$

where δ_{ij} is the Kronecker delta with $\delta_{ij} = 0$ for $i \neq j$ and $\delta_{ij} = 1$ for $i = j$.

[2]The derivation of the budget share w_i with respect to log (C) and log (p_j) is given by β_i and $\gamma_{ij} - \beta_i$ (log(P)), respectively. Applying Shephard's Lemma and using the Stone price approximation, the elasticity formulae can then be derived.

Table 1.2 Price and expenditure elasticity of nondurable consumption, EU 27 (1995–2012)

Nondurable consumption	Own price elasticity	Expenditure elasticity	
		Time series	Cross section
Food	−0.14	0.85	0.61
Clothing	−0.64	1.04	1.28
Furniture/equipment	−1.06	1.11	1.46
Health	−0.83	0.98	1.20
Communication	−0.89	0.96	0.68
Recreation/accommodation	−0.50	1.08	1.27
Financial Services	−0.94	1.33	1.00
Other	−0.68	1.09	1.00

As can be observed from (1.10), the parameter of the expenditure elasticity (β_i) also enters the formula for the compensated price elasticity, so that the two elasticities are tied together. Estimating both the time series and the cross section model, therefore, and combining them will also change the compensated price elasticity. This is not taken into account in the results presented in Table 1.2. These results just show the difference in expenditure elasticity values from the time series vs. the cross section model. It clearly comes out that heterogeneity in expenditure elasticity is higher in the case of the cross section model. The most important result is that introducing household heterogeneity not only introduces additional socio-economic variables that also influence behavior, besides income and prices, but that it also changes the reaction of households to income and prices and, therefore, aggregate results.

The approach presented can still be seen as sub-optimal, as a combination of time series and cross section estimation is needed, and no direct use of household group panel data has been used for estimation. This latter approach has been applied in Kim et al. (2015) and also yields considerable differences in the income and price elasticities of households, when age groups are introduced. Integrating this model into a macroeconomic IO model, Kim et al. (2015) reveal the difference for aggregate outcomes, compared to the model of the representative consumer.

1.3 Production and Technical Progress

The main workhorse in CGE modeling on the production side are nested constant elasticity of substitution (CES) functions or flexible forms like the translog function (Jorgenson et al. 2013). The translog model can be set up with inputs of capital (K), labor (L), energy (E), imported non-energy material (M^m), and domestic non-energy material (M^d), and their corresponding input prices p_K,p_L,p_E, p_{Mm} and p_{Md}.

Each industry faces a unit cost function for the price (p_Q) of output Q, with constant returns to scale:

$$\log p_Q = \alpha_0 + \sum_i \alpha_i \log(p_i) + \frac{1}{2}\sum_i \gamma_{ii}(\log(p_i))^2 + \sum_{i,j} \gamma_{ij} \log(p_i)\log\left(p_j\right) + \alpha_t t + \frac{1}{2}\alpha_{tt}t^2 + \sum_i \rho_{ti} t \log(p_i) \tag{1.11}$$

where p_i, p_j are the input prices for input quantities x_i, x_j,t is the deterministic time trend, and TFP is measured by α_t, and α_{tt}. As is well known, Shepard's Lemma yields the cost share equations in the translog case, which in this case of five inputs can be written as:

$$\begin{aligned}
v_K &= [\alpha_K + \gamma_{KK}\log(p_K/p_{Md}) + \gamma_{KL}\log(p_L/p_{Md}) + \gamma_{KE}\log(p_E/p_{Md}) \\
&\quad + \gamma_{KM}\log(p_{Mm}/p_{Md}) + \rho_{tK}t] \\
v_L &= [\alpha_L + \gamma_{LL}\log(p_L/p_{Md}) + \gamma_{KL}\log(p_K/p_{Md}) + \gamma_{LE}\log(p_E/p_{Md}) \\
&\quad + \gamma_{LM}\log(p_{Mm}/p_{Md}) + \rho_{tL}t] \\
v_E &= [\alpha_E + \gamma_{EE}\log(p_E/p_{Md}) + \gamma_{KE}\log(p_K/p_{Md}) + \gamma_{LE}\log(p_L/p_{Md}) \\
&\quad + \gamma_{EM}\log(p_{Mm}/p_{Md}) + \rho_{tE}t] \\
v_M &= [\alpha_M + \gamma_{MM}\log(p_{Mm}/p_{Md}) + \gamma_{KM}\log(p_K/p_{Md}) + \gamma_{LM}\log(p_L/p_{Md}) \\
&\quad + \gamma_{EM}\log(p_E/p_{Md}) + \rho_{tM}t]
\end{aligned} \tag{1.12}$$

