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Demand-Driven Structural Change in Applied General Equilibrium Models

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Abstract

This study analyzes the variations in industrial structure induced by income-sensitive patterns of final consumption, and how these changes can be captured by a multi-sector numerical model with a flexible demand system. We focus, in particular, on the estimation of parameters for an AIDADS (An Implicitly, Directly Additive Demand System) specification. We then test the latter by inserting it in the ENVISAGE global general equilibrium dynamic model, which is run under the SSP2 scenario from 2011 to 2050. It is found that time-varying income elasticity can generate sizable variations in the industrial structure. This finding has important practical implications, particularly when structural models are applied at a medium and long term horizon.

Keywords

Demand systems, structural change, economic dynamics, computable general equilibrium models.

Jel Codes

C33, C68, D58, E21, O11, O41.

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1 Introduction

Structural change refers to the variations in the patterns of industrial output, consumption and trade flows inside an economic system. In the short run, this change is mainly determined by income and relative prices, but in the medium and long run other forces shape the economic structure in a more persistent way. Technological progress, modifications of production processes, shifts in aggregate consumption, possibly driven by demographic evolution, all contribute to long lasting structural change.

Understanding structural change, and its determinants, is clearly an interesting and relevant scientific topic in itself, with direct policy implications. It is also practically important when applied, multi-sector general equilibrium models are used for the assessment of policies and effects having impacts in the long run, like in the case of climate change. Indeed, whereas these models are usually characterized by a detailed account of the economic structure, which is often essential when dealing with impacts affecting specific sectors, they are also normally calibrated on the basis of some past data (e.g., input-output tables or their social accounting matrix (SAM) extensions), meaning that they mirror an economic structure quite different from the one we could possibly observe in the distant future.

Some of the factors affecting the long run structural change are clearly unpredictable. Most of the technological breakthroughs of the past, affecting various industries, appear to have occurred in a seemingly random fashion.Harberger (1998) points out that the whole dynamics of economic progress actually resembles the growth process of“mushrooms”, rather than the steady rise of“yeast” (as neoclassical models of economic growth posit).

Some other factors, however, are quite predictable, in the sense that some of the forces which will affect the economic structure tomorrow are already active and observable today. Technology adoption and diffusion is under way. Catching up by fast growing developing economies is occurring. Demographic transitions are taking place, as well as mass migrations.

Broadly speaking, there are two classes of effects at work. There are supply side effects, affecting industrial productivity, either directly or indirectly, and there are demand side effects, involving variations in the structure of final demand. In this paper, we focus on the issue of modeling and numerical estimating changes in the pattern of aggregate household consumption, driven by varying (growing) levels of per capita income. Therefore, income levels are taken here as given, although in a full-fledged numerical model they could be determined endogenously, or obtained from an hypothetical scenario.

Modeling a time-varying and income-dependent structure of household consumption implies introducing a sufficiently sophisticated demand system, capable of capturing whatMatsuyama (2016) terms“Generalized Engel Law”: the fact that budget shares in consumption expenditure (and, more generally, industrial shares in terms of employment, value added or output) do not vary monotonically over time at progressively higher income levels. Therefore, in the next section, we briefly review what functional forms have been employed in the recent economics literature for this purpose. We focus, in particular, on the AIDADS (An Implicitly, Directly Additive Demand System;Rimmer and Powell 1992), presenting in Section 3 an exercise of parameters estimation for this demand system, based on the recently published Report of the 2011 International Comparison Program(ICP, 2015). Section 4 illustrates how results obtainable from a dynamic, computable general equilibrium model may change when the AIDADS specification, instead of a simpler, conventional form is employed to model consumption demand. A final section draws some concluding remarks.

2 Long-run changes in consumption patterns

Several demand systems, utility and expenditure functions, all with differentiated income elasticity, have been proposed. Desirable properties for their utilization in applied economic models are: (1) relative simplicity and analytical tractability; (2) generation of well behaved demand curves; (3) easiness of parameters estimation. Of course, the choice should also depend on the characteristics of the underlying model and on its purpose, for instance:

- the model could focus either on relatively small variations in income or expenditure levels (e.g., a single country CGE for short run policy assessment), or on more substantial variations (long run scenarios or intercountry comparison);
- the model could primarily focus on changes in income, rather than changes in relative prices.

