Climate policy design and the competitiveness of the French industry: A Computable General Equilibrium Analysis

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1 Introduction

The Intended Nationally Determined Contributions (INDCs) announced during the COP21 in Paris involve pursue with domestic climate policy implementation. However, tensions between countries, households and economic industries still represent a barrier that must be lifted. Beyond equity issues at the regional or international scale, globalization drives concerns about unilateral actions. In particular, preservation of the competitiveness of energy-intensive and trade-exposed (EITE) industries and the risk of carbon leakage in the case of asymmetric action often come up in the debate. Although the value-added of these industries represents a small fraction of the industrialised countries' GDP, their production remains highly strategic, and the power of industrial lobbies has proven to be decisive regarding any attempt to implement ambitious environmental taxation or quantitative control of greenhouse gas emissions.

To protect these industries and increase the environmental efficiency of a unilateral climate policy, different policy design has been proposed. Compensation mechanisms or border tax adjustments (BTA) are often considered (Böhringer et al., 2012), but raise international objections. Beside consequences for international cooperation, this kind of policy also drives compatibility issues with world trade organization (WTO) (Trachtman, 2016). Thus, unilateral carbon tax reform is easier to set up, and, the way to use the tax revenues represents a great potential of action to appropriately balance macroeconomic, equity and competitiveness concerns (Bovenberg et al., 2008). Numerous studies, based on either partial equilibrium models or computable general equilibrium models (CGE), examined the impact of alternative policy design on competitiveness and leakage issues. One the one hand, partial equilibrium models bring high details on some keys EITE sectors (in particular cement and steel sectors) and use relevant empirical information to analyse specific competitiveness constraints facing by those sectors.On the other hand, CGE models often embark poor details on EITE sectors, as by representing the economic system in a more aggregated way. However, CGE models reveal all feedback effects on the economy, and therefore can be used to estimate both industry and economy-wide effects. Recently, some efforts have been be made to disaggregate EITE sectors in CGE models. These attempts have shown that taking into account this higher level of "granularity" changes significantly the evaluation of the distributional effects of climate policies (Alexeeva-Talebi et al., 2012; Caron, 2012).

The paper proposes a method to keep benefits from both sectorial and general equilibrium analysis. This method has originally been developed to build a hybrid energy-economy Input-Output Table (IOT) at a regional scale but it can be apply for any quantity flows(Lefèvre et al., 2014). The approach consists in combining economic and physical data from sectors analysis with monetary input-output data from national accounts within a consistent and comprehensive "hybrid" accounting system. It goes beyond previous disaggregation techniques only based on economic data (Böhringer et al., 2012). So, in addition to the description of energy flows, we apply this methodology to steel and iron, as well as cement (i.e. tons of steel and cement). We illustrate the procedure with French data, and we analyse the effects of a unilateral French carbon tax reform using a country-scale CGE model, Imaclim-Sİn order to analyse disaggregation consequences, Imaclim-S is calibrated either on IOT with aggregated mineral and metal sectors, or on an hybrid IOT which isolates cement from other minerals, and steel and iron from other metals. Finally, we proceed to comparative static exercises by implementing a unilateral carbon tax of €80 per tonne of CO2 (tCO_2) based on the carbon content of all intermediate and final energy consumptions. We analyse and compare the macroeconomic and distributive effects of two policy options regarding the use of carbon tax revenues: (i) a non-recycled carbon tax revenues case, which are allocated to the reduction of public deficits, (ii) a recycled-revenues to finance a reduction of existing labour tax rates, which is a classical option in double-dividend literature (Goulder, 2013).

The results show that keeping aggregated heterogeneous industrial sectors can be misleading when exploring distributive consequences of a carbon price policy. The disaggregation of cement and steel is required to analyse the important distributive consequences into the production of minerals and metals. However, the use of the carbon tax revenue has first-order effects on macroeconomic magnitudes, while the level sectoral description has only second-order effects. This suggests the existence of trade-offs in the use of the carbon tax revenues. Giving back revenues via labour tax reductions is better for overall macroeconomic indicators. But, it is not enough for EITE industries, as labour represents a smaller share in their cost than energy.

The next parts of this paper are organized as follows. Sub-section 2.1 Sub-section 2-1 describes our original protocol to build a hybrid quantity-economy Input-Output Table (IOT) at a regional scale. We illustrate this protocol with 2010 data for France. For better reading, we only present in the text a simplified version of the hybrid IOT, with high level of aggregation (only one energy sector and one non-energy sector). The technical details of the all hybridization procedure for France, for energy, cement and steel, and the real 29-sectors table that have been built are given in appendices. Sub-section 2.2 shows how procedure introduces differences in the empirical description for metal and mineral sectors that matter for carbon policy analysis. Section 3 presents the IMACLIM-S CGE model. Section 4 describes the macroeconomic and distributive results obtained for the two recycling options of the carbon tax revenue and the two level of sectoral aggregation. Section 5 concludes.

2 Hybrid accounting approach: the IMACLIM procedure

Applied 2010 French economy, the hybridization method for IMACLIM leads to an input-output matrix of 29 sectors: 15 energy products and 13 industries and a composite sector, gathering the remainder of the economy. All energy sectors, as well as steel and iron and cement sectors, are described by flow quantities linked to monetary values by a consistent system of price. In the following, we describe the main ideas of the procedure. More details are available in the appendices 6 and 7.

2.1 Global approach for energy goods

"Hybrid" models are increasingly used to bridge the historical gap between bottom-up and top-down approaches to energy-economy-environment (E3) modelling (Hourcade et al., 2006). By nature, hybrid models should rely on benchmark databases that provide dual information on the economic flows in monetary value and in physical units, notably for energy goods - the necessary condition to control the interface between economic and technical systems. Before be extended to industrial sectors, the

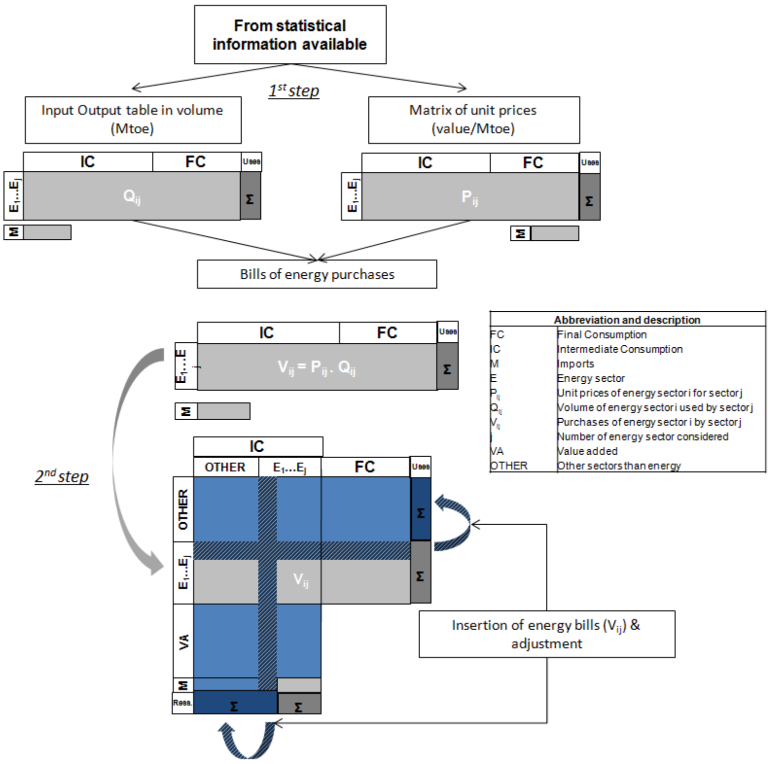

Figure 1: Overview of the IMACLIM hybridization procedure

procedure has initially been developed for energy sectors, thus showing it a significant impacts on key empirical features that are important for policy evaluation (Lefèvre et al., 2014).

The method develops in two main steps (Figure 1).

The *first step* consists in reorganizing the physical datasets - that are the energy balance (in million tons-of-oil equivalent, *Mtoe*) and energy prices (in Euros per *Mtoe*, €/*Mtoe*) - into input-output formats compatible with that of national accounts. As regards consumptions, this is not only a question of reallocating the physical energy flows of the energy balance to production sectors or households; rather, this entails re-interpreting the flows in national accounting terms, i.e. sorting out those that indeed correspond to an economic transaction between national accounting agents, or even combining some of them to compute such flows (e.g. directly assigning to their accounting sectors the fuel consumptions of electricity autoproducers).

The real singularities of the IMACLIM procedure come up in the *second step* where the trade-offs to adjust variables are made to guarantee the accounting balances. It starts with the reconstitution of energy expenses at the disaggregated level by the term-by-term product of volume and price tables. It then goes on with substituting this table of energy expenditures to that pre-existing in the system of national accounts in order to fully enforce energy statistics within the hybrid IOT. Other components of the system are further adjusted to maintain the accounting identities, without modifying the total value-added of domestic production. This is done (i) for all producing sectors and households, by compensating the difference between the recomputed energy expenditures and the original economic statistics through an adjustment of the expenses on the most aggregated non-energy good, a composite remainder of not specifically described economic activities, usually encompassing all service activities in E3 models; (ii) for the energy sectors, by adjusting all non-energy expenses (including value-added) pro rata the adjustment induced on total energy expenses.

The full technical details of each step are given in appendix 6 .

An important innovative feature of the IMACLIM procedure is the introduction of net-of-taxes purchasing price heterogeneities faced by economic agents. This feature is motivated by observing a wide gap in the unit energy prices faced by firms and households in energy prices statistics. To give just one example, in 2010 for France, the average net-of-VAT purchaser's price of electricity comodity was 105 €/MWh for households vs 72 €/MWh for producing sectors - 45% higher. A closer scrutiny of price data, available both net-of-taxes and all-taxes included, confirms that this gap is not caused by taxation alone. Neither by sole means of transport and trade margins [1]. It indeed but reflects contrasted pricing policies. It unquestionably translates extra actual costs incurred for the fragmented distribution to individual households ("retail element" of the cost), be they administrative or technical in nature. It is however doubtful that any data outside undisclosed corporate data could allow a meaningful distribution of these extra costs over the cost structure of energy production.

Because of this lack of information we introduce a set of "pricing margins" that aggregate, for each economic user category, the deviations of the producers's price faced by each economic agent from the average producer's price emerging from the cost structure. A user-specific margin rate τ_{SMij} linked to the purchase of energy good i by user j can be introduced to link the user-specific producers' price to the average producer's price of energy good i :

$$p_{ij} = p_i \cdot \left(1 + \tau_{SMij}\right)$$

By construction the aggregate margins compensate, and the balance of each energy sector (or the energy aggregate in our numerical example here) is not modified.

The same approach is applied for decomposed metal sectors and non-metal mineral sectors in order to isolate steel and iron and cement from the rest of the production. Finally, we obtain description in quantities consistent with prices for those two sub-sectors.

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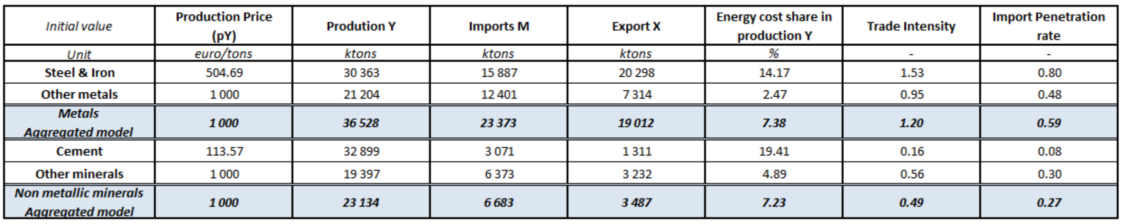
[1] Transport margins are small globally - 1,5% of domestic electricity bill - and trade margins are null for electricity.



Initial value	**Production Price (pY)**	**Prodution Y**	**Imports M**	**Export X**	**Energy cost share in production Y**	**Trade Intensity**	**Import Penetration rate**
Unit	*euro/tons*	*ktons*	*ktons*	*ktons*	*%*	-	-
Steel & Iron	504.69	30 363	15 887	20 298	14.17	1.53	0.80
Other metals	1 000	21 204	12 401	7 314	2.47	0.95	0.48
Metals Aggregated model	***1 000***	***36 528***	***23 373***	***19 012***	***7.38***	***1.20***	***0.59***
Cement	113.57	32 899	3 071	1 311	19.41	0.16	0.08
Other minerals	1 000	19 397	6 373	3 232	4.89	0.56	0.30
Non metallic minerals Aggregated model	***1 000***	***23 134***	***6 683***	***3 487***	***7.23***	***0.49***	***0.27***

Figure 2: Breakdown of metal and non-metal mineral sectors in hybrid IOT

2.2 Comparison between Imaclim hybrid IOTs for France 2010 with original national accounts

The discussion around data hybridization procedures could be argued to be purely technical if in practice the three sources of information (for values, prices and volumes) were more or less spontaneously consistent and data hybridization processes would result in similar IOTs. However, as practical results demonstrate, it may not be the case by large amounts.

Hybridization process changes macroeconomic characteristics of IMACLIM hybrid IOTs for France 2010 compare to original national accounts. Much specifically, it impacts the size of the energy sector within the total economy,and the breakdown of total energy expenses and consumption between firms (productive sectors) and households. These changes are explained in (Lefèvre et al., 2014).

The hybridization method allows to highlight sectoral heterogeneities originally hidden in the initial descritption and the simulation without this data processing effort.

Figure 2 shows that energy cost shares in production are much more important for cement and steel and iron production than for the rest of their aggregated sectors. Indeed, for the steel industry, energy expenditure represents over 14% of expenses for a production unit, while for the rest of the metal sector, energy represents only 2.5%. The share of energy in cement production reached nearly 20%, while for the rest of non-metallic minerals, energy represents only 4.9% of spending. Considering these sectors as a whole, energy costs represent 7.4% for metallurgy and 7.2% for non-metallic minerals. Not taking into account this heterogeneity could be misleading when implementing carbon tax reform.

Trade intensity is also heterogenous across sectors. Steel industry has a 61% higher rate than the rest of the metallurgy. Its import penetration rate is 85% higher than the rest of the metallurgy. Regarding cement sectors compared to the rest of non-metallic mineral sector, it appears that cement is less trade exposed compared to the rest of the non-metallic minerals sector, which is easily understandable because of transport problems. We can observe same conclusion for import penetration rate.

Not taking into account these heterogeneities by keeping average value for aggregated sectors could be misleading when implementing carbon tax reform. As the weight of the energy differs significantly in production accros sectors, the impacts on production, consumption and ultimately on international trade could be different. To explore tax arrangements at the country scale of France that can help to reduce the negative aspects of the application of carbon tax through objectives comprising equity, competitiveness for EITE sectors and better environmental efficiency, it seems relevant to introduce all these heteorgineity into the modelling framework.

3 IMACLIM-S FRANCE modeling framework

3.1 General description of IMACLIM-S

The IMACLIM-S model is a computable general equilibrium model devoted to carbon policy analysis through comparative statics (Samuelson, 1948). The version V2.5 applied in this paper is an open-economy version distinguishing four types of agents (households, firms, public administrations, and the 'rest of the world') and upto 29 productions (15 energy goods, 13 industries and a composite good aggregating all other goods and services).