The homogeneity restriction for the price parameters $\sum_i \gamma_{ij} = 0$, $\sum_j \gamma_{ij} = 0$ has already been imposed in (1.12), so that the terms for the price of domestic intermediates p_{Md} have been omitted. The immediate *ceteris paribus* reaction to price changes is given by the own and cross price elasticities. These own- and cross-price elasticities for changes in input quantity x_i can be derived directly, or via the Allen elasticities of substitution (AES), and are given as:

$$\varepsilon_{ii} = \frac{\partial \log x_i}{\partial \log p_i} = \frac{v_i^2 - v_i + \gamma_{ii}}{v_i}, \tag{1.13}$$

$$\varepsilon_{ij} = \frac{\partial \log x_i}{\partial \log p_j} = \frac{v_i v_j + \gamma_{ij}}{v_i}. \tag{1.14}$$

Here, the v_i represent the factor shares in equation (1.12), and the γ_{ij} the cross-price parameters.

The total impact of t on factor x_i is given by:

$$\frac{d\log x_i}{dt} = \frac{\rho_{ti}}{v_i} + \alpha_t + \alpha_{tt}t. \tag{1.15}$$

Table 1.3 Price elasticities of factor demand and the factor bias of technical change

Production	Own price elasticity	Cross price elasticity, E/K	Rate of factor bias
K, all industries	−0.95		0.00
L, all industries	−0.51		−0.01
E, all industries	−0.53		0.02
E, energy intensive	−0.37	0.20	0.00
All industries		0.15	
M(m)	−0.75		0.02

This expression takes into account the TFP effect on costs $(\alpha_t + \alpha_{tt}t)$, as well as the factor bias of technical change.

The systems of output price and factor demand equation by industry across the EU 27 have been estimated applying the Seemingly Unrelated Regression (SUR) estimator for the balanced panel under cross section fixed effects. This estimation was based on data from the World Input-Output Database (WIOD) that contains World Input-Output Tables (WIOTs) in current and previous years' prices, Environmental Accounts (EA), and Socioeconomic Accounts (SEA). The estimation results (Table 1.3) yield own and cross price elasticities for capital, labour, energy, and imported intermediates, respectively. The own price elasticity of labour is on average about −0.5, with relatively high values in some manufacturing industries. The own price elasticity of energy is very heterogenous across industries and slightly higher in energy intensive industries (−0.37) than for the un-weighted average of all industries (−0.53). Capital and energy are complementary in many industries, but on average are substitutes with an un-weighted cross price elasticity of 0.15. This elasticity is slightly higher for the energy intensive industries (0.2), though in two of them (paper and pulp, non-metallic minerals) energy and capital are complementary.

This simple model of production with constant returns to scale, deterministic trends for technical change and perfect competition can be extended in order to incorporate different features that have turned out to be important in the research on production and trade in the last decades.

Imperfect competition has important consequences for macroeconomic adjustment to demand shocks. If several of these components (technical progress and imperfect competition) are to be introduced into a cost/factor demand system, these components, all leading to a deviation from the perfect competition price level, have to be identified and disentangled.

The translog structure is linked to the IO system by splitting up the factor shares v_E, v_M and v_D (the residual) into the technical coefficients (in current prices) by using fixed use structure matrices $\mathbf{S}^{\mathrm{m}}_{\mathrm{NE}}$, $\mathbf{S}^{\mathrm{m}}_{\mathrm{E}}$ for imported goods and $\mathbf{S}^{\mathrm{d}}_{\mathrm{NE}}$, $\mathbf{S}^{\mathrm{d}}_{\mathrm{E}}$for domestic goods (with E as energy and NE as non-energy goods). A single IO technical coefficient of a domestic input i in industry j(in current prices) therefore is defined as:

$$a^d_{ij} = s^d_{ij} v_D. \tag{1.16}$$

This holds for non-energy and energy inputs, where s_{ij}^{d} is the corresponding coefficient of the use structure matrix.