Assessing long run changes in the structure of consumption demand means considering significant changes in income, with variations in relative prices entering only as a second order effect. Therefore, the selection of a demand system should be restricted to functional forms that, at higher income levels but constant relative prices, simulate structural changes consistent with historical"stylized facts".

One interesting option is the Hierarchical Demand System(Matsuyama, 2002; Buera et al., 2013). The idea behind the HDS is deceptively simple: goods and services are ranked from lowest to highest priority in terms of needs. All consumers spend their income in a sequential way, starting from basic needs and stepping up to the the highest level they can afford with their income. Once a need is satisfied, the corresponding good or service provides no more marginal utility. This is broadly consistent with the observation that goods could be initially regarded as a luxury (e.g., air conditioning), and when they can be obtained they become a necessity. When associated with a given income distribution, HDS can produce some interesting dynamics, with goods / industries"taking off" at various stages of economic development, possibly generating"hump shaped" trajectories as well.

Generally, HDS works well for theoretical models (possibly to be validated econometrically), but its implementation in applied macro-economic models like the CGEs would require information about the distribution of income and how it could evolve over time. This may be quite problematic, especially when a large set of countries are considered, including data-poor developing countries.

Gohin (2005) illustrates how to implement any regular configuration of price and income effects through"latent separability". Latent separability can be seen within an intermediate production process, where goods are first used to produce commodities, which are the true arguments of the utility function and not the goods. Even if each intermediate utility function is homothetic, there is a wide spectrum of possible income and substitution effects for purchased goods generated from the combination of different groups to which each good belongs. The problem with this method here is that is assumes knowledge of income and substitution elasticities from the outset. Indeed, this information is used to infer a consistent latent separability structure, which is not observable.

A number of authors have recently work with some variants of CES functions, with industry-specific but time-constant income elasticities. InFieler (2011) a single parameter plays the double role of substitution and income elasticity.Caron and Markusen (2014) set relative income elasticities equal to relative substitution elasticities, whereasComin et al. (2015) use separate and independent parameters for the two good-specific elasticities.

In all cases, income elasticities are constant. This implies that the demand pattern does not stabilize over time and, actually, the good with the highest income elasticity would asymptotically cover 100% of the budget. Clearly, this is not an appealing property for a realistic assessment of long run changes in demand patterns.

A demand system for structural change simulation should be"sufficiently flexible" or, technically speaking,"full rank". Rank one demands, the most restrictive demand systems, are independent of income; rank two demand systems are less restrictive, allowing linear Engel curves not necessarily through the origin; while rank three (i.e., full rank) demand systems are least restrictive, allowing for non-linear Engel responses(Cranfield et al., 2003).

Among the many full-rank demand systems which have been proposed, AIDADS (An Implicitly, Directly Additive Demand System;Rimmer and Powell 1992) appears to be especially suited for implementation in multi-sector, applied general equilibrium models. Indeed, it was introduced by CGE modelers and it has already been applied in a number of CGE models(Yu et al., 2000, 2004; Golub and Hertel, 2008).

The AIDADS can be seen as a generalization of the Linear Expenditure System (LES). The demand for good$i$ is expressed as:

$$q_i = \gamma_i + \phi_i \frac{y - \sum_j p_j \gamma_j}{p_i} \tag{1}$$

where$y$ is total income or expenditure,γ_i is a parameter andϕ_i (which in a LES would itself be a fixed parameter) is given by:

$$\phi_i = \frac{\alpha_i + \beta_i e^u}{1 + e^u} \tag{2}$$

with α_i, β_i parameters and u being the *implicitly* defined, *cardinal* utility function. To understand how AIDADS behaves, notice that:

$$\lim_{u \to -\infty} \phi_i = \alpha_i \tag{3}$$

$$\lim_{u \to \infty} \phi_i = \beta_i \tag{4}$$

$$\alpha_i < \phi_i < \beta_i \tag{5}$$

$$\lim_{y \to \infty} \frac{p_i q_i}{y} = \phi_i = \beta_i \tag{6}$$

Expenditure shares therefore stabilize at the level ϕ_i in the long run, although at different"speeds". It is not possible to get a closed form solution for the utility level u, which must then be estimated numerically, alongside the parameters α_i, β_i and γ_i . A number of constraints must also be taken into account, to ensure regularity conditions for the system(Powell et al., 2002).Cranfield (1999) shows how to use maximum likelihood methods to this purpose, employing also bootstrapping techniques to get parameters statistics (e.g., confidence intervals) and maximum entropy for multiple demands, disaggregated in terms of per-capita income.