IMACLIM-S is a 'hybrid' model in the sense that it pictures energy volumes that are not deduced from national accounts statistics and a single energy price hypothesis, but rather result from an effort to harmonise these macroeconomic data with energy balances and energy prices statistics in the reference year. This hybridisation of the input-output table facilitates the integration of some engineering expertise about technical flexibilities at a given time horizon. In particular, energy efficiency improvements of equipments and infrastructures used by both the producer and the consumer are bounded by exogenous asymptotes. As a result, the model exhibits price elasticities that gradually decrease as the relative energy prices increase (rather than constant elasticities).

The income flow associated with the flow of goods starts with the remuneration of production factors plus net payments from/to the rest of the world. It continues with distribution operations orchestrated by the public administration between the four categories of agents: taxes (payroll taxes, value-added tax, energy product tax, corporate tax, income tax, etc.) and transfers (unemployment benefits, pensions, etc.). Once they have made their consumption and investment choices, agents lend or borrow on financial markets depending on whether their exhibit positive or negative savings. This affects their financial positions and the associated income flows (debt services, interest payments).

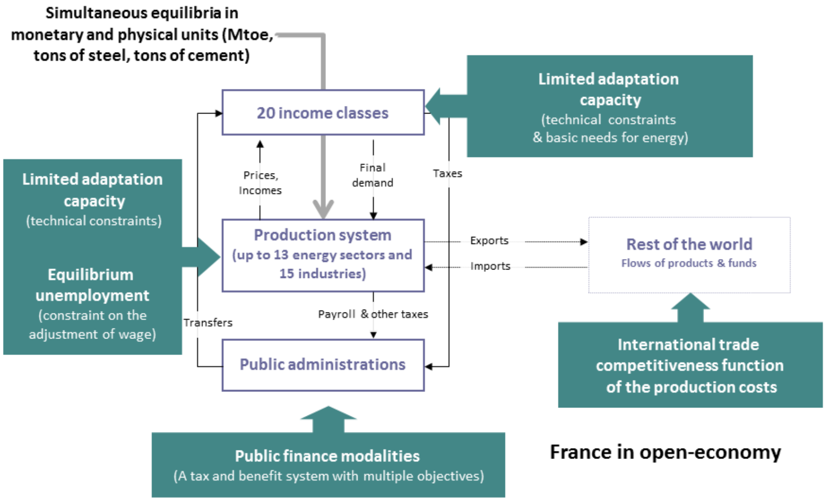


Figure 3: Overview of the IMACLIM-S FRANCE model framework

The model is calibrated on 2010 data. Its formal structure are available in appendix 8.

The work of hybridization data allows to calibrate the model on an input-output table with up to 29 sectors. In order to not multiply the distributional effects, the paper focus on two levels of aggregation, described in table 1 and table 2. In both cases, we keep a detailed description of main energy sectors. Industrial sectors are aggregated in except for metallurgy and non-metallic mineral sectors. The composite sector is the rest of the economy, mostly composed by service sectors.

The model is then calibrated on both level of aggregation. The model calibrated on sectors described on table 1 considered metallic and non-metallic mineral sectors as a whole. The model calibrated on sectors described on table 2 divides each of these sectors into two sub-sectors. The description of the steel and cement is then "hybrid": production are described in both physical quantities and values, linked by consistent price system.

3.2 Carbon tax policy

The comparative statics analysis amounts to distort the 'image' of the no-policy economy by an external shock: the carbon tax. The simulated tax reforms differ only in the way in which tax proceeds are recycled. The carbon tax common to all reforms

Imaclim-S France - aggregated version		
Sectors	Hybrid accounting system	Quantity units
Crude oil	YES	Mtoe
Gas	YES	Mtoe
Coal	YES	Mtoe
Fuel Products	YES	Mtoe
Electricty	YES	Mtoe
Heat,Geothermy, solar thermic	YES	Mtoe
Metals	NO	-
Minerals	NO	-
Other Industries	NO	-
Agriculture	NO	-
Composite	NO	-

Table 1: Sectoral details of aggregated model

Imaclim-S France - hybrid and disaggregated version		
Sectors	Hybrid accounting system	Quantity units
Crude oil	YES	Mtoe
Gas	YES	Mtoe
Coal	YES	Mtoe
Fuel Products	YES	Mtoe
Electricty	YES	Mtoe
Heat,Geothermy, solar thermic	YES	Mtoe
Iron and steel	YES	tons of steel and iron
Non ferrous metals	NO	-
Cement and clinker	YES	tons of cement and clinker
Minerals	NO	-
Other Industries	NO	-
Agriculture	NO	-
Composite	NO	-

Table 2: Sectoral details of disaggregated model

is assumed unilateral, without border adjustment measures for now, imposed on the carbon content of all fossil fuel sales. It is supposed to have grown smoothly since 1990, leading to 'counterfactual 2010 Frances' adjusted to the 10-year reform.

We analyze the impact of a substantial €80 per tonne of CO2 (tCO_2). For early observations, we focus on two cases. First, we analyze an implementation of carbon tax without any redistribution of the revenues generated by this tax. As any strong feedback effect of public debt variation are modelled, this option isolates the consequences of higher energy prices from those of returning revenues to domestic agents. Secondly, we simulate a classical recycling option in the "double-dividend literature" : a carbon tax which revenues are used to decrease existing labour tax. In France, as in most European countries, the best option from a macroeconomic point of view is to use the revenue to finance a reduction of labour tax rates (Goulder, 2013)

4 Early results

4.1 Macroeconmic effects

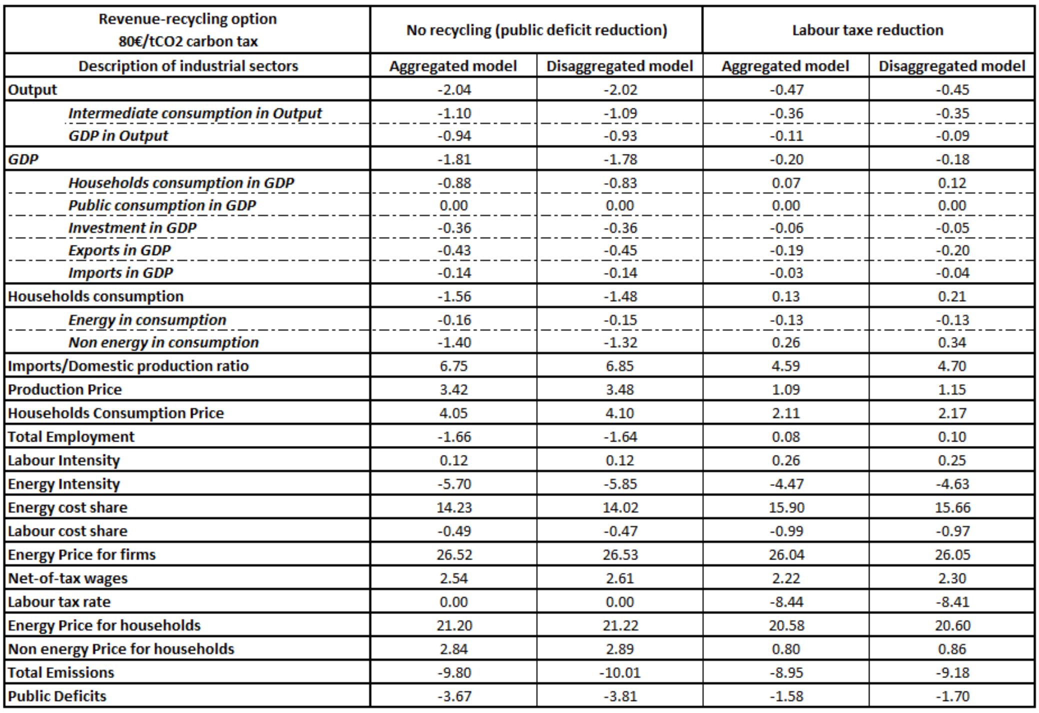
From the macroeconomic point of view, two main conclusions emerge from results represent in figure 4. Firstly, macroeconomic outcomes are sensitive to the recycling option used for carbon tax revenues. This is in line with the double dividend literature (Bovenberg, 1999; Goulder, 1994, 2013). The macroeconomic cost of the environmental tax reform in terms of *GDP* and employment is lowered when the carbon tax revenue is used to finance a reduction of the labour tax. Secondly, macroeconomic outcomes are hardly sensitive to the initial "granularity" description of the industry sectors. This appears to be also in line with studies focusing on the macroeconomic and distributive effects of border tax adjustments (Caron, 2012; Böhringer et al., 2012). The level of industrial aggregation has only second order effects on the variations of aggregate components.

More precisely, public deficits is further reduced when carbon tax revenues are not returned to domestic agents (around -3.7% instead of -1.6% with recycling revenues of carbon tax). However, the economic activity and the level of employment are much more impacted without any recycled process(-1.8% instead of -0.2% for real *GDP*, and -1.6% instead of +0.1% for employment). This is a classic result from the double dividend literature: when the revenue of a carbon tax is not returned to domestic agents, the reform harms the whole economy by increasing the firm production cost and reducing purchasing power of households. This leads to higher costs for comparable emissions reductions (-9% to 10% reductions). Without recycled revenue, production and consumption prices are greatly affected (+3.4% and +4.1%

respectively). Therefore, both domestic and external demand shrink, contributing in *GDP* depression (-0.8% for the contribution of household consumption to *GDP*, -0.4% for investment, and -0.4% for exports). In addition, domestic consumption shifts to foreign products and the proportion of imported goods increases (+6.7%). This reduces even more *GDP* (-0.1% for the contribution of higher imports to the *GDP* reduction). Technical substitutions and structural change induce a decrease in energy intensity of domestic productions (-5.7%). However, this is not enough to outweigh the increase in energy prices for firms (+26.5%), and energy cost share greatly increases (+14%). Furthermore, through the wage curve equation, workers tend to maintain their purchasing power by demanding higher net-of-tax wages (+2.5%). Thus, part of energy tax is shifted to the firms, which harms the production costs and international trade.

On the contrary, when carbon tax revenues are recycled, price's increase is mitigated by a lower level of labour taxation (+1.0% for production prices, +2% for consumption prices). However, as energy intensive sectors are less negatively affected, the energy intensity remains higher (-4.5% instead of -5.7% without recycled revenues), and therefore energy cost share (+15%). But this negative effect is outweighed by the positive effect of lower labour costs (+2.2% instead of +2.5%). On the one hand, the higher net-of-tax wages demanded by workers (+2.2%) is compensated by lower labour taxes (-8.4%). As a result, both wage incomes and households'demand are sustained, and the lower increase in production costs limits the negative consequences on the real trade balance. The decrease in exports and the increase in imports less contribute to a drop of effective demand and *GDP* (-0.1% instead of -0.4% for exports, and slightly less for imports). On the other hand, recycled revenues reduce the relative cost of labour compared to energy. As a result, the labour intensity of production also progress more (+4.5%) and total employment is preserved (+0.1%). Therefore, although the carbon tax revenue is returned to domestic agents, the other tax bases are less eroded. Thus, the tax reform also reduces slightly the public deficits (-1.5%).

As noted before, disaggregating industrial sectors has only second order effects on macroeconomic magnitudes. However, the sectoral disaggregation leads to slightly higher penetration of imported productions (0.1% more for both recycled revenues simulations) and slightly higher decrease in exports. Total emissions are also lowered. We will see that this is the result of describing the most energy intensive segments of the industrial production. Indeed, these aggregate results hide an important heterogeneity among production sectors.



Revenue-recycling option 80€/tCO2 carbon tax	No recycling (public deficit reduction)		Labour taxe reduction	
Description of industrial sectors	Aggregated model	Disaggregated model	Aggregated model	Disaggregated model
Output	-2.04	-2.02	-0.47	-0.45
Intermediate consumption in Output	-1.10	-1.09	-0.36	-0.35
GDP in Output	-0.94	-0.93	-0.11	-0.09
GDP	-1.81	-1.78	-0.20	-0.18
Households consumption in GDP	-0.88	-0.83	0.07	0.12
Public consumption in GDP	0.00	0.00	0.00	0.00
Investment in GDP	-0.36	-0.36	-0.06	-0.05
Exports in GDP	-0.43	-0.45	-0.19	-0.20
Imports in GDP	-0.14	-0.14	-0.03	-0.04
Households consumption	-1.56	-1.48	0.13	0.21
Energy in consumption	-0.16	-0.15	-0.13	-0.13
Non energy in consumption	-1.40	-1.32	0.26	0.34
Imports/Domestic production ratio	6.75	6.85	4.59	4.70
Production Price	3.42	3.48	1.09	1.15
Households Consumption Price	4.05	4.10	2.11	2.17
Total Employment	-1.66	-1.64	0.08	0.10
Labour Intensity	0.12	0.12	0.26	0.25
Energy Intensity	-5.70	-5.85	-4.47	-4.63
Energy cost share	14.23	14.02	15.90	15.66
Labour cost share	-0.49	-0.47	-0.99	-0.97
Energy Price for firms	26.52	26.53	26.04	26.05
Net-of-tax wages	2.54	2.61	2.22	2.30
Labour tax rate	0.00	0.00	-8.44	-8.41
Energy Price for households	21.20	21.22	20.58	20.60
Non energy Price for households	2.84	2.89	0.80	0.86
Total Emissions	-9.80	-10.01	-8.95	-9.18
Public Deficits	-3.67	-3.81	-1.58	-1.70

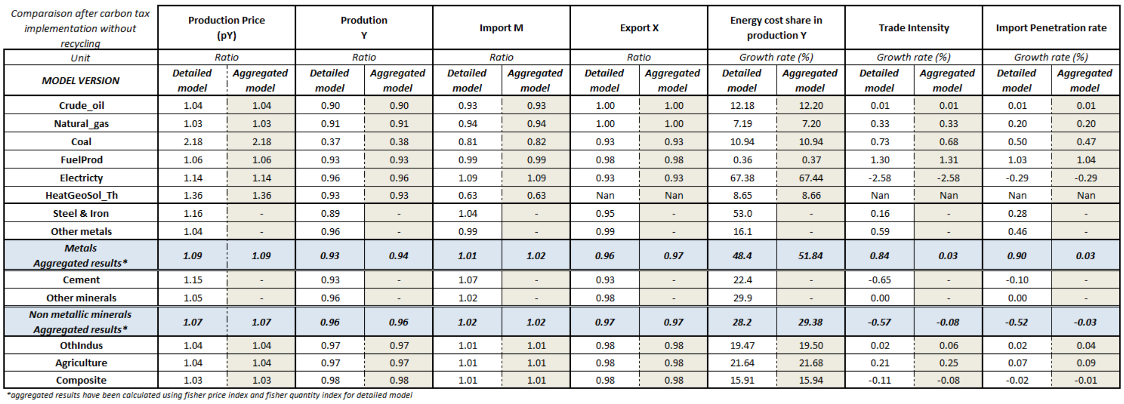
Figure 4: Cross comparaison of macroeconomic key indicators

4.2 Distributional impacts on sectors

The tables in figure 5 and 6 represent main results of the four simulations : either on disaggregated or agregated input-output table, with a carbon tax implementation which revenues are recycled or not.

First of all, we observe that the distributional effects are different between sectors, some sectors are much impacted by an implementation of a carbon tax than others: production prices pY increase more, production faces higher reduction. Within a same carbon tax reform, one or the other, we observe that for sectors which keep the same level of description between the two model versions, impact of the policy on different indicators remains at the same degree. Indeed, the carbon tax policy without recycled revenues induces a 1.14 increase in electricity production price, either on detailed model or the aggregated model, the production faced a 0.96 decrease in quantities term in both model, while imports growth from 1 to 1.09 compared to the initial value.