As far as technical change is concerned, there are two main avenues for enriching this standard model with new features. One is making technical change depend on some variable measuring innovation activity, like R&D expenditure, R&D stocks or patent stocks, instead of the deterministic trend. This approach does not deal explicitly with technical change, and still uses some 'black box' philosophy on technical change, which is seen as a mixture of technological and organizational improvement that is driven by general innovation activities. Most studies in that line still leave the deterministic trend in the estimation, and the standard result is that controlling for innovation activity still leaves a significant part of technical change explained by the deterministic trend (i.e., unexplained). The theoretical base for this endogenous explanation of technical change stems from endogenous growth theory and represents technology as a stock of knowledge (Sue Wing 2006; Gillingham et al. 2008). Technological change is then the outcome of innovative activity within the model and, therefore, endogenous. Moreover, when innovations respond to policy instruments, such as taxes, government R&D and regulations, the direction or bias of technological change itself becomes endogenous.

The other line is combining bottom-up technology information with the top-down structure of the production model, which—in the case of CGE models—mainly is a nested CES function structure. Schumacher and Sands (2007) present a CGE model, where the top-down (CES) structure of one industry (iron and steel) is split up into different technologies that are combined in the sector and in turn have a flexible input structure. One prerequisite for the application of this approach is the availability of input data, which characterize each technology. Schumacher and Sands (2007) take this information from the German Association of Steelmakers and other sources. They nest the technologies and their choice into the CES function of the steel industry. The general logic of this approach is that the unit cost function of an industry (equation (1.11)) has fixed coefficients, like in the standard IO model:

$$\log p_Q = \alpha_0 + \sum_i v_i \log(p_i) + \alpha_t t + \frac{1}{2}\alpha_{tt} t^2 + \sum_i \rho_{ti} t \log(p_i). \tag{1.17}$$

This specification *directly* uses the factor shares (v_i) and still allows for deterministic trend variables representing technical change, like TFP ($\alpha_t + \alpha_{tt} t$) and the factor bias. The main idea is that this unit cost function is the weighted sum of different (fixed) technologies, because any factor share of the industry is the weighted sum of the input coefficients of all technologies:

$$v_i = \sum_k v_{ik} \tau_k, \tag{1.18}$$

where the τ_k are the shares of the technologies in the output of the sector, i.e., the part of sector output that has been produced with the corresponding technology.

Combining (1.16) with (1.18), the IO technical coefficient of a domestic input i in industry j can be defined as the product of (fixed) technology factor shares with the coefficient of the use structure matrix:

$$a_{ij}^{d} = s_{ij}^{d} \sum_{k} v_{Dk} \tau_{k}. \tag{1.19}$$

This formulation allows for technical change via substitution of technologies only at the level of the factor shares (v_i) of the translog model. In the model presented here, this comprises the factors K, L, E, M^m and M^d. In Schumacher and Sands (2007), this includes labour, capital, different energy sources, raw material for steel production and a bundle of all other inputs. This could in principle be extended by allowing for different columns of the use structure matrix for each technology. In that case, a specific $s_{ij,k}^{d}$ for each of the k technologies exists.

Technical change in this framework can occur by shifts in the shares of technologies (τ_k) as well as by changes in the productivity that lead to changes in technology factor shares (v_{ik}). The main issue in this framework is the determining factors for shifts in the share of technologies. In the CGE framework of Schumacher and Sands (2007), this is driven by a substitution elasticity, similar to the one used in the industry CES function. As the factor shares include capital, the allocation of investment across technologies is directly determined by technical change in terms of shifts in the shares of technologies.