Furthermore,Cranfield et al. (2003) assesses the ability of five structural demand systems to predict demands when estimated with cross sectional data spanning countries with widely varying per capita expenditure levels. Results indicate demand systems with less restrictive income responses are superior to demand systems with more restrictive income effects. Among the least restrictive demand systems considered, the AIDADS and the Quadratic Almost Ideal Demand System (QUAIDS) seem roughly tied for best, while the Quadratic Expenditure System (QES) is a close second. They notice that an important advantage of the QUAIDS model over AIDADS is its ease of estimation. Yet, and despite the fact that AIDADS is not exactly aggregable, the latter has fewer price related parameters to estimate and is designed so that budget shares lie between zero and one at all expenditure levels. This property suggests a preference for AIDADS when expenditure (income) shows substantial variation (or when extrapolations would involve large changes in expenditure) but prices are anticipated to experience little change.

3 Estimation of an AIDADS demand system

ICP (2015) provides data on real and nominal consumption expenditure for 180 countries at the year 2011, in 14 categories, which are further aggregated here in 11 consumption classes:

- Food and nonalcoholic beverages (**FOOD**)
- Alcoholic beverages, tobacco, and narcotics (**BEVTOB**)

- Clothing and footwear (**CLOTHING**)
- Housing, water, electricity, gas and other fuels + Furnishings, household equipment and maintenance (**HOUSE**)
- Health + Education (**HEAEDU**)
- Transport (**TRANSP**)
- Communication (**COMMUN**)
- Recreation and culture (**RECREAT**)
- Restaurants and hotels + Miscellaneous goods and services (**OTHER**)
- Machinery and equipment (**MACHINE**)
- Construction (**CONSTR**)

Ratios between real and nominal consumption readily give a set of country and sector specific price indexes. For the estimation of AIDADS parameters, we closely followCranfield (1999), by formulating the equations in terms of budget shares, and adding a stochastic error term:

$$w_{ir} = \frac{p_{ir}\gamma_i}{y_r} + \frac{\alpha_i + \beta_i \exp(u_r)}{1 + \exp(u_r)} \left(1 - \frac{\sum_i p_{ir}\gamma_i}{y_r}\right) + \epsilon_{ir} \tag{7}$$

wherew_{ir} is the observed household budget for the item$i$ in country$r$;y_r stands for total*per capita*expenditure (income) in country$r$;p_{ir} is the price index for the item$i$ in country$r$;ϵ_{ir} is a normal multivariate error term, distributed independently across observation, with zero mean and finite covariance matrix, where the sum over all items in each country is zero. All remaining symbols, including the cardinal utilityu_r, are parameters to be estimated.

The following restrictions apply:

$$\begin{gathered} \sum_i \alpha_i = 1 \\ \boldsymbol{\sum_i \beta_i = 1} \\ 0 \leq \alpha_i, \beta_i \leq 1 \end{gathered} \tag{8}$$

The estimation is performed using a non-linear maximum likelihood procedure[1], and gives the results shown in Table1.

Figure1 graphically displays how the budget shares evolve at constant prices, when annual per capita income (total consumption expenditure) varies from a minimum level of 8691 USD up to 168788 USD.

To interpret the meaning of the estimated parameters, consider that gamma (γ) expresses the fixed and unavoidable consumption, therefore the higher the value for this parameter, the more essential a certain good or service is seen, in terms of basic needs. On the other hand, beta (β) is the asymptotic budget

[1] Technical details about the specific algorithm and software are available on request.

Table 1: Estimated parameter values

	alpha	*beta*	*gamma*
FOOD	0.40	0.00	116
BEVTOB	0.02	0.02	16
CLOTHING	0.04	0.03	29
HOUSE	0.08	0.21	136
TRANSP	0.07	0.09	6
COMMUN	0.02	0.02	1
RECREAT	0.00	0.07	10
CONSTR	0.16	0.13	40
MACHINE	0.10	0.10	16
HEAEDU	0.08	0.14	98
OTHER	0.02	0.20	38