Comparing the distributional impacts in the two policy cases, it appears that recycling tax revenues into a reduction of labour tax rate preserve a bit more all industries. Globally, production prices of all firms increase less and production, as well as exports, fall less. Keeping the example of electricity, the production price increase by 11% (1.11 as ratio of prices) compared to initial value against 14%, as said earlier. The production faced a 2% decrease (0.98 as a ratio of prices) against 4%. As production



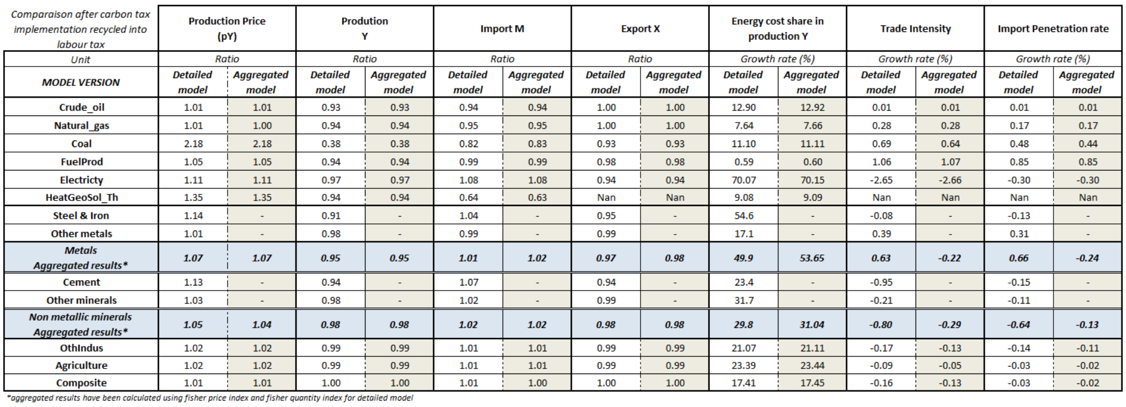
Comparaison after carbon tax implementation without recycling	**Production Price (pY)**		**Prodution Y**		**Import M**		**Export X**		**Energy cost share in production Y**		**Trade Intensity**		**Import Penetration rate**	
Unit	*Ratio*		*Ratio*		*Ratio*		*Ratio*		*Growth rate (%)*		*Growth rate (%)*		*Growth rate (%)*	
MODEL VERSION	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***
Crude_oil	1.04	1.04	0.90	0.90	0.93	0.93	1.00	1.00	12.18	12.20	0.01	0.01	0.01	0.01
Natural_gas	1.03	1.03	0.91	0.91	0.94	0.94	1.00	1.00	7.19	7.20	0.33	0.33	0.20	0.20
Coal	2.18	2.18	0.37	0.38	0.81	0.82	0.93	0.93	10.94	10.94	0.73	0.68	0.50	0.47
FuelProd	1.06	1.06	0.93	0.93	0.99	0.99	0.98	0.98	0.36	0.37	1.30	1.31	1.03	1.04
Electricty	1.14	1.14	0.96	0.96	1.09	1.09	0.93	0.93	67.38	67.44	-2.58	-2.58	-0.29	-0.29
HeatGeoSol_Th	1.36	1.36	0.93	0.93	0.63	0.63	Nan	Nan	8.65	8.66	Nan	Nan	Nan	Nan
Steel & Iron	1.16	-	0.89	-	1.04	-	0.95	-	53.0	-	0.16	-	0.28	-
Other metals	1.04	-	0.96	-	0.99	-	0.99	-	16.1	-	0.59	-	0.46	-
Metals Aggregated results*	***1.09***	***1.09***	***0.93***	***0.94***	***1.01***	***1.02***	***0.96***	***0.97***	***48.4***	***51.84***	***0.84***	***0.03***	***0.90***	***0.03***
Cement	1.15	-	0.93	-	1.07	-	0.93	-	22.4	-	-0.65	-	-0.10	-
Other minerals	1.05	-	0.96	-	1.02	-	0.98	-	29.9	-	0.00	-	0.00	-
Non metallic minerals Aggregated results*	***1.07***	***1.07***	***0.96***	***0.96***	***1.02***	***1.02***	***0.97***	***0.97***	***28.2***	***29.38***	***-0.57***	***-0.08***	***-0.52***	***-0.03***
OthIndus	1.04	1.04	0.97	0.97	1.01	1.01	0.98	0.98	19.47	19.50	0.02	0.06	0.02	0.04
Agriculture	1.04	1.04	0.97	0.97	1.01	1.01	0.98	0.98	21.64	21.68	0.21	0.25	0.07	0.09
Composite	1.03	1.03	0.98	0.98	1.01	1.01	0.98	0.98	15.91	15.94	-0.11	-0.08	-0.02	-0.01

**aggregated results have been calculated using fisher price index and fisher quantity index for detailed model*

Figure 5: Cross sectorial comparaison of key indicators with a non-reycled carbon tax

price increases, exports fall down, of 6% , that is not so much than the policy without recycled-revenues. Finally, imports rise less; 8% against 9%.

If the level of sectorial description seems to not change global impacts, disaggregation reveals high level of heterogeneity among sectors. Steel and cement sectors are much more impact by a carbon tax policy implementation than the rest of their corresponding sectors. As steel and cement sectors are much more energy intensive, their production prices increase a lot compared to the rest of their rest of metals and minerals sectors. Indeed, in the case with recycled-revenues of the carbon tax, production prices of steel and cement sectors rise up to respectively 14% and 13%, while the rest of those sectors only faces respectively 1% and 3% of increase. This is very understanding espacially for steel, as the energy cost share in production growth up significaly to 54.6%. Behaviors are also very different in analyzing trade intensity and the import penetration rate, and even sometimes go in opposite directions. Keeping those sectors aggregated introduce a consequent bias. As example, trade intensity decreases, although few, for steel industry (-0.08%) while trade intensity of the rest of the metallurgy increases (0.39%), whith the recycled-revenues policy. The sign of trade intensity for steel sector can be explained. Production in value increases (production price increases more than production in quantities decreases), as well as imports plus exports in value increases. However, production in value increases more than the terms of trade. As consequence, trade intensity growth rate fall down to under 0, but for the rest of the sector, trade intensity goes up (+0.39%). If we keep metal sector as a whole, trade intensity goes down (-22%). Cement trade intensity goes down much more than the rest of the minerals sectors (-0.95% against -0.21%). Considering the minerals sector as one entire sector in the simulation, we hide this difference (-0.29%). The negative growth rate import penetration rate for steel (-0.13%), and cement (0.15%) is due to a rise for domestic demand in value, that is more important than the rise of imports in value. Once more, keeping aggregated those sectors hide very different effects across their "sub-sectors" and reveal significant aggregation biais.



Comparaison after carbon tax implementation recycled into labour tax	**Production Price (pY)**		**Prodution Y**		**Import M**		**Export X**		**Energy cost share in production Y**		**Trade Intensity**		**Import Penetration rate**	
Unit	*Ratio*		*Ratio*		*Ratio*		*Ratio*		*Growth rate (%)*		*Growth rate (%)*		*Growth rate (%)*	
MODEL VERSION	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***	***Detailed model***	***Aggregated model***
Crude_oil	1.01	1.01	0.93	0.93	0.94	0.94	1.00	1.00	12.90	12.92	0.01	0.01	0.01	0.01
Natural_gas	1.01	1.00	0.94	0.94	0.95	0.95	1.00	1.00	7.64	7.66	0.28	0.28	0.17	0.17
Coal	2.18	2.18	0.38	0.38	0.82	0.83	0.93	0.93	11.10	11.11	0.69	0.64	0.48	0.44
FuelProd	1.05	1.05	0.94	0.94	0.99	0.99	0.98	0.98	0.59	0.60	1.06	1.07	0.85	0.85
Electricty	1.11	1.11	0.97	0.97	1.08	1.08	0.94	0.94	70.07	70.15	-2.65	-2.66	-0.30	-0.30
HeatGeoSol_Th	1.35	1.35	0.94	0.94	0.64	0.63	Nan	Nan	9.08	9.09	Nan	Nan	Nan	Nan
Steel & Iron	1.14	-	0.91	-	1.04	-	0.95	-	54.6	-	-0.08	-	-0.13	-
Other metals	1.01	-	0.98	-	0.99	-	0.99	-	17.1	-	0.39	-	0.31	-
Metals Aggregated results*	***1.07***	***1.07***	***0.95***	***0.95***	***1.01***	***1.02***	***0.97***	***0.98***	***49.9***	***53.65***	***0.63***	***-0.22***	***0.66***	***-0.24***
Cement	1.13	-	0.94	-	1.07	-	0.94	-	23.4	-	-0.95	-	-0.15	-
Other minerals	1.03	-	0.98	-	1.02	-	0.99	-	31.7	-	-0.21	-	-0.11	-
Non metallic minerals Aggregated results*	***1.05***	***1.04***	***0.98***	***0.98***	***1.02***	***1.02***	***0.98***	***0.98***	***29.8***	***31.04***	***-0.80***	***-0.29***	***-0.64***	***-0.13***
OthIndus	1.02	1.02	0.99	0.99	1.01	1.01	0.99	0.99	21.07	21.11	-0.17	-0.13	-0.14	-0.11
Agriculture	1.02	1.02	0.99	0.99	1.01	1.01	0.99	0.99	23.39	23.44	-0.09	-0.05	-0.03	-0.02
Composite	1.01	1.01	1.00	1.00	1.01	1.00	1.00	1.00	17.41	17.45	-0.16	-0.13	-0.03	-0.02

**aggregated results have been calculated using fisher price index and fisher quantity index for detailed model*

Figure 6: Cross sectorial comparaison of key indicators with a reycled carbon tax in labour tax reduction

5 Conclusion

We have focused on one of the major constraint on policy design: the competitive pressure that companies are facing in a highly globalized world. More precisely, we have focused on the risk of profit losses for major industrial stakeholders which often hinder political acceptability. We have proposed a methodological development which consists in combining the economic and physical data from sectoral analysis with monetary data from national accounts. The result is a consistent accounting system can then be used for general equilibrium evaluations of alternative policy designs. It can also be used to reach a relevant level of description of the main vulnerable economic actors.

The early numerical results show that the macroeconomic outcomes of a carbon tax are very sensitive to policy design, in this paper, the recycling revenue strategy, but much less to the level of sectorial description on which the model is calibrated. This result is consistent with previous studies focused on BTA, as Caron (2012). However, the distributional outcomes are important, especially within the production of metals and minerals. Thus, aggregation hides important disparities and losses for segments of those sectors, which are both highly energy intensive and exposed to international trade. Nevertheless, this level of granularity is not captured in most macroeconomic and multi-sectoral models. Lowering the labour tax with the carbon tax revenue preserve most of economic activities, and leads to better macroeconomic outcomes. However, it is not enough to avoid important profitability losses for major industrial stakeholders. Some accompanying measures are expected to preserve these industries and to reconcile competitiveness issues with macroeconomic efficiency.

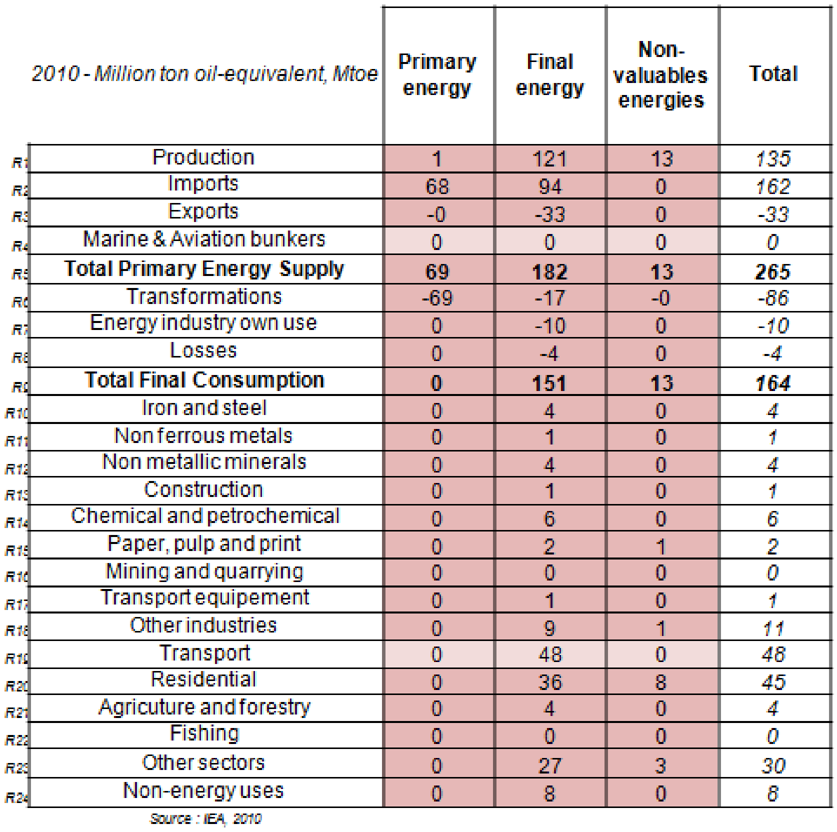
Some limits deserve to be highlighted. These first simulations do not consider the existing uncertainty on some crucial parameters, in particular: (i) the substitution possibilities away from fossil energies, (ii) the wage-setting behaviours, (iii) the sensitivity of international trade to production costs and prices (exports and imports). A sensitivity analysis should be provided in order to examine how these parameters can influence the cost rankings of the alternative policy options. In addition, other trade-offs are to be considered to rightly evaluate the costs and benefits of these alternative options. In particular, other important national objectives have been neglected: the distribution issues among individuals and the equity concerns, the control of public deficits and the other public finance objectives. The scope of the trade-offs to be considered in the use of the carbon tax revenue is larger. Some portion of the proceeds can be allocated to vulnerable households, and the fiscal envelop available for compensations depend on the budgetary rules followed by the government. All these considerations influence the cost rankings of policy options (Goulder, 2013). Further developments are needed to analyse the distributive effects among households and to simulate different systems of public finance.

Finally, the model does not account for carbon leakages. The simulations display an increase in imports of energy intensive products while domestic production costs increase. However, in those cases, the "production-based" level of the country's emissions decreases, while these energy-intensive products are still consumed within the country. An indicator of "consumption-based" emissions will be provided in further analysis in order to fully observe the environmental impacts of these policies.

6 Appendix A: technical details of the IMACLIM hybridization procedure illustrated on the example of France for 2010

Step 1: Elaborating supply-use tables in physical units for energy

Before getting dual accounting systems for some intensive industries, we begin the procedure with energy sectors. Because tables of resources and uses of energy flows and prices are not available from statistical institutes in a standardized manner, they must be built through the collection of different data sources.