The approach chosen by Pan (2006) and Pan and Köhler (2007) uses an IO model as the framework and, thus, directly aims at determining the single IO coefficients as the weighted sum of technology shares (τ_k) and the fixed input coefficients of a technology ($a_{ij,k}^{d}$):

$$a_{ij}^{d} = \sum_{k} a_{ij,k}^{d} \tau_{k}. \tag{1.20}$$

Pan (2006) presents a profound critique of the standard way of including technical change in economic models, i.e., via a trend or an accumulated stock of knowledge. His concept is based on the lifecycle of technologies and describes a discontinuous process of new technologies substituting old technologies. The R&D activities and the allocation of investment across technologies are driving this substitution process in Pan (2006). It can be shown that technical coefficients exhibit considerable long-run changes through this substitution process. This approach as well as the one lined out in Schumacher and Sands (2007) present options to describe technical change as an explicit process of change, driven by prices, investment and innovation activities.

1.4 Calibration and Stock-flow Consistency

Very often the results of econometric IO models show simplistic straight lines/trends into the future, which seem quite unrealistic. Partly, this has to do with the fact that in such cases the forecasts of exogenous data are not accounted for in the model. On the other hand, it is also due to the fact that the observed data are not or, most probably, cannot be (closely or perfectly) replicated by the model at hand, especially over time whenever the model claims to be a dynamic model.

By now there is a vast amount of literature in agricultural economics on farm-level production modeling focusing solely on perfect or incomplete calibration techniques. It turns out that until the late 80s, agricultural economists for policy analyses widely used linear programming (LP) models, and as such had to introduce (many) calibration constraints in order to solve the problem of overspecialization. However, this solution is not really a reasonable solution, since "models that are tightly constrained can only produce that subset of normative results that the calibration constraints dictate" (Howitt 1995, p. 330). Therefore, a more formal approach called Positive Mathematical Programming (PMP) was developed that solved the calibration issues in agricultural policy analysis modeling. Technically, this was implemented by introducing *non-linear* terms in the objective function of a model such that its optimality conditions are satisfied at the observed levels of endogenous (or decision) variables without introducing artificial calibrating constraints. Thus, inclusion of the so-called "implicit total cost function" captures the aggregate impact of all other relevant factors that are not explicitly modeled. Applications of the PMP approach date back to Kasnakoglu and Bauer (1988), but it was first rigorously formalized and developed by Howitt (1995). The last paper, consequently, led to an immense amount of empirical applications of the PMP approach and further raised extensive theoretical discussions within the field of agricultural economics. Review papers on the theory, applications, criticisms and extensions of the PMP approach include Heckelei and Britz (2005), Henry de Frahan et al. (2007), Heckelei et al. (2012), Langrell (2013), and Mérel and Howitt (2014).

Recently, Temurshoev et al. (2015), and Temurshoev and Lantz (2016) have borrowed ideas from the PMP literature for economic modeling of the global refining industry and proposed a perfect calibration procedure for multi-regional or global refining modeling, adopting a PMP-like technique of calibration of *spatial models of trade* introduced by Paris et al. (2011). One could also adopt the Bayesian highest posterior density estimator of Jansson and Heckelei (2011) from the same literature, if there exist a time series of observed data to be closely replicated and, as such, also accounting for the impact of other variables (not necessarily economic ones) not modeled. Given the success of the numerous and diverse applications of PMP-related literature, we tend to believe that their adoption in econometric IO modeling would be equally fruitful.

The second line of research from which, in our view, econometric IO modeling would gain, is to consider seriously the issue of consistency of the real and financial flows and stocks. This issue has recently gained particular importance in what is now called the Stock-Flow Consistent (SFC) models within the post-Keynesian school of thought (see Godley and Lavoie 2007). SFC models are a type of macroeconomic model that rigorously take into account the accounting constraints, which are, for example, not fully accounted for with SAM modeling or the standard textbook macromodels. Referring to such standard economic models, Godley and Lavoie (2007, p. 6) state that “this system of concepts is seriously incomplete. Consideration of the matrix [i.e. the standard macro-framework] immediately poses the following questions. What form does personal saving take? Where does any excess of sectoral income over expenditure actually go to—for it must all go somewhere? Which sector provides the counterparty to every transaction in assets? Where does the finance for investment come from? And how are budget deficits financed?” These are apparently all legitimate questions, and equally important for a full-fledged, realistic analysis.