Figure 1: Expenditure shares by income levels

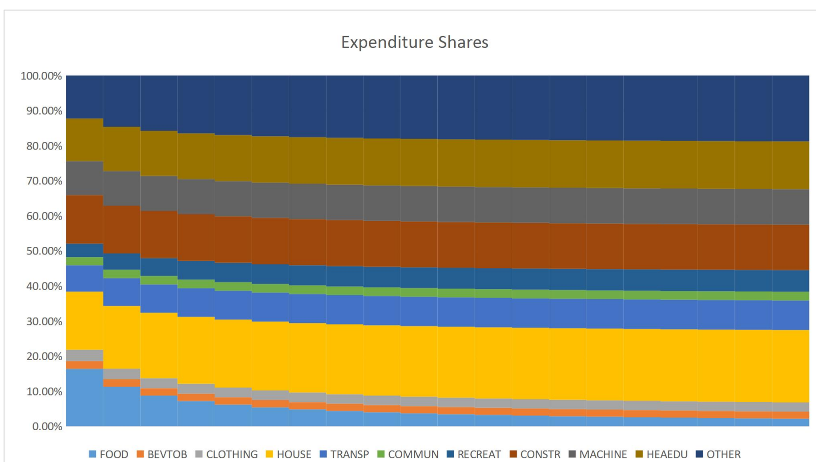
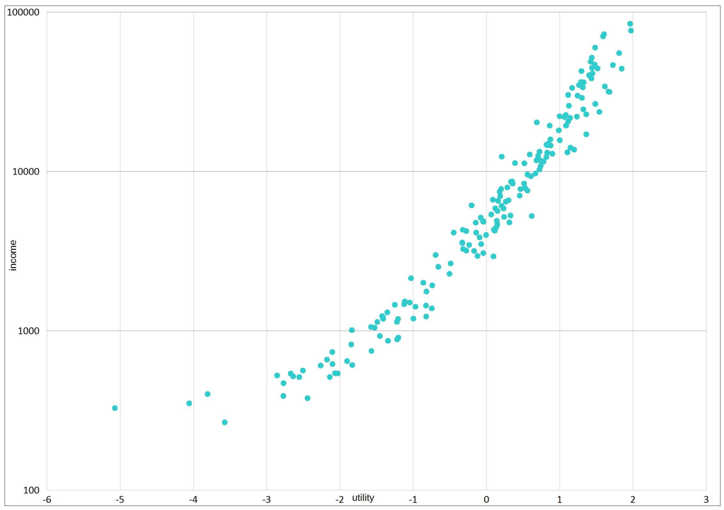


Figure 2: Income vs. cardinal utility levels



share, for income levels going to infinity. The higher this share is, the more important a consumption item becomes, as we get very rich.

To make the AIDADS system functional for a numerical simulation model, an additional step is necessary. Indeed, the procedure illustrated above allows to estimate country specific values for the cardinal utility u, but that variable is not available in the destination model, so a link must be established between utility and income levels. To this end, observe the plot contrasting income (vertical axis, logarithmic scale) with cardinal utility levels in Figure2.

The Figure suggests that the relationship is semi-logarithmic. Indeed, after trying several specifications of the functional form, the best regression results have been obtained with the following heteroskedasticity corrected OLS formulation, where u_r is regressed against $\ln(y_r)$:

```
Model 1:  Heteroskedasticity-corrected, using observations 1-177
Dependent variable:  u
           coefficient std.error t-ratio p-value
-------------------------------------------------------
const      -7.17788   0.160788   -44.64 1.45e-097 ***
lnm        0.839040  0.0183408   45.75 2.80e-099 ***
Statistics based on the weighted data:
Sum squared resid 656.4597 S.E. of regression 1.936801
R-squared 0.922833 Adjusted R-squared 0.922392
F(1, 175) 2092.804 P-value(F) 2.80e-99
Log-likelihood -367.1501 Akaike criterion 738.3002
Schwarz criterion 744.6525 Hannan-Quinn 740.8764
Statistics based on the original data:
Mean dependent var -0.047430 S.D. dependent var 1.348156
Sum squared resid 28.07932 S.E. of regression 0.400566
```

When the estimated coefficients of the regression are plugged into the AIDADS demand (2), the latter becomes a function of income and prices only, as one would expect from a regular demand function:

$$q_i = \gamma_i + \left(\frac{\alpha_i + \beta_i K y^Z}{1 + K y^Z} \right) \cdot \frac{y - \sum_j p_j \gamma_j}{p_i} \tag{9}$$

where we have added the two constants$K = 0.000763284$ and$Z = 0.83904$.