	2010 - Million ton oil-equivalent, Mtoe	Primary energy	Final energy	Non-valuables energies	Total
R1	Production	1	121	13	*135*
R2	Imports	68	94	0	*162*
R3	Exports	-0	-33	0	*-33*
R4	Marine & Aviation bunkers	0	0	0	*0*
R5	**Total Primary Energy Supply**	**69**	**182**	**13**	***265***
R6	Transformations	-69	-17	-0	*-86*
R7	Energy industry own use	0	-10	0	*-10*
R8	Losses	0	-4	0	*-4*
R9	**Total Final Consumption**	**0**	**151**	**13**	***164***
R10	Iron and steel	0	4	0	*4*
R11	Non ferrous metals	0	1	0	*1*
R12	Non metallic minerals	0	4	0	*4*
R13	Construction	0	1	0	*1*
R14	Chemical and petrochemical	0	6	0	*6*
R15	Paper, pulp and print	0	2	1	*2*
R16	Mining and quarrying	0	0	0	*0*
R17	Transport equipement	0	1	0	*1*
R18	Other industries	0	9	1	*11*
R19	Transport	0	48	0	*48*
R20	Residential	0	36	8	*45*
R21	Agricuture and forestry	0	4	0	*4*
R22	Fishing	0	0	0	*0*
R23	Other sectors	0	27	3	*30*
R24	Non-energy uses	0	8	0	*8*

Source : IEA, 2010

Table 3: Simplified structure of the IEA energy balance

The methodology, explained as follows, has been carried out for those energy sectors : Crude oil/ LNG/feedstocks, Natural gas, Coking coal, Bituminous coal, Coke oven coke, Other coal products, Gasoline, LPG, Jet Fuel, Diesel and heating oil, Heavy fuel oil, Other petroleum products, Biomass & Waste, Biofuels, Electricity, Nuclear, Hydro, Wind/Solar PV/Tide, Heat/Geothermal/Solar Th. For the sake of simplicity we illustrate the method with only two aggregated energy types: primary energy and final energy.

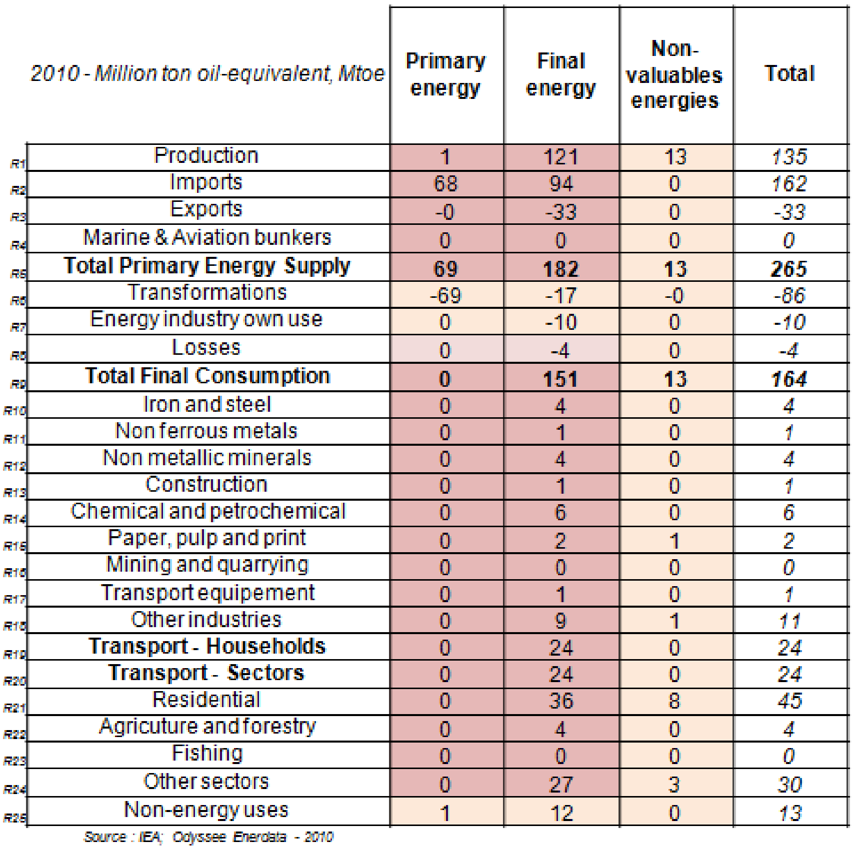
Starting from IEA energy balance, statistical gaps and stock changes are first distributed between primary supply and consumptions (transformations or final consumption). Then, we isolate in marine and aviation bunkers, the consumption corresponding to national company to return those volume of energy in the sector of transport. The amounts of remaining energy are returned to exportation. After those pre-treatments, we can identify (Table 3) domestic production (R1), international trade (R3-4), transformation processes and the distribution of final consumption across activities (R10-24).

Difficulties of the transformation from the energy balance to a supply-use format are twofold. On the one hand, the energy balance does not distinguish between intermediate consumption of productive sectors and households' final demand because it does not include information whether energy consumption serves to produce goods or directly the final consumer's needs (for mobility, heating, etc.). This question arises essentially for transport (R19) and residential (which mixes residential and tertiary-R20), and the decomposition for these two activities is dependent upon the availability of complementary datasets (e.g., transport and households' surveys). On the other hand, energy flows must be explicitly reconstituted to exclude the elements of the balance that do not correspond to commercial energy uses (e.g., non-energy uses, renewable energies, transformation by autoproduction of secondary heat or electricity).

In practice, the elaboration of physical accounting systems can be divided in three sub-steps:

Sub-step 1.1 : disaggregating the description of certain products or uses. This step requires additional information from external statistical sources to define the split of quantities reported in an aggregate manner in the balance (in the absence of information, ad-hoc assumptions must be made). In the case of France, an important feature is, for example, to distinguish fuels used for households' mobility of those used for transport sectors. To this aim, the description of refined products in the energy balance must be complemented by more precise information on the details of uses. Table 4 illustrates the disaggregation of the transport sector (R19-20) using external sources of information.

Sub-step 1.2 : delineating the domain of analysis. In practice, this comes down to isolating the crucial components of the balance for the question under consideration. This means suppressing the rows and columns that correspond to activities outside the core analysis without introducing disequilibria in the balance. For example, the withdrawal of renewables and wastes is not problematic because it is a rather independent production process and it is then sufficient to add the volume of electricity produced from these sources . On the contrary, suppressing non-energy uses requires



	2010 - Million ton oil-equivalent, Mtoe	Primary energy	Final energy	Non-valuables energies	Total
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R2	Imports	68	94	0	*162*
R3	Exports	-0	-33	0	*-33*
R4	Marine & Aviation bunkers	0	0	0	*0*
R5	**Total Primary Energy Supply**	**69**	**182**	**13**	***265***
R6	Transformations	-69	-17	-0	*-86*
R7	Energy industry own use	0	-10	0	*-10*
R8	Losses	0	-4	0	*-4*
R9	**Total Final Consumption**	**0**	**151**	**13**	***164***
R10	Iron and steel	0	4	0	*4*
R11	Non ferrous metals	0	1	0	*1*
R12	Non metallic minerals	0	4	0	*4*
R13	Construction	0	1	0	*1*
R14	Chemical and petrochemical	0	6	0	*6*
R15	Paper, pulp and print	0	2	1	*2*
R16	Mining and quarrying	0	0	0	*0*
R17	Transport equipement	0	1	0	*1*
R18	Other industries	0	9	1	*11*
R19	**Transport - Households**	0	24	0	*24*
R20	**Transport - Sectors**	0	24	0	*24*
R21	Residential	0	36	8	*45*
R22	Agricuture and forestry	0	4	0	*4*
R23	Fishing	0	0	0	*0*
R24	Other sectors	0	27	3	*30*
R25	Non-energy uses	1	12	0	*13*

Source : IEA; Odyssee Enerdata - 2010

Table 4: Energy balance after sub-step 1.1

an equivalent decrease of resources.

Sub-step 1.3 : aggregating and allocating quantities of the energy balance in Table 4 according to the nomenclature of the final input-output matrix. This imposes to adopt a level of aggregation compatible with the nomenclature of national accounts, which comes down to aggregating columns and rows consistently with the level of description adopted in the input-output matrix. In our illustrative example, the columns have not to be modified because they directly correspond to the level of disaggregation of energy in national accounts; but, concerning rows, the study being focused on industries and households, intermediate consumption by tertiary activities must not be isolated and can then be aggregated with the consumption of other sectors.

Sub-steps 1.2 and 1.3 cannot be completely automated because they involve a number of tradeoffs depending on available datasets, the context and the question under consideration. The most important choices concern:

1. **How to assign final energy use.** When surveys on consumption per use are missing, it becomes necessary to use information from similar economies where

these data exist (e.g. Odyssee, Eurostat, or Enerdata database for transport sector) or or to deduct the diffracting coefficients from national accounts by adapting the Leontief technique (Moll et al., 2007).

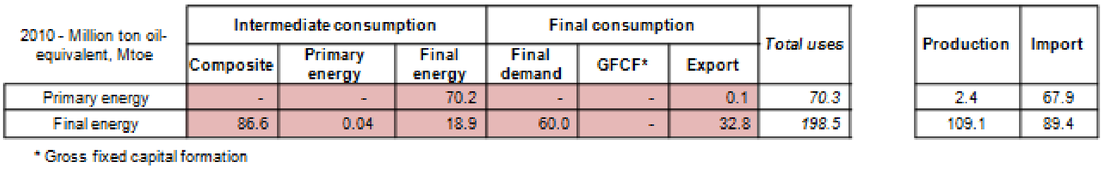
2. **How to establish input-output description consistent with the level of aggregation.** Volumes of energy must be allocated in accordance with the concepts of supply and use tables (Resources, Uses and Intermediate Consumption). The way to do this assignment depends on the level of aggregation used. In the example of France, only cross-sectoral exchanges associated with refining are described (disaggregated industry), other processing methods are not detailed (aggregated sector) .

3. **How to assign own uses.** Most of the time, the amount of own used energy is not linked to any economic transaction, but must be recognized because it account for the estimation of technical coefficients, CO_2 emissions, and the opportunity cost they represent during the introduction of the carbon price (because losses and own uses reduce the net efficiency of the transformation). In particular, it seems consistent to identify own uses with distribution losses for coal, gas and electricity, and to transformation processes for refineries.

4. **How to describe the processes of co-productions.** The relationship between coproductions is not described in the symmetrical input-output tables, which conventionally postulates a separation of the conditions of goods' production. This assumption is not acceptable for some sectors (for example, in studies of agricultural production systems) and flows of co-production must then be described as well as the technical fundamentals which link the productions. In the example of France, this question remains of second order: in the circuit of commercial energies, only a small amount of refined products and industrial gases are by-products of other production processes (petrochemicals and inorganic chemistry) and we treat them as domestic resources into refined products and gas.

From sub-steps 1.1 to 1.3, we are finally able to get the input-output table in physical unit, represented in Table 5. For the sake of simplicity, for next explanations, and next illustrations, non-energy sectors have been aggregated into one composite sector. However, this work has been carried out keeping all following sectors isolated from the composite sector : nteel and iron, non ferrous metals, minerals, buildings construction, chemical and pharmaceutical, paper, mining, transport equipment, transport services, agri-forestry, fishing, food industry

Sub-step 1.4 : computing the energy expenses and resources of the economy in monetary values. It simply consists in multiplying on a one-to-one basis the input-output

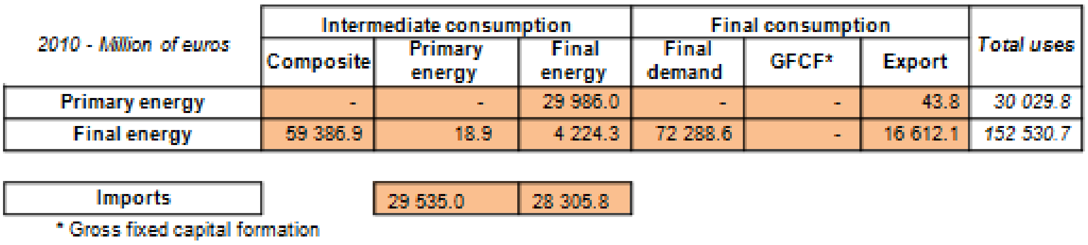


2010 - Million ton oil-equivalent, Mtoe	Intermediate consumption			Final consumption			Total uses	Production	Import
	Composite	Primary energy	Final energy	Final demand	GFCF*	Export			
Primary energy	-	-	70.2	-	-	0.1	70.3	2.4	67.9
Final energy	86.6	0.04	18.9	60.0	-	32.8	198.5	109.1	89.4

* Gross fixed capital formation

Table 5: Energy Input-output table

tables in quantities and prices to obtain a table in monetary units which corresponds to energy bills at the desired level of aggregation (Table 6). This table is fully consistent with the energy statistics on the diversity of prices, energy consumption, carbon content, etc.



2010 - Million of euros	Intermediate consumption			Final consumption			Total uses
	Composite	Primary energy	Final energy	Final demand	GFCF*	Export	
Primary energy	-	-	29 986.0	-	-	43.8	30 029.8
Final energy	59 386.9	18.9	4 224.3	72 288.6	-	16 612.1	152 530.7
Imports		29 535.0	28 305.8				

* Gross fixed capital formation

Table 6: Balance of energy bills

Step 2: Aligning monetary and physical matrices

Once the input-output table that describes the economic circuit of energy flows in quantity, value and price have been built, it remains to integrate it into the national accounts input-output table without changing the important variables for empirical analysis. This is the hybridization step *per se* (Figure 7) that can be analyzed in two stages: a set of actions on the rows of the table (1 - adjustment of uses) to insert the monetary sub-table resulting from step 1 and inform the energy expenses of the economy; and a set of actions on the columns (2 - adjustment of resources) to provide the description of the content of energy expenses: the cost structure of one litre of fuel purchased, one kWh, etc.. These columns describe the fixed and variable costs of industries that supply, process and distribute energy to consumers.

The result is a modified input-output table in which the value added of energy flows is isolated from those corresponding to non-energy products from "energy branches" aggregated in the composite sector. This rearrangement in the nomenclature maintains the total value added of the economy as well as its sub-totals (wage bill, gross operating surplus, etc.), total imports and totals of final uses (Households' consumption, exports) while specifying the description of energy circulation.

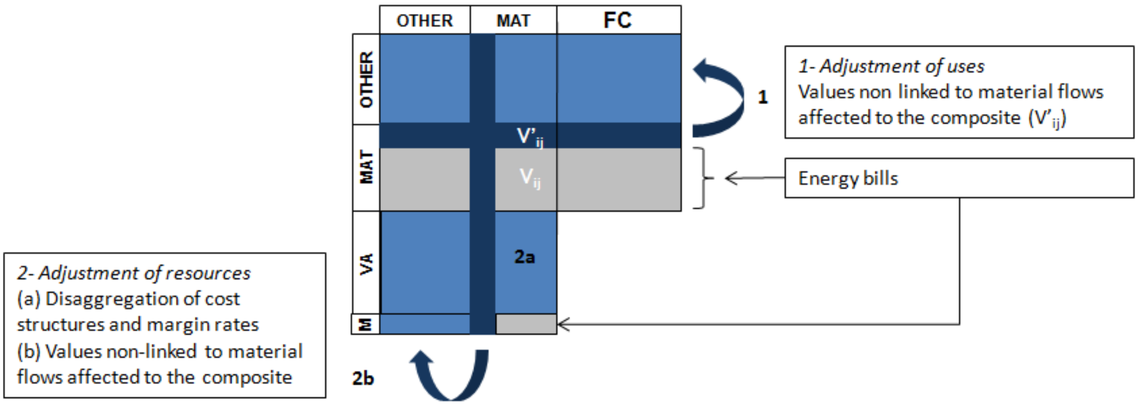
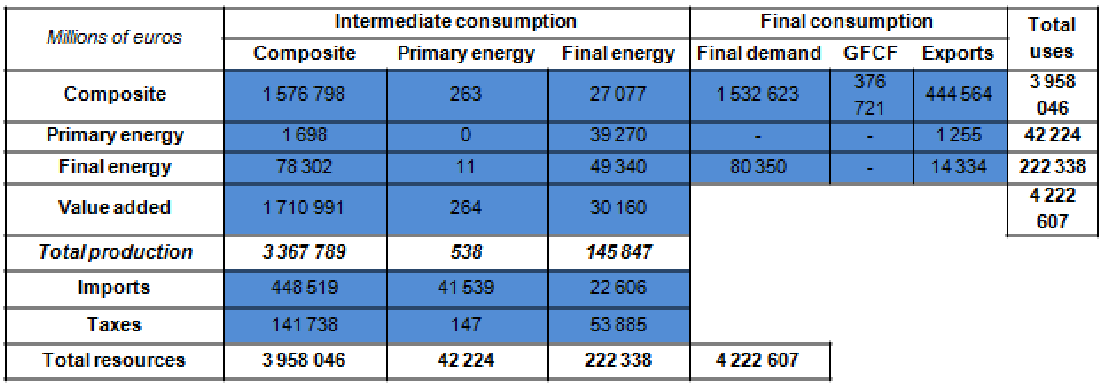


Figure 7: Principles of alignment of material balances and monetary flows

To carry out this step 2 in the case of France, we start from the input-output table obtained from National Accounts (Table 7).