It is, of course, true that some stock-flow relationships are present in the existing dynamic econometric IO models, e.g., equations relating investment to capital stock, or consumption of durables to the stock of the durable goods. The consumption model described in Sect. 1.2 takes into account this type of stock-flow consistency within the household sector, by making income relevant flows (property income, debt service payments) depending on stocks as well as stocks on income and expenditure flows (gross saving and net lending). However, this is only one part of the stock-flow consistency requirement. What is important is that such consistency in accounting has to cover all stock-flow aspects of all sectors (households, firms, government, and the external sector) in the sense that ‘everything comes from somewhere and everything goes somewhere,’ which thus requires adequate consideration of not only real (tangible) assets, but also financial assets (cash, deposits, loans, shares, bonds, etc.). In this respect, Godley and Cripps (1983, p. 18) state that “the fact that money stocks and flows must satisfy accounting identities in individual budgets and in an economy as a whole provides a fundamental law of macroeconomics analogous to the principle of conservation of energy in physics”. The important implication of being stock-flow coherent in economic modeling is that it allows for realistic restraining of the space of possible outcomes of economic agents’ behavior, which would otherwise be almost surely an impossible task, especially with the medium- to large-scale economic models. In the words of Taylor (2004, p. 2), an explicit account of the stock-flow restrictions “remove[s] many degrees of freedom from possible configurations of patterns of payments at the macro level, making tractable the task of constructing theories to “close” the accounts into complete models”.

Although SFC modeling is by now a rather well-established approach, its extension to multi-sectoral and/or multi-product modeling is still in the stage of its infancy. The first such contributions, to the best of our knowledge, include SFC IO model of Berg et al. (2015), and the multisectoral SFC *macro* model of Naqvi (2015); we are not aware of any work on the integration of the SFC techniques into the econometric IO modeling. Therefore, we expect that such attempts in the future would definitely benefit this modeling strain in particular, and regional research in general.

1.5 Conclusion

In this chapter we have presented our views on the prospective future research directions in the strain of econometric input-output (IO) modeling. We think that some important recent developments, both theoretical and empirical, in other fields of economics, in particular, in macroeconomics, agricultural economics, and post-Keynesian economics, have been completely ignored in this type of modeling. Given their importance and usefulness for a sound economic analysis, regional research in general would benefit in the future, if these issues were incorporated into and/or appropriately adopted to the needs of econometric IO modeling.

The issues discussed in this chapter that could very well become the forefront topics of research and empirical applications in econometric IO modeling could be briefly summarized as follows:

- Importance of modeling *consumers' heterogeneity*, which includes, among other issues, using a concave consumption function across household income groups indicating non-constant marginal propensities to consume, different sensitivity of different household types in their consumption reaction to transitory income changes, heterogeneity with respect to the impacts of debt deleveraging and wealth shocks, concavity in the consumption function with respect to the level of wealth, and heterogeneity of households at the level of commodities.
- Importance of accounting for several *socio-economic characteristics* of households as additional variables, complementing income, wealth and debt limits. These variables include age group dummies for the household head; dummies if the household head is retired, unemployed, and is the owner of the house; household size; population density; etc. Introducing household heterogeneity not only introduces additional socio-economic variables other than income and prices that also influence behavior, but it also changes the reaction of households to income and prices and, therefore, aggregate results.
- Importance of *imperfect competition* and *technical change* in production modeling. Imperfect competition has important consequences for macroeconomic adjustment to demand shocks. Two approaches of modeling technical change (one in which technical change depends on innovation activities, and second where the bottom-up technology information and the top-down structure of the production model are combined) are discussed.
- Complete or close *calibration* of the observed data implies accounting for many relevant factors that are not explicitly modeled, which is essential for (more) realistic analysis of simulation scenarios. Here adoption of the discussed approaches of positive mathematical programming and related techniques seems to be promising.
- Importance of *stock-flow consistency*, i.e., full integration of stock and flow variables, both real (tangible) and financial assets. This would also greatly contribute to the more realistic economic modeling since then the diverse budget constraints imposed on all economic agents would be respected. Here the techniques developed in stock-flow consistent models could be readily used or adopted for the purposes of econometric IO modeling.

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