4 Introducing a flexible demand system into a dynamic CGE model

We have used the recursive dynamic global CGE model ENVISAGE(van der Mensbrugghe, 2017) to assess how results may change in a multi-sector structural model, when a flexible demand system like the AIDADS is introduced. First, a baseline was built, by running the model with endogenous labor productivity[2] and exogenous GDP growth (using OECD projections) and population (using IIASA projections), according to the Shared Socio-Economic Scenario 2 (SSP2), from 2011 to 2050. In two subsequent rounds, labor productivity was kept fixed at its baseline level, but two alternative specifications for the final consumption demand were tested: a simple homothetic Cobb-Douglas and the more flexible AIDADS system[3]. The purpose is verifying how the model output could vary when income elasticity for households consumption is switched from constant and unitary values to non-constant and time-varying ones.

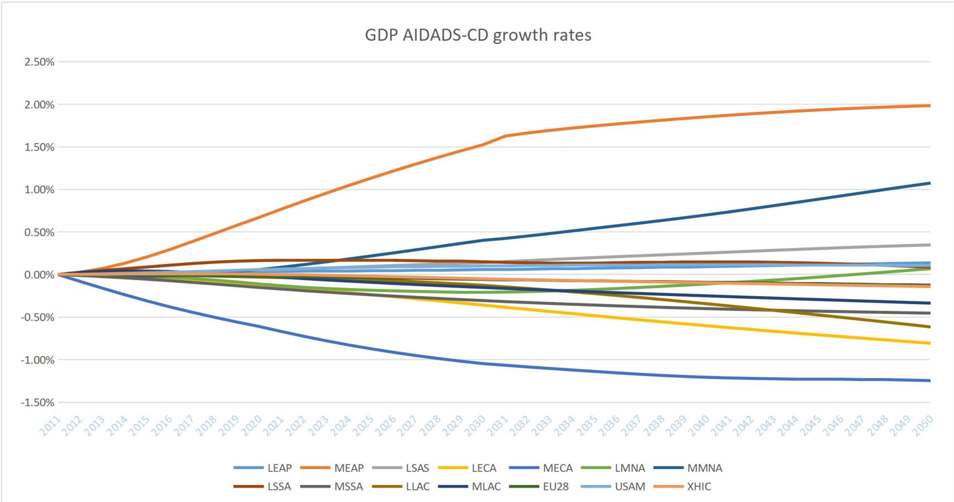
[2]Labor productivity growth is assumed to be smaller for Services and greater for Manufacturing industries.

[3]Parameters of the AIDADS system were adjusted to fit the different industrial classification in ENVISAGE.

Figure3 shows the differences in GDP produced by the AIDADS simulation with respect to the Cobb Douglas benchmark, for the following 14 macroregions in the ENVISAGE model:

- Low income East Asia & Pacific (LEAP)
- Middle income East Asia & Pacific (MEAP)
- South Asia (LSAS)
- Low income Europe & Central Asia (LECA)
- Middle income Europe & Central Asia (MECA)
- Low income Middle East & North Africa (LMNA)
- Middle income Middle East & North Africa (MMNA)
- Low income Sub-Saharan Africa (LSSA)
- Middle income Sub-Saharan Africa (MSSA)
- Low income Latin America & Carib. (LLAC)
- Middle income Latin America & Carib. (MLAC)
- European Union (EU28)
- United States (USAM)
- Rest of high-income countries (XHIC)

Figure 3: Differences in GDP growth rates



The different regions exhibit a differentiated response after the introduction of time-variant elasticities of substitution. Some regions get a higher growth, most notably Middle income East Asia & Pacific (MEAP), whereas other regions are characterized by lower growth, in particular Middle income Europe & Central Asia (MECA).

To understand the reasons behind such divergence, we look at the composition of the gross industrial output in the two regions (Table2), recalling that Manufacturing is the sector with the highest productivity growth in ENVISAGE, while Services is the slowest one. Notice that East Asia is characterized by a very large share of Manufacturing, whose component is significantly larger under the AIDADS specification. By contrast, middle income countries in Central Asia and Europe (outside the EU) are characterized by a much smaller Manufacturing sector, but a much larger share for Services (in particular, Transport and communications). As aggregate GDP growth can be seen as a weighted average of industrial growth rates, the different structure obtained under the AIDADS and CD formulations has direct implications for the national income increase. Regionswith relatively high shares of manufactures, relative to services, will seean accentuation of aggregate GDP growth when using the AIDADS specificationrelative to the C-D specification.