Millions of euros	Intermediate consumption			Final consumption			Total uses
	Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
Composite	1 576 798	263	27 077	1 532 623	376 721	444 564	3 958 046
Primary energy	1 698	0	39 270	-	-	1 255	42 224
Final energy	78 302	11	49 340	80 350	-	14 334	222 338
Value added	1 710 991	264	30 160				4 222 607
Total production	***3 367 789***	***538***	***145 847***				
Imports	448 519	41 539	22 606				
Taxes	141 738	147	53 885				
Total resources	3 958 046	42 224	222 338	4 222 607			

Table 7: Input-Output tables in National Accounts

Sub-step 2.1 : adjustments of uses. Starting from the IOT (Table 7), we replace the values of energy branches (R2, R3 in orange) by the values of reconstructed energy bills from Table 6. Differences are added to uses and imports of composite (all R1 and R6-C1, in dark blue). These operations do not affect the total value of uses, but change those of different products. Therefore, the supply-use balances are broken for individual sectors.

Sub-step 2.2 : adjustment of resources. Balances between uses and resources are restored by manipulating the cost structure of industries (columns of the IOT). Values of imports and intermediate consumption are given by the energy statistics and other cost components - value added, margins, taxes on products - are adjusted to restore equality of resources with uses (Table 9). Since, in our example, energy taxation is known (R7-C1/C2), the adjustment is made by value added (R4). Finally, in the case of

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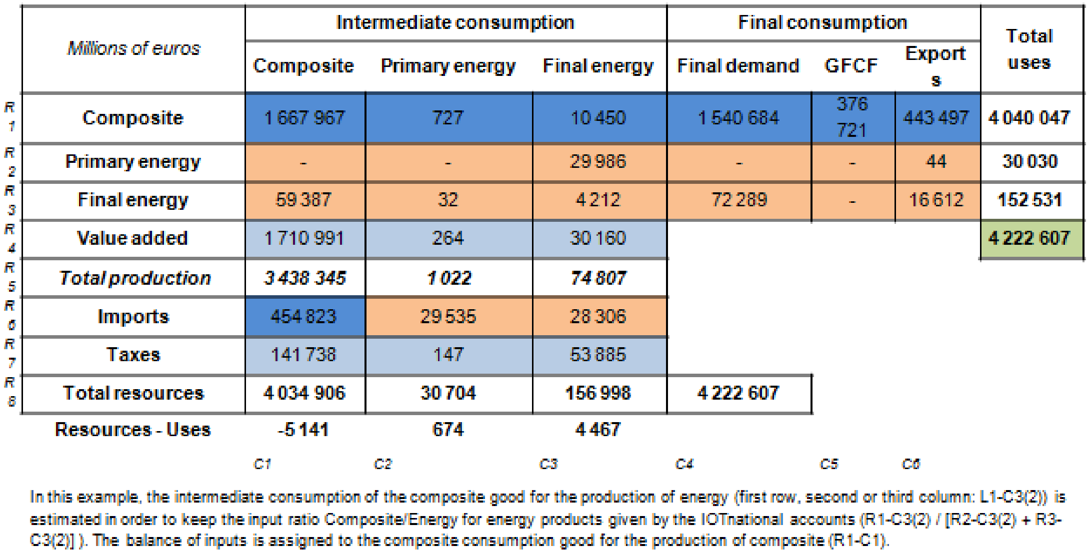
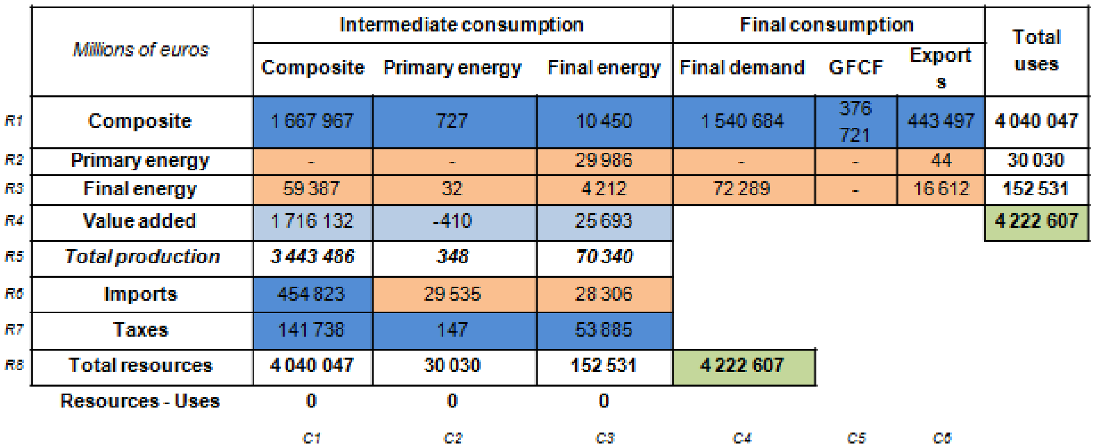


	Millions of euros	Intermediate consumption			Final consumption			Total uses
		Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
R1	Composite	1 667 967	727	10 450	1 540 684	376 721	443 497	4 040 047
R2	Primary energy	-	-	29 986	-	-	44	30 030
R3	Final energy	59 387	32	4 212	72 289	-	16 612	152 531
R4	Value added	1 710 991	264	30 160				4 222 607
R5	*Total production*	***3 438 345***	***1 022***	***74 807***				
R6	Imports	454 823	29 535	28 306				
R7	Taxes	141 738	147	53 885				
R8	Total resources	4 034 906	30 704	156 998	4 222 607			
	Resources - Uses	-5 141	674	4 467				
		C1	C2	C3	C4	C5	C6	

In this example, the intermediate consumption of the composite good for the production of energy (first row, second or third column: L1-C3(2)) is estimated in order to keep the input ratio Composite/Energy for energy products given by the IOTnational accounts (R1-C3(2) / [R2-C3(2) + R3-C3(2)]). The balance of inputs is assigned to the composite consumption good for the production of composite (R1-C1).

Table 8: Input-Output table after adjustments of uses



	Millions of euros	Intermediate consumption			Final consumption			Total uses
		Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
R1	Composite	1 667 967	727	10 450	1 540 684	376 721	443 497	4 040 047
R2	Primary energy	-	-	29 986	-	-	44	30 030
R3	Final energy	59 387	32	4 212	72 289	-	16 612	152 531
R4	Value added	1 716 132	-410	25 693				4 222 607
R5	*Total production*	***3 443 486***	***348***	***70 340***				
R6	Imports	454 823	29 535	28 306				
R7	Taxes	141 738	147	53 885				
R8	Total resources	4 040 047	30 030	152 531	4 222 607			
	Resources - Uses	0	0	0				
		C1	C2	C3	C4	C5	C6	

Table 9: Input-Output table after adjustments of resources

France, the margin rate is modulated according to buyers, which helps to distinguish the purchaser prices of energy products. After this last step, all accounting identities of the hybrid description are satisfied.

It is useful to keep in mind some principles to guide the choice of adjusting resources. We can offer a procedure to select the set of assumptions to be used to isolate the cost structures of two products (Figure 8) with the objective of mobilizing the maximum statistical information available on intermediate consumption and unit costs of each input, labor, consumption of fixed capital and operating margin.

We can then guide the search for information by discussing the conditions of production:

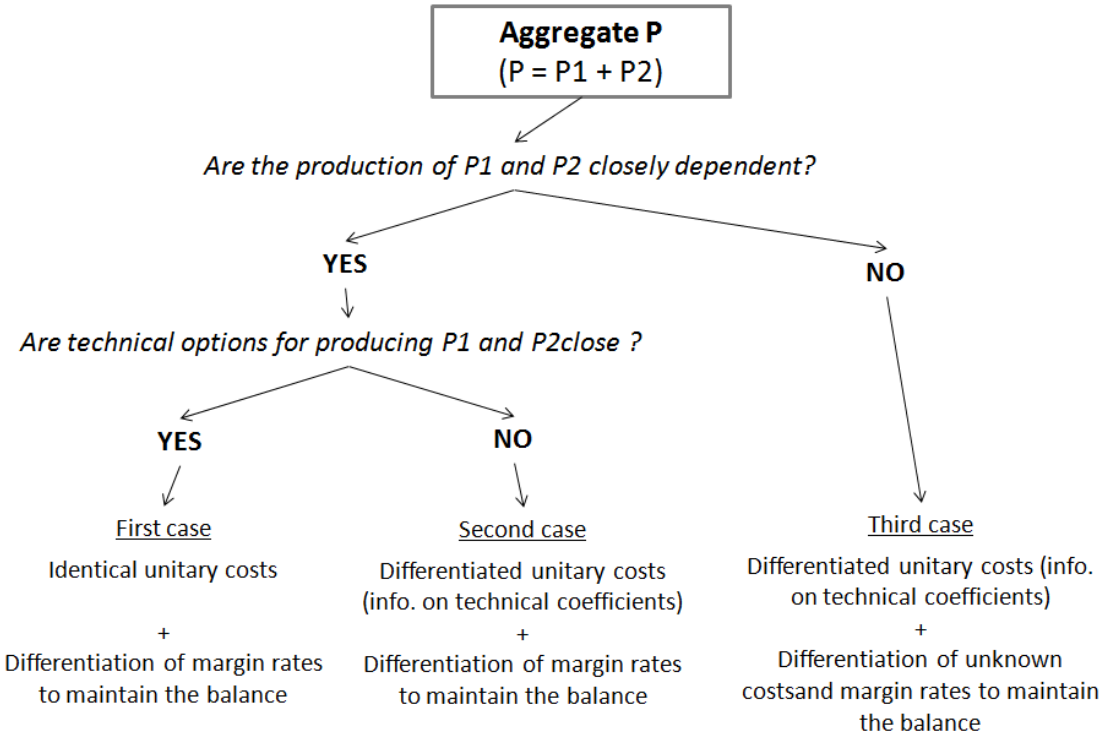


Figure 8: Methodology for disaggregating cost structures and margin rates

- **First case**: productions P1 and P2 are the result of separate units, the level of dependence is low. It is then likely that the information on one or the other of the structures of this cost is available. This is the case of industries specialized and concentrated, like the nuclear industry that can be isolated from other energy industries.

- **Second case**: P1 and P2 are products within the same units but with different processes. Information on technical coefficients (the unit quantities of inputs, capital, and labor) can be used to distinguish costs. This is the case, for example, for refined petroleum products which are derived from a combination of different methods of physico-chemical separation implemented in refineries.

- **Third case**: the production unit and the processes are similar. Therefore, it is justified to retain the assumption of the same cost structure. Information is used either on unit costs or on the technical coefficients, but for both productions. Associated with the assumption of returns to scale and / or factor prices, this information can help reconstructing a structure of unitary costs for aggregates (since the total quantities produced are known). This case corresponds, for example, to the distinction between diesel and heating oil, used for transportation or heating (but these products are actually physically identical.

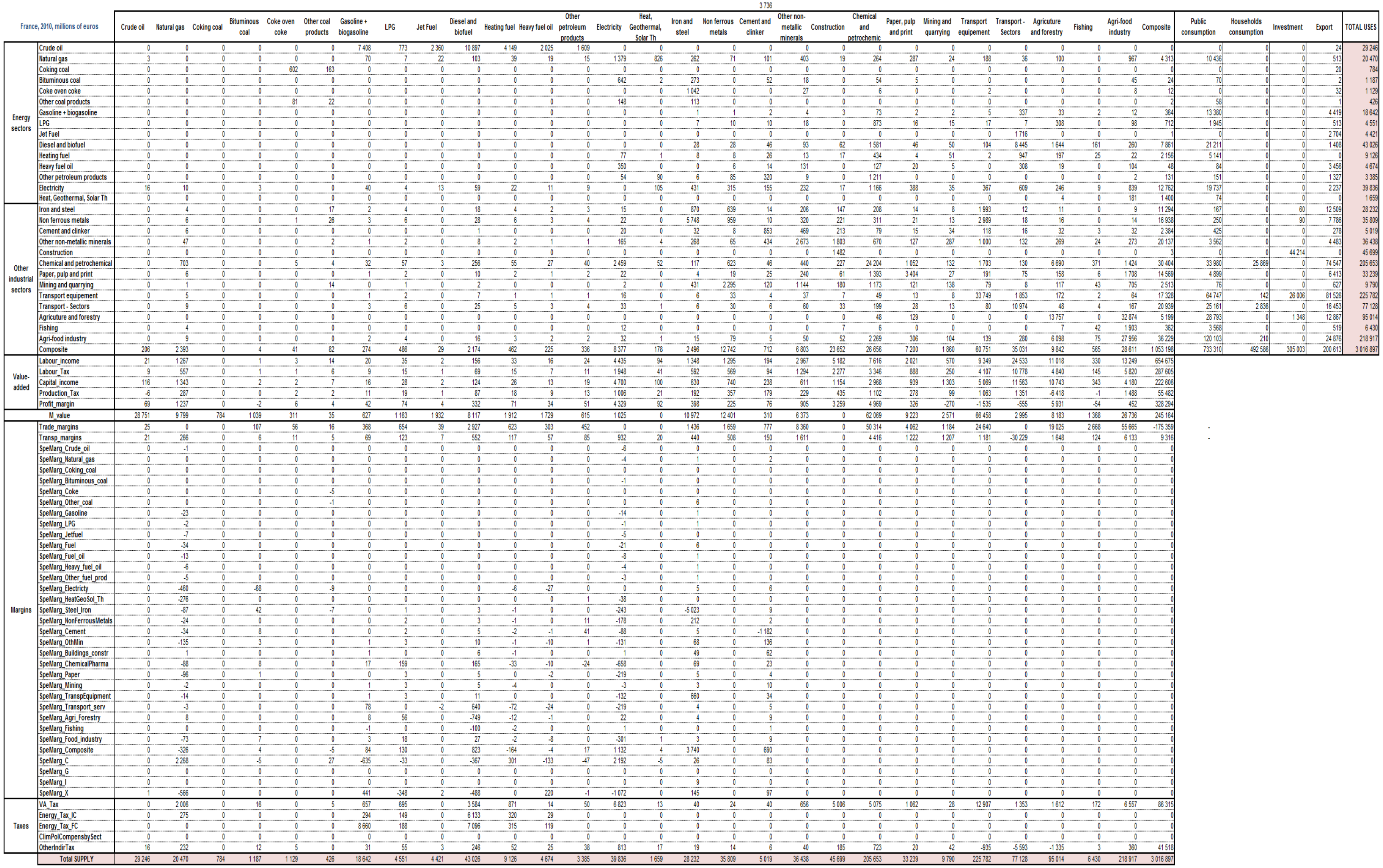
Extension of the procedure to cement, and iron and steel sector

7 Appendix B: hybrid input-output table for France

France 2010, energy/physical and '*quasi*' quantities (Mtoe, Mtons)		Crude oil	Natural gas	Coking coal	Bituminous coal	Coke oven coke	Other coal products	Gasoline + biogasoline	LPG	Jet Fuel	Diesel and biofuel	Heating fuel	Heavy fuel oil	Other petroleum products	Electricity	Heat, Geothermal, Solar Th	Iron and steel	Non ferrous metals	Cement and clinker	Other non-metallic minerals	Construction	Chemical and petrochemical	Paper, pulp and print	Mining and quarrying	Transport equipement	Transport - Sectors	Agricuture and forestry	Fishing	Agri-food industry	Composite	Public consumption	Households consumption	Investment	Export	TOTAL USES	Output	Imports	BALANCE
Energy sectors	Crude oil	-	-	-	-	-	-	17	2	5	25	10	5	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	67	2	65	-
	Natural gas	0	-	-	-	0	0	0	0	0	0	0	0	0	4	3	1	0	0	1	0	1	1	0	0	0	0	0	2	11	14	-	-	3	43	1	42	-
	Coking coal	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	3	-	3	-
	Bituminous coal	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0	2	0	0	0	-	0	0	-	-	-	-	-	0	0	0	-	-	0	8	0	8	-
	Coke oven coke	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	0	-	0	-	-	0	-	-	-	0	0	-	-	-	0	3	2	1	-
	Other coal products	-	-	-	-	0	0	-	-	-	-	-	-	-	0	-	0	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	0	1	1	0	-
	Gasoline + biogasoline	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	-	-	7	15	14	1	-
	LPG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	-	1	0	0	0	0	0	-	0	1	1	-	-	1	4	2	2	-
	Jet Fuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	0	-	-	-	5	8	4	4	-
	Diesel and biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0	0	8	2	0	0	7	16	-	-	3	38	22	16	-
	Heating fuel	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	4	6	-	-	-	13	8	5	-
	Heavy fuel oil	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	-	0	0	0	-	0	0	0	0	1	0	-	0	0	0	-	-	8	11	4	7	-
	Other petroleum products	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	-	2	-	-	-	-	-	-	0	0	0	-	-	3	6	4	2	-0
	Electricity	0	0	-	0	0	0	0	0	0	0	0	0	0	-	0	1	1	0	0	0	2	1	0	1	1	0	0	1	15	14	-	-	4	42	40	2	-
	Heat, Geothermal, Solar Th	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0	2	0	-	-	-	2	2	-	-
Hybrid Industries	Iron and steel	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	10	1	0	0	0	0	0	0	2	0	0	-	0	12	0	-	0	20	46	30	16	-
	Cement and clinker	-	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	15	2	1	0	0	0	1	0	0	0	0	12	2	-	-	1	36	33	3	-

France, 2010 - Prices (€/toe, €/tons)		Crude oil	Natural gas	Coking coal	Bituminous coal	Coke oven coke	Other coal products	Gasoline + biogasoline	LPG	Jet Fuel	Diesel and biofuel	Heating fuel	Heavy fuel oil	Other petroleum products	Electricity	Heat, Geothermal, Solar Th	Iron and steel	Non ferrous metals	Cement and clinker	Other non-metallic minerals	Construction	Chemical and petrochemical	Paper, pulp and print	Mining and quarrying	Transport equipement	Transport - Sectors	Agricuture and forestry	Fishing	Agri-food industry	Composite	Public consumption	Households consumption	Investment	Export
Energy sectors	Crude oil	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	436	458
	Natural gas	329	439	439	439	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	476	329	329	408	408	408	476	476	408	408	725	530	530	201
	Coking coal	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238
	Bituminous coal	146	146	146	146	146	146	146	146	146	146	146	146	146	132	172	172	172	172	172	146	172	172	146	146	146	146	146	172	172	172	187	187	132
	Coke oven coke	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386	386
	Other coal products	349	349	349	349	329	329	349	349	349	349	349	349	349	329	349	329	349	349	349	349	349	349	349	349	349	349	349	349	112	779	383	383	387
	Gasoline + biogasoline	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 099	1 430	1 430	1 430	1 430	1 430	1 430	1 430	1 430	1 430	1 430	1 430	663	1 430	1 430	1 711	1 796	1 796	663
	LPG	879	879	879	879	879	879	879	879	879	879	879	879	879	879	879	1 076	1 076	1 076	1 076	879	1 076	1 076	1 076	1 076	917	1 076	879	1 076	1 076	1 425	1 463	1 463	469
	Jet Fuel	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532	532
	Diesel and biofuel	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 016	1 135	1 135	1 135	1 135	1 135	1 135	1 135	1 135	1 135	1 099	698	627	1 135	1 135	1 357	1 385	1 385	512
	Heating fuel	642	642	642	642	642	642	642	642	642	642	642	642	642	596	596	596	596	596	596	596	596	596	596	596	596	604	596	596	596	835	776	776	590
	Heavy fuel oil	440	440	440	440	440	440	440	440	440	440	440	440	440	409	409	440	409	409	409	440	409	409	409	409	409	419	440	409	409	428	1 232	1 232	450
	Other petroleum products	522	522	522	522	522	522	522	522	522	522	522	522	522	526	526	526	600	600	600	522	512	522	522	522	522	522	522	600	600	532	781	781	512
	Electricity	580	580	788	580	580	580	580	580	580	580	580	580	580	788	580	504	504	504	504	865	504	504	727	580	580	865	865	580	865	1 451	1 205	1 205	518
	Heat, Geothermal, Solar Th	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	682	684	682	684	684	769	827	827	675
Hybrid Industries	Iron and steel	610	912	610	610	912	912	912	912	912	912	912	912	912	912	912	90	912	912	912	912	912	912	912	912	912	912	610	912	912	912	740	912	616
	Cement and clinker	138	195	138	138	195	195	195	195	195	195	195	195	195	195	195	195	195	58	195	195	195	195	195	195	195	195	195	195	195	195	153	153	212

Figure 9: Hybrid input-output table for France - Volumes and prices



3 736

France, 2010, millions of euros		Crude oil	Natural gas	Coking coal	Bituminous coal	Coke oven coke	Other coal products	Gasoline + biogasoline	LPG	Jet Fuel	Diesel and biofuel	Heating fuel	Heavy fuel oil	Other petroleum products	Electricity	Heat, Geothermal, Solar Th	Iron and steel	Non ferrous metals	Cement and clinker	Other non-metallic minerals	Construction	Chemical and petrochemic	Paper, pulp and print	Mining and quarrying	Transport equipement	Transport - Sectors	Agricuture and forestry	Fishing	Agri-food industry	Composite	Public consumption	Households consumption	Investment	Export	TOTAL USES
Energy sectors	Crude oil	0	0	0	0	0	0	7 408	773	2 360	10 897	4 149	2 025	1 609	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	29 246
	Natural gas	3	0	0	0	0	0	70	7	22	103	39	19	15	1 379	826	262	71	101	403	19	264	287	24	188	36	100	0	967	4 313	10 436	0	0	513	20 470
	Coking coal	0	0	0	0	602	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	784
	Bituminous coal	0	0	0	0	0	0	0	0	0	0	0	0	0	642	2	273	0	52	18	0	54	5	0	0	0	0	0	45	24	70	0	0	2	1 187
	Coke oven coke	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 042	0	0	27	0	6	0	0	2	0	0	0	8	12	0	0	0	32	1 129
	Other coal products	0	0	0	0	81	22	0	0	0	0	0	0	0	148	0	113	0	0	0	0	0	0	0	0	0	0	0	0	2	58	0	0	1	426
	Gasoline + biogasoline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	4	3	73	2	2	5	337	33	2	12	364	13 380	0	0	4 419	18 642
	LPG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	10	10	18	0	873	16	15	17	7	308	0	98	712	1 945	0	0	513	4 551
	Jet Fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 716	0	0	0	1	0	0	0	2 704	4 421
	Diesel and biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	28	46	93	62	1 581	46	50	104	8 445	1 644	161	260	7 861	21 211	0	0	1 408	43 026
	Heating fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	77	1	8	8	26	13	17	434	4	51	2	947	197	25	22	2 156	5 141	0	0	0	9 126
	Heavy fuel oil	0	0	0	0	0	0	0	0	0	0	0	0	0	350	0	0	6	14	131	0	127	20	5	0	308	19	0	104	48	84	0	0	3 456	4 674
	Other petroleum products	0	0	0	0	0	0	0	0	0	0	0	0	0	54	90	6	85	320	9	0	1 211	0	0	0	0	0	0	2	131	151	0	0	1 327	3 385
	Electricity	16	10	0	3	0	0	40	4	13	59	22	11	9	0	105	431	315	155	232	17	1 166	388	35	367	609	246	9	839	12 762	19 737	0	0	2 237	39 836
	Heat, Geothermal, Solar Th	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	181	1 400	74	0	0	0	1 659
Other industrial sectors	Iron and steel	0	4	0	0	0	17	2	4	0	18	4	2	3	15	0	870	639	14	206	147	208	14	8	1 993	12	11	0	9	11 294	167	0	60	12 509	28 232
	Non ferrous metals	0	6	0	0	1	26	3	6	0	28	6	3	4	22	0	5 748	959	10	320	221	311	21	13	2 989	18	16	0	14	16 938	250	0	90	7 786	35 809
	Cement and clinker	0	6	0	0	0	0	0	0	0	1	0	0	0	20	0	32	8	853	469	213	79	15	34	118	16	32	3	32	2 384	425	0	0	278	5 019
	Other non-metallic minerals	0	47	0	0	0	2	1	2	0	8	2	1	1	165	4	268	65	434	2 673	1 803	670	127	287	1 000	132	269	24	273	20 137	3 562	0	0	4 483	36 438
	Construction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 482	0	0	0	0	0	0	0	0	3	0	0	44 214	0	45 699
	Chemical and petrochemical	0	703	0	0	5	4	32	57	3	256	55	27	40	2 459	52	117	623	46	440	227	24 204	1 052	132	1 703	130	6 690	371	1 424	30 404	33 980	25 869	0	74 547	205 653
	Paper, pulp and print	0	6	0	0	0	0	1	2	0	10	2	1	2	22	0	4	19	25	240	61	1 393	3 404	27	191	75	158	6	1 708	14 569	4 899	0	0	6 413	33 239
	Mining and quarrying	0	1	0	0	0	14	0	1	0	2	0	0	0	2	0	431	2 295	120	1 144	180	1 173	121	138	79	8	117	43	705	2 513	76	0	0	627	9 790
	Transport equipement	0	5	0	0	0	0	1	2	0	7	1	1	1	16	0	6	33	4	37	7	49	13	8	33 749	1 853	172	2	64	17 328	64 747	142	26 006	81 526	225 782
	Transport - Sectors	0	9	0	0	0	0	3	6	0	25	5	3	4	33	1	6	30	6	60	33	199	28	13	80	10 974	48	4	167	20 939	25 161	2 836	0	16 453	77 128
	Agricuture and forestry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	129	0	0	0	13 757	0	32 874	5 199	28 793	0	1 348	12 867	95 014
	Fishing	0	4	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	7	6	0	0	0	0	7	42	1 903	362	3 568	0	0	519	6 430
	Agri-food industry	0	9	0	0	0	0	2	4	0	16	3	2	2	32	1	15	79	5	50	52	2 269	306	104	139	280	6 098	75	27 956	36 229	120 103	210	0	24 876	218 917
	Composite	206	2 393	0	4	41	82	274	486	29	2 174	462	225	336	8 377	178	2 496	12 742	712	6 803	23 652	26 656	7 200	1 860	60 751	35 031	9 842	565	28 611	1 053 198	733 310	492 586	305 003	200 613	3 016 897
Value-added	Labour_income	21	1 267	0	1	3	14	20	35	2	156	33	16	24	4 435	94	1 348	1 295	194	2 967	5 182	7 616	2 021	570	9 349	24 533	11 018	330	13 249	654 675					
	Labour_Tax	9	557	0	1	1	6	9	15	1	69	15	7	11	1 948	41	592	569	94	1 294	2 277	3 346	888	250	4 107	10 778	4 840	145	5 820	287 605					
	Capital_income	116	1 343	0	2	2	7	16	28	2	124	26	13	19	4 700	100	630	740	238	611	1 154	2 968	939	1 303	5 069	11 563	10 743	343	4 180	222 606					
	Production_Tax	-6	287	0	0	2	2	11	19	1	87	18	9	13	1 006	21	192	357	179	229	435	1 102	278	99	1 063	1 351	-6 418	-1	1 488	55 482					
	Profit_margin	69	1 237	0	-2	6	4	42	74	4	332	71	34	51	4 329	92	398	225	76	905	3 259	4 969	326	-270	-1 535	-555	5 931	-54	452	328 294					
	M_value	28 751	9 799	784	1 039	311	35	627	1 163	1 932	8 117	1 912	1 729	615	1 025	0	10 972	12 401	310	6 373	0	62 069	9 223	2 571	66 458	2 995	8 183	1 368	26 736	245 164					
Margins	Trade_margins	25	0	0	107	56	16	368	654	39	2 927	623	303	452	0	0	1 436	1 659	777	8 360	0	50 314	4 062	1 184	24 640	0	19 025	2 668	55 665	-175 359	-				
	Transp_margins	21	266	0	6	11	5	69	123	7	552	117	57	85	932	20	440	508	150	1 611	0	4 416	1 222	1 207	1 181	-30 229	1 648	124	6 133	9 316	-				
	SpeMarg_Crude_oil	0	-1	0	0	0	0	0	0	0	0	0	0	0	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Natural_gas	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Coking_coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Bituminous_coal	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Coke	0	0	0	0	0	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Other_coal	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Gasoline	0	-23	0	0	0	0	0	0	0	0	0	0	0	-14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_LPG	0	-2	0	0	0	0	0	0	0	0	0	0	0	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Jetfuel	0	-7	0	0	0	0	0	0	0	0	0	0	0	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Fuel	0	-34	0	0	0	0	0	0	0	0	0	0	0	-21	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Fuel_oil	0	-13	0	0	0	0	0	0	0	0	0	0	0	-8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Heavy_fuel_oil	0	-6	0	0	0	0	0	0	0	0	0	0	0	-4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Other_fuel_prod	0	-5	0	0	0	0	0	0	0	0	0	0	0	-3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Electricty	0	-460	0	-68	0	-9	0	0	0	0	-6	-27	0	0	0	5	0	6	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_HeatGeoSol_Th	0	-276	0	0	0	0	0	0	0	0	0	0	1	-38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Steel_Iron	0	-87	0	42	0	-7	0	1	0	3	-1	0	0	-243	0	-5 023	0	9	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_NonFerrousMetals	0	-24	0	0	0	0	0	2	0	3	-1	0	11	-178	0	212	0	2	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Cement	0	-34	0	8	0	0	0	2	0	5	-2	-1	41	-88	0	5	0	-1 182	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_OthMin	0	-135	0	3	0	0	1	3	0	10	-1	-10	1	-131	0	68	0	136	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Buildings_constr	0	1	0	0	0	0	1	0	0	6	-1	0	0	1	0	49	0	62	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_ChemicalPharma	0	-88	0	8	0	0	17	159	0	165	-33	-10	-24	-658	0	69	0	23	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Paper	0	-96	0	1	0	0	0	3	0	5	0	-2	0	-219	0	5	0	4	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Mining	0	-2	0	0	0	0	1	3	0	5	-4	0	0	-3	0	3	0	10	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_TranspEquipment	0	-14	0	0	0	0	1	3	0	11	0	0	0	-132	0	660	0	34	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Transport_serv	0	-3	0	0	0	0	78	0	-2	640	-72	-24	0	-219	0	4	0	5	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Agri_Forestry	0	8	0	0	0	0	8	56	0	-749	-12	-1	0	22	0	4	0	9	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Fishing	0	0	0	0	0	0	-1	0	0	-100	-2	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Food_industry	0	-73	0	7	0	0	3	18	0	27	-2	-8	0	-301	1	3	0	9	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_Composite	0	-326	0	4	0	-5	84	130	0	823	-164	-4	17	1 132	4	3 740	0	690	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_C	0	2 268	0	-5	0	27	-635	-33	0	-367	301	-133	-47	2 192	-5	26	0	83	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0					
	SpeMarg_X	1	-566	0	0	0	0	441	-348	2	-488	0	220	-1	-1 072	0	145	0	97	0	0	0	0	0	0	0	0	0	0	0					
Taxes	VA_Tax	0	2 006	0	16	0	5	657	695	0	3 584	871	14	50	6 823	13	40	24	40	656	5 006	5 075	1 062	28	12 907	1 353	1 612	172	6 557	86 315					
	Energy_Tax_IC	0	275	0	0	0	0	294	149	0	6 133	320	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	Energy_Tax_FC	0	0	0	0	0	0	8 660	188	0	7 096	315	119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	ClimPolCompensbySect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
	OtherIndirTax	16	232	0	12	5	0	31	55	3	246	52	25	38	813	17	19	14	6	40	185	723	20	42	-935	-5 593	-1 335	3	360	41 518					
	Total SUPPLY	29 246	20 470	784	1 187	1 129	426	18 642	4 551	4 421	43 026	9 126	4 674	3 385	39 836	1 659	28 232	35 809	5 019	36 438	45 699	205 653	33 239	9 790	225 782	77 128	95 014	6 430	218 917	3 016 897					