Table 2: Industrial output composition in MEAP and MECA regions

MEAP	**2011**	**2050-CD**	**2050-AID**
Cereals (CERL)	3.04%	4.21%	2.33%
Livestock (LVST)	3.14%	4.48%	2.72%
Processed food (PFUD)	3.80%	5.22%	3.23%
Textile, apparel and leather goods (TXWP)	5.03%	4.97%	3.93%
Other manufacturing (MANU)	40.76%	38.62%	40.73%
Housing utilities (HUTL)	11.89%	9.23%	10.05%
Wholesale and retail trade (TRAD)	5.30%	5.74%	6.85%
Transport and communication (TRCM)	9.63%	9.72%	10.64%
Financial services (FSRV)	7.68%	7.54%	8.90%
Housing services (HSRV)	9.73%	10.27%	10.62%

MECA	**2011**	**2050-CD**	**2050-AID**
Cereals (CERL)	2.15%	2.21%	1.29%
Livestock (LVST)	4.08%	4.40%	2.74%
Processed food (PFUD)	3.30%	3.58%	2.53%
Textile, apparel and leather goods (TXWP)	2.56%	2.36%	1.72%
Other manufacturing (MANU)	17.28%	17.60%	17.78%
Housing utilities (HUTL)	15.27%	15.98%	16.50%
Wholesale and retail trade (TRAD)	11.56%	11.94%	12.63%
Transport and communication (TRCM)	22.56%	22.34%	22.46%
Financial services (FSRV)	8.88%	8.54%	9.11%
Housing services (HSRV)	12.35%	11.05%	13.24%

Table3 presents the same industrial output composition, but for the whole world. With a unitary income elasticity (CD) all changes in the structure of final consumption must be due to variations in relative prices, so as to keep the shares in value terms constant. Here the drivers of variations in relative prices are differentiated productivity growth rates: since services are characterized by slower growth, their relative prices increases and real consumption first, then gross output decrease (in relative terms).

When the AIDADS formulation replaces the CD one, the effect of income elasticity overlaps to the relative price effect. For both Agriculture and Services industries, income and relative prices work to the opposite directions, and the industrial shares at 2050 do not differ very much from those of the 2011 base year (except Housing services). For Manufacturing, instead, the two effects reinforce each other, bringing about a share for“Other manufacturing” 3.81% larger than it was in 2011.

Table 3: Industrial output composition - World

World	**2011**	**2050-CD**	**2050-AID**
Cereals (CERL)	2.03%	3.64%	2.04%
Livestock (LVST)	2.47%	3.44%	2.54%
Processed food (PFUD)	3.09%	4.01%	2.88%
Textile, apparel and leather goods (TXWP)	2.12%	2.80%	2.25%
Other manufacturing (MANU)	24.26%	26.86%	28.07%
Housing utilities (HUTL)	11.50%	11.35%	11.90%
Wholesale and retail trade (TRAD)	10.27%	9.23%	10.08%
Transport and communication (TRCM)	12.64%	12.72%	13.21%
Financial services (FSRV)	12.80%	10.57%	11.46%
Housing services (HSRV)	18.81%	15.38%	15.57%

5 Conclusion

Changes in the economic structure are due to variations in technology and preferences, but also to differentiated sectoral productivity growth and varying patterns of consumption, sensitive to income per capita levels. Whereas future technology and preferences are not observable, trends in productivity are, as well as the response of consumption patterns to different income levels.

This work has focused on the estimation of the latter effect, that is on the changes in the economic structure driven by a different composition of final consumption in the medium and long term. An empirical estimation of parameters for a flexible demand system has been presented, and the system was tested in a structural dynamic general equilibrium model. We found that time-varying income elasticity can generate sizable variations in the industrial structure.

This finding has important practical implications, because numerical structural models like CGE are increasingly been employed to assess long terms effecst of policies and other impacts (e.g., economic impacts of climate change), but structural parameters are still derived from past input-output and social accounting matrices.

More work is needed to understand and gauge how income effects interact with differentiated productivity growth rates. Different sectoral"speeds" have been assumed in the ENVISAGE model, but not empirically estimated. We leave this topic for future research.

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