Figure 10: Hybrid input-output table for France - Values

8 Appendix C: formulary of IMACLIM-S FRANCE

IMACLIM-S , a comparative statics model, boils down to a set of simultaneous equations:

$$\begin{cases} f_1(x_1,...,x_n,z_1,...,z_m) = 0 \\ f_2(x_1,...,x_n,z_1,...,z_m) = 0 \\ ... \\ f_n(x_1,...,x_n,z_1,...,z_m) = 0 \end{cases}$$

with :

- x_i, $i \in [1,v]$, a set of variables (as many as equations),
- z_i, $i \in [1,p]$, a set of parameters,
- f_i, $i \in [1,v]$, a set of functions, some of which are non linear in x_i.

The f_i constraints are of two quite different natures: one subset of equations describes accounting constraints that are necessarily verified to ensure that the accounting system is properly balanced; the other subset translates various behavioural constraints, written either in a simple linear manner (e.g. households consume a fixed proportion of their income) or in a more complex non-linear way (e.g. the trade-offs of the producers and the consumers). It is these behavioural constraints that ultimately reflect, in the flexible architecture of IMACLIM-S FRANCE a certain economic "vision".

The presentation of the equations successively details (i) the accounting construction of the set of consumer prices, (ii) the accounting and behavioural equations that govern the four institutional sectors represented (households, firms, public administrations and the'rest of the world'), (iii) the market clearing conditions. For reference purposes, variables and parameters are listed and described in an appendix. A variable name with a '0' index designates the specific value taken by the variable in the reference equilibrium (i.e. the value calibrated on either the 2010 hybrid input-output or the 2010 economic account table).

8.1 Producer and Consumer Prices

p_{Y_i} the producer price of good i is built following the cost structure of the production of good i , that is as the sum of intermediate consumptions, labour costs, capital costs, a tax on production, and a constant mark-up rate (corresponding to the net operating surplus):

$$p_{Y_i} = \sum_{j=1}^{n} p_{IC_i} \cdot \alpha_{ij} + p_{L_i} \cdot l_i + p_{K_i} \cdot k_i + \overline{\tau_{Y_i}} \cdot p_{Y_i} + \overline{\pi_i} \cdot p_{Y_i} \tag{1}$$

p_{M_i} the price of imported good i is assumed constant-more precisely, the imported variety of one of the goods is considered as the numéraire of the model and the prices of the other imported goods relative to that of the numéraire are assumed constant.

$$p_{M_i} = p_{M_{i_0}} \tag{2}$$

p_i the average price of the resource of good i is the weighted average of the two previous prices:

$$\frac{p_{Y_i} \cdot Y_i + p_{M_i} \cdot M_i}{Y_i + M_i} \tag{3}$$

The domestic and foreign varieties of the energy goods are indeed assumed homogeneous: the alternative assumption of product differentiation, adopted by many CGEM through their use of an Armington specification for international trade (Armington, 1969), has the disadvantage of creating 'hybrid' good varieties, whose volume unit is independent from that of the foreign and national varieties they hybridise; this forbids to maintain an explicit accounting of the physical energy flows and thus an energy balance. For the sake of simplicity the non-energy goods are treated similarly. p_{IC_i} the price of good i consumed in the production of good j is equal to the resource price of good i plus trade and transport margins, specific margins, a domestic excise on oil products (energy product tax, EnT) , an aggregate of other excise taxes and a carbon tax .

$$p_{IC_i} = p_i \cdot (1 + \tau_{CM_i} + \tau_{TM_i} + \overline{\tau_{SMIC_i}}) + \overline{t_{En_{TIC_i}} + \overline{t_{OPT_i}} + t_{IC} \cdot \gamma_{IC_{ij}}} \tag{4}$$

The consumer price of good i for households p_{IC_i}, public administrations (p_{G_i}) and investment (p_{I_i}), and the export price of good i (p_{X_i}), are constructed similarly and only differ on whether they are subject to value-added tax (the same rate is applied to all consumptions of one good) and the carbon tax or not. The latter tax applies to household prices only, as national accounting makes households the only final consumer of energy goods.

$$p_{C_i} = [p_i \cdot (1 + \tau_{CM_i} + \tau_{TM_i} + \overline{\tau_{SMC_i}}) + \overline{t_{EnT_{FC_i}}} + \overline{t_{OPT_i}} + t_{FC} \cdot \gamma_{FC_{ij}}] \cdot (1 + \overline{\tau_{VAT_i}}) \quad (5)$$

$$p_{G_i} = [p_i \cdot (1 + \tau_{CM_i} + \tau_{TM_i} + \overline{\tau_{SMG_i}}) + \overline{t_{EnT_{FC_i}}} + \overline{t_{OPT_i}}] \cdot (1 + \overline{\tau_{VAT_i}}) \quad (6)$$

$$p_{I_i} = [p_i \cdot (1 + \tau_{CM_i} + \tau_{TM_i} + \overline{\tau_{SMI_i}}) + \overline{t_{EnT_{FC_i}}} + \overline{t_{OPT_i}}] \cdot (1 + \overline{\tau_{VAT_i}}) \quad (7)$$

$$p_{X_i} = p_i \cdot (1 + \tau_{CM_i} + \tau_{TM_i} + \overline{\tau_{SMX_i}}) + \overline{t_{EnT_{FC_i}}} + \overline{t_{OPT_i}} \quad (8)$$

Trade margins τ_{CM_i} and transport margins τ_{TM_i} , identical for all intermediate and final consumptions of good i, are calibrated at the reference equilibrium and kept constant-except those on the productions aggregating transport and trade activities (hereafter indexed COM and TRANS), which are simply adjusted, in the derived equilibrium, to have the two types of margins sum up to zero :

$$\begin{aligned} &\sum_{j=1}^{n} \tau_{CM_{COM}} \cdot p_{COM} \cdot \alpha_{COM_j} + \tau_{CM_{COM}} \cdot p_{COM} \cdot (C_{COM} + G_{COM} + I_{COM} + X_{COM}) \\ &+ \sum_{i \neq COM}^{n} \sum_{j=1}^{n} \overline{\tau_{CM_i}} \cdot p_i \cdot \alpha_{ij} \cdot Y_j + \sum_{i \neq COM} \overline{\tau_{CM_i}} \cdot p_i \cdot (C_i + G_i + I_i + X_i) = 0 \end{aligned} \quad (9)$$

and similarly :

$$\begin{aligned} &\sum_{j=1}^{n} \tau_{CM_{TRANS}} \cdot p_{TRANS} \cdot \alpha_{TRANS_j} + \tau_{CM_{TRANS}} \cdot p_{TRANS} \cdot (C_{TRANS} + G_{TRANS} + I_{TRANS} + X_{TRANS}) \\ &+ \sum_{i \neq TRANS}^{n} \sum_{j=1}^{n} \overline{\tau_{CM_i}} \cdot p_i \cdot \alpha_{ij} \cdot Y_j + \sum_{i \neq TRANS} \overline{\tau_{CM_i}} \cdot p_i \cdot (C_i + G_i + I_i + X_i) = 0 \end{aligned} \quad (10)$$

Labour costs are equal to the net wage ω_i plus payroll taxes (both employers and employees' social contributions in the case of France) that are levied based on a unique rate τ_{LT} (common to all productions for lack of detailed calibration data) :

$$p_{L_i} = (1 + \tau_{LT}) \cdot \omega_i \quad (11)$$

In the version used to sustain Hourcade et al. (2009) τ_{LT} adjusts following either tax revenues ('euro for a euro' recycling rule), or any other public budget constraint (equations (48),(49), (50)) for those options explored in Hourcade et al., 2009); ω_i varies as the average wage ω :

$$\omega_i = \frac{\omega}{\omega_0} \cdot \omega_{i_0} \quad (12)$$

ω being defined as

$$\omega = \frac{\sum_{i=1}^{n} \omega_i \cdot l_i \cdot Y_i}{\sum_{i=1}^{n} l_i \cdot Y_i} \quad (13)$$

and subject to variations dictated by the labour market (see Section II.6).

The cost of capital is understood as the cost of the 'machine' capital (see the description of the production trade-offs Section II.3.2). It is obtained as the average price of investment goods.

$$p_K = \frac{\sum_{i=1}^{n} p_{I_i} \cdot I_i}{\sum_{i=1}^{n} I_i} \tag{14}$$

CPI the consumer price index is computed following Fisher, i.e. as the geometric mean of the Laspeyres index (variation of the cost of the no-policy basket of goods) and the Paasche index (variation of the cost of the policy-induced basket of goods).

$$CPI = \sqrt{\frac{\sum_{i=1}^{n}(p_{C_i} \cdot C_{i_0}) \cdot \sum_{i=1}^{n}(p_{C_i} \cdot C_i)}{\sum_{i=1}^{n}(p_{C_{i_0}} \cdot C_{i_0}) \cdot \sum_{i=1}^{n}(p_{C_{i_0}} \cdot C_i}\,)} \tag{15}$$

8.2 Households

Households can be disaggregated into m classes (index $h, h \in [1, m]$) to take into account income structures and eventually behaviours and adaptation capacities that can vary significantly from one household to the next. For now, the work is in process for IMACLIM-S FRANCE calibrated on 2010 data.

8.2.1 Income formation, savings and investment decision

R_{PGD_h} the gross primary income of class h is defined as the addition and the subtraction of the following terms:

- A share ω_{L_h} of the sum of aggregate endogenous net wage income $\omega_i \, l_i \, Y_i$, which varies with the number of active people employed in each class ((74)).
- A share ω_{K_h} of the fraction of 'capital income'(the gross operating surplus of national accounting) that goes to households, GOS_H (equation (18)). ω_{K_h} are exogenous and their calibration is based on the so called *Budget des Familles* survey and the economic account table.
- Social transfers, in three aggregates (pensions $\rho_{P_h} \, N_{P_h}$, unemployment benefits $\rho_{U_h} \, N_{U_h}$, other social transfers $\rho_{O_h} \, N_{O_h}$) the calculation of which is similarly based on the product of a per capita income ρ and a target population N_h . The number of retirees N_{P_h} and the size of the total population of class h, N_h are assumed constant; the number of unemployed N_{U_h} varies (equation (73)).
- An exogenous share ω_{OT_h} of residual transfers OT_H , which correspond to the

sum of "other current transfers" and "capital transfers", accounts D7 and D9 of the economic account table.

- A 'debt service' $i_H D_h$, which is indeed negative and corresponds to property income (account D4 of the economic account table: interests, dividends, real estate revenues, etc.), the overwhelming majority of classes being net creditors. This service is the product of the households'net debt D_h , the evolution of which is explained below (equation (23)), and an endogenous effective interest rate i_H (equation (67)).

Hence,

$$R_{PGD_h} = \omega_{L_h} \sum_{i=1}^{n} \omega_i l_i Y_i + \overline{\omega_{K_h}}\, GOS_H + \rho_{P_h} \overline{N_{P_h}} + \rho_{U_h} N_{U_h} + \rho_{O_h} \overline{N_h} + \overline{\omega_{OT_h}}\, OT_H - i_h D_h \quad (16)$$

with in particular OT_H and GOS_H defined as constant shares ω_{OT_H} and ω_{K_H} of OT (equation (65)) and GOS (equation (37)) :

$$OT_H = \overline{\omega_{OT_H}}\, OT \quad (17)$$

$$GOS_H = \overline{\omega_{K_H}}\, GOS \quad (18)$$

The gross disposable income R_{GD_h} of class h is obtained by subtracting from R_{PGD_h} the income tax T_{I_h} levied at a constant average rate (equation (44)), and other direct taxes T_{D_h} that are indexed on CPI (equation (45)). R_h, the consumed income of class h, is inferred from disposable income by subtracting savings. The savings rate τS_h is exogenous (calibrated to accommodate the values of R_{GD_h} and R_h in the no-policy equilibrium).

$$R_{GD_h} = R_{PGD_h} - T_{I_h} - T_{D_h} \quad (19)$$

$$R_h = (1 - \overline{\tau_{S_h}})\, R_{GD_h} \quad (20)$$

A further exploration of the data available in the economic account table gives households'investment $GFCF_h$ (Gross Fixed Capital Formation) as distinct from their savings; $GFCF_h$is assumed to follow the simple rule of a fixed ratio to gross disposable income (equation (22)). The difference between savings and investment gives the self-financing capacity of class h: AFC_h.

$$\frac{GFCF_h}{R_{GD_h}} = \frac{GFCF_{h_0}}{R_{GD_{h_0}}} \quad (21)$$

$$AFC_h = \overline{\tau_{S_h}}\, R_{GD_h} - GFCF_h \quad (22)$$

The evolution of AFC_h between the no-policy and the policy-induced equilibrium can then be used to estimate the evolution of net debt D_h . The computation is based on the simple assumption of a gradual wedge of AFC over the years, starting t_{REF} years in the past.

$$D_h = D_{h_0} + \frac{t_{REF}}{2}\left(AFC_{h_0} - AFC_h\right) \tag{23}$$

8.2.2 Consumption

While the previous equations apply to an undetermined number of sectors, the following equations determining household demand specifically apply to the version of Imaclim-S France distinguishing energy commodities and other sectors.

A major premise of the arbitrage process is to consider that energy consumptions are constrained by basic needs, considering the finite time t_REF over which the reform deploys. Tp account for this premise earlier versions of Imaclim-S France resorted to utility functions of the Stone-Geary type. However, the imply fixed budget shares beyond the satisfaction of the basic needs, which have been considered too restrictive. In addition, the use of a constant utility function, where energy consumption appears as such, while only the energy services arising from this consumption genuinely impact welfare, is questionable.

For these reasons, the energy consumptions of households have been defined, without resorting to any explicit utility function, as the sum of a exogenous basic needs, common to all classes, and a consumption in excess of this need that varies according to some income elasticity σ_{CR_i} , and some price-elasticity σ_{CP_i} . For the time being these elasticities are calibrated on time series of aggregate consumption, and hence common to all classes-some pending econometric research on disaggregated data will allow to differentiate them by class.

$$for\ i \in [Energy\ sectors], \quad C_{i_h} = \beta_{i_h} C_{i_{h_0}} + \left(1 - \beta_{i_h}\right) \left(\frac{p_{C_i}}{CPI} \cdot \frac{1}{p_{C_{i_0}}}\right)^{\sigma_{CP_i}} \left(\frac{R_h}{CPI} \cdot \frac{1}{R_{h_0}}\right)^{\sigma_{CR_i}} C_{i_{h_0}} \tag{24}$$

where β_{i_h} represents the share of the reference consumption of class h that corresponds to a basic need, and with prices indexed in the same way as the consumptions they value.

The demand for other goods of class h is then simply defined as the balance of the class's consumed income-which amounts to imposing a binding budget constraint.

$$for\ i \notin [Energy\ sectors], \quad C_{i_h} = R_h - \sum_{j=Energy\ sectors} \left(p_j C_j\right) \tag{25}$$

8.3 Production (institutional sector of firms)

8.3.1 Gross disposable income and investment decision

Similar to households, the firms' disposable income R_{GD_S} is defined as the addition and subtraction of:

- an exogenous share ω_{K_S} of capital income i.e. GOS (equation (37)),
- a 'debt service' (interests, dividends) $i_S\, D_S$, which is strongly positive in the reference equilibrium (firms are net debtors), and served at an interest rate i_S that varies in the same way as i_H (equation (67)),
- corporate tax payments T_F ,
- and an exogenous share ω_{OT_S} of other transfers OT, which are assumed a constant share of GDP (equation (65)).

$$R_{GD_S} = \overline{\omega_{K_S}}\, GOS - i_S\, D_S - T_F + \overline{\omega_{OT_S}}\, OT \tag{26}$$

The ratio of the gross fix capital formation of firms $GFCF_S$ to their disposable income R_{GD_S} is assumed constant; same as for households and in accordance with national accounting their self-financing capacity AFC_S then arises from the difference between R_{GD_S} and $GFCF_S$. The net debt of firms D_S is then calculated from their AFC_S on the same reasoning as that applied to households.

$$\frac{GFCF_S}{R_{GD_S}} = \frac{GFCF_{S_0}}{R_{GD_{S_0}}} \tag{27}$$

$$AFC_S = R_{GD_S} - GFCF_S \tag{28}$$

$$D_S = D_{S_0} + \frac{t_{REF}}{2}\,(AFC_{S_0} - AFC_S) \tag{29}$$

8.3.2 Production trade-offs

For reasons similar to those presented for the demand of households, the production trade-offs, which are the subject of a specific publication (Ghersi and Hourcade, 2006), are assumed technical asymptotes that constrain the unit consumptions of factors above some floor values. For lack of appropriate bottom-up simulations, the calibration work on pseudo-data described by Ghersi and Hourcade (2006) could not be conducted for the particular situation of 2010 France, and the restrictive assumption is made that the variable shares of the unit consumptions of each factors (secondary inputs, labour and capital) are substitutable according to a CES specification: the existence of a fix share of each of these consumptions implies that the elasticities of substitution of total unit consumptions (sum of the fix and variable shares) are not fixed, but decrease as the consumptions approach their asymptotes. Under these assumptions and constraints, the minimisation of unit costs of production leads to a formulation of the unitary consumptions of secondary factors α_{ji} , of labour l_i and of capital k_i which can be written as the sum of the floor value and a consumption above this value. The latter corresponds to the familiar expression of conditional factor demands of a CES production function with an elasticity of σ (the coefficients of which, IC_{ij}, $\lambda_{L_{i_0}}$ and $\lambda_{K_{i_0}}$, are calibrated in the no-policy equilibrium).

$$\alpha_{ji} = \frac{\Theta_i}{\Phi_i} \left[\beta_{ji}\, \alpha_{ji_0} + \left(\frac{\lambda_{ji}}{p_{IC_{ji}}} \right)^{\sigma} \left(\sum_{j=1}^{n} \lambda_{ji}{}^{\sigma}\, p_{IC_{ji}}{}^{1-\sigma} + \lambda_{L_i}{}^{\sigma}\, p_{L_i}{}^{1-\sigma} + \lambda_{K_i}{}^{\sigma}\, p_{K_i}{}^{1-\sigma} \right)^{-\frac{1}{\rho}} \right] \tag{30}$$

$$l_i = \frac{\Theta_i}{\Phi_i} \left[\beta_{L_i}\, l_{i_0} + \left(\frac{\lambda_{L_i}}{p_{L_i}} \right)^{\sigma} \left(\sum_{j=1}^{n} \lambda_{ji}{}^{\sigma}\, p_{IC_{ji}}{}^{1-\sigma} + \lambda_{L_i}{}^{\sigma}\, p_{L_i}{}^{1-\sigma} + \lambda_{K_i}{}^{\sigma}\, p_{K_i}{}^{1-\sigma} \right)^{-\frac{1}{\rho}} \right] \tag{31}$$

$$k_i = \frac{\Theta_i}{\Phi_i} \left[\beta_{K_i}\, k_{i_0} + \left(\frac{\lambda_{K_i}}{p_{K_i}} \right)^{\sigma} \left(\sum_{j=1}^{n} \lambda_{ji}{}^{\sigma}\, p_{IC_{ji}}{}^{1-\sigma} + \lambda_{L_i}{}^{\sigma}\, p_{L_i}{}^{1-\sigma} + \lambda_{K_i}{}^{\sigma}\, p_{K_i}{}^{1-\sigma} \right)^{-\frac{1}{\rho}} \right] \tag{32}$$

where for convenience:

$$\rho = \frac{\sigma - 1}{\sigma} \tag{33}$$

This sum is however modified to take into account a combination of static decreasing returns Θ_i and endogenous technical progress Φ_i. Static decreasing returns Θ_i are supposed to adjust to the quantity produced with an elasticity σ_{Θ_i}, which is calibrated under the assumption of marginal cost pricing. Φ_i coefficient comes from the hypothesis of a Hicks-neutral endogenous technical progress and is elastic to changes in the volume of fixed capital consumption (meant as a proxy of cumulated investment) of production *i*. In the model, Φ_i is neutralised (set to 1) for the three energy productions, and only operates for the production of the composite good.

$$\Theta_i = \left(\frac{Y_i}{Y_{i_0}} \right)^{\sigma_{\Theta_i}} \tag{34}$$

$$\sigma_{\Theta_i} = \frac{\overline{\pi_i}}{1 - \overline{\pi_i}} \tag{35}$$

$$\Phi_i = \left(\frac{k_i\, Y_i}{k_{i_0}\, Y_{i_0}} \right)^{\sigma_{\Phi_i}} \tag{36}$$

Let us emphasise again that the 'cost of capital' p_K entering the trade-offs is stricto sensu the price of 'machine capital', i.e. equal to a simple weighted sum of the investment prices of immobilised goods (equation (14)), and unrelated to the interest rates charged on financial markets: on the one hand production trade-offs are based upon the strict cost of inputs, including that of physical capital k_i (calibrated on the consumption of fixed capital of the input-output table); on the other hand, regardless of this arbitrage, the firm's activity and a rule of self-investment ($GFCF_S$, equation (27)) lead to a change in financial position D_S , whose service is not assumed to specifically weigh on physical capital as an input.

8.3.3 Gross operating surplus

Trade-offs in the i productions, constant rates of operating margin π_i and specific margins τ_{SM} determine the gross operating surplus (GOS) :

$$GOS = \sum_{i=1}^{n} \left(p_{K_i} \, k_i \, Y_i + \overline{\pi_i} \, p_{Y_i} \, Y_i \right) + SM \tag{37}$$

This GOS, which corresponds to capital income, is split between agents following constant shares (calibrated in the no-policy equilibrium). By construction, the specific margins on the different sales SM sum to zero in the no-policy equilibrium (this is a constraint of the hybridising process), however they do not in the policy runs, their constant rates being applied to varying prices. Their expression is then:

$$SM = \sum_i \left(\sum_j \overline{\tau_{SMIC_{ij}}} \, p_i \, \alpha_{ij} \, Y_j \; + \; \overline{\tau_{SMC_i}} \, p_i \, C_i + \overline{\tau_{SMG_i}} \, p_i \, G_i \; + \overline{\tau_{SMX_i}} \, p_i \, X_i \right) \tag{38}$$

8.4 Public administrations

8.4.1 Tax, social security contributions and fiscal policy

Tax and social security contributions form the larger share of government resources. In most versions of the model, which for the sake of economic efficiency study the substitution of a carbon tax to social contributions, tax rates and excise taxes other than the carbon tax and social contributions are supposed constant, and the various tax revenues are defined by applying these rates to their respective bases:

$$T_Y = \sum_{i=1}^{n} \overline{\tau_{Y_i}}\, p_{Y_i}\, Y_i \tag{39}$$

$$T_{EnT} = \sum_{i=1}^{n} \sum_{j=1}^{n} \overline{t_{EnT\,IC_{ji}}}\, \alpha_{ji}\, Y_i + \sum_{i=1}^{n} \overline{t_{EnT\,FC_i}}\, (C_i + G_i + I_i) \tag{40}$$

$$T_{OPT} = \sum_{i=1}^{n} \sum_{j=1}^{n} \overline{t_{OPT\,j}}\, \alpha_{ji}\, Y_i + \sum_{i=1}^{n} \overline{t_{OPT\,i}}\, (C_i + G_i + I_i) \tag{41}$$

$$T_{VAT} = \sum_{i=1}^{n} \frac{\overline{\tau_{VAT_i}}}{1 + \overline{\tau_{VAT_i}}} \left(p_{C_i}\, C_i + p_{G_i}\, G_i + p_{I_i}\, I_i\right) \tag{42}$$

$$T_F = \overline{\tau_{FT}}\, GOS_S \tag{43}$$

$$T_{I_h} = \overline{\tau_{IT_h}}\, R_{PGD_h} \tag{44}$$

$$T_{D_h} = CPID\dot{}_{T_{h_0}} \tag{45}$$

Fiscal revenues of the carbon tax T_{CARB} and the sum of labour tax (social insurance contributions and benefits) T_{LT} are computed following the same logic:

$$T_{LT} = \tau_{LT} \sum_{i=1}^{n} w_i\, l_i\, Y_i \tag{46}$$

$$T_{CARB} = \sum_{i=1}^{n} \sum_{j=1}^{n} t_{IC}\, \gamma_{IC_{ji}}\, \alpha_{ji}\, Y_i + \sum_{i=1}^{n} t_{FC}\, \gamma_{FC_i}\, C_i \tag{47}$$

But the carbon tax on intermediate consumptions (tIC) and on final consumptions (tFC) is obviously exogenous (it is the main control variable of the model), and the rate of social contributions is adjusted depending on the precise interpretation of the conventional 'budget neutrality' condition. Hourcade et al. (2009) propose three such interpretations:

- a 'constant taxation' option in which the sum of social contributions decreases by the exact amount of carbon tax revenues (equation (48));
- a 'constant fiscal pressure' option guaranteeing, ex post, a constant ratio of total taxes and social contributions to GDP (equation (49));
- the option of a constant ratio of public debt to GDP (equation (50)).

$$T_{LT} = \tau_{LC_0} \sum_{i=1}^{n} w_i \, l_i \, Y_i - T_{CARB} \tag{48}$$

$$\frac{T}{GDP} = \frac{T_0}{GDP_0} \tag{49}$$

$$\frac{D_G}{GDP} = \frac{D_{G_0}}{GDP_0} \tag{50}$$

Where T is the sum of taxes and social contributions:

$$T = T_{LT} + T_Y + T_{EnT} + T_{OPT} + T_{VAT} + T_F + \sum_{h=1}^{m} T_{I_h} + \sum_{h=1}^{m} T_{D_h} + T_{CARB} \tag{51}$$

8.4.2 Gross disposable income, public spending, investment and transfers

Similar to households and firms (following the logic prevailing in the economic account table), the gross disposable income of public administrations R_{GD_G} is the sum of taxes and social contributions, of exogenous shares ω_{K_G} of GOS and ω_{OT_G} of 'other transfers' OT , from which are subtracted public expenditures $p_G \, G$, a set of social transfers R_P , R_U and R_O , and a debt service $i_G \, D_G$:

$$R_{GD_G} = T + \overline{\omega_{K_G}} \, GOS + \overline{\omega_{OT_G}} \, OT - \sum_{i=1}^{n} p_{G_i} \, G_i - R_P - R_U - R_O - i_G \, D_G \tag{52}$$

Public expenditures $p_G \, G$ are assumed to keep pace with national income, and therefore are constrained as a constant share of GDP:

$$\frac{\sum_{i=1}^{n} p_{G_i} \, G_i}{GDP} = \frac{\sum_{i=1}^{n} p_{Gi_0} \, G_{i_0}}{GDP_0} \tag{53}$$

Social transfers R_P , R_U and R_O are the sum across household classes of the transfers defined as components of their before-tax disposable income (equation (16)) :

$$R_P = \sum_{h=1}^{m} \overline{N_{P_h}} \, \rho_{P_h} \tag{54}$$

$$R_U = \sum_{h=1}^{m} N_{U_h} \, \rho_{U_h} \tag{55}$$

$$R_O = \sum_{h=1}^{m} \overline{N_h} \, \rho_{O_h} \tag{56}$$

With *per capita* transfers ρ_{P_h} , ρ_{U_h} and ρ_{O_h} indexed on the average net wage:

$$\forall\ K \in [P, U, O],\ \forall\ h \in [1, m] \quad \rho_{K_h} = \frac{w}{w_0}\, \rho_{K_{h_0}} \tag{57}$$

At last, the interest rate i_G of public debt evolves as do i_H and i_S (equation (67)).

Public investment $GFCF_G$, same as public expenditures $p_G\, G$, is supposed to mobilise a constant share of GDP. Subtracting it from R_{GD_G} gives AFC_G , which determines the variation of the public debt:

$$\frac{GFCF_G}{GDP} = \frac{GFCF_{G_0}}{GDP_0} \tag{58}$$

$$AFC_G = R_{GD_G} - GFCF_G \tag{59}$$

$$D_G = D_{G_0} + \frac{t_{REF}}{2}\,(AFC_{G_0} - AFC_G) \tag{60}$$

8.5 "Rest of the World"

8.5.1 Balance of Trade

Concerning international trade the assumption is made of an open economy whose weight does not affect world prices: global import prices p_M retain their relative values (equation (2)). Then the ratio of imports to domestic production on the one hand, and the ′absolute′ exported quantities on the other hand, are elastic to the terms of trade, according to fixed good-specific elasticities :

$$\frac{M_i}{Y_i} = \frac{M_{i_0}}{Y_{i_0}} \left(\frac{p_{M_{i_0}}}{p_{Y_{i_0}}}\, \frac{p_{Y_i}}{p_{Mi}} \right)^{\sigma_{M_{p_i}}} \tag{61}$$

$$\frac{X_i}{X_{i_0}} = \left(\frac{p_{M_{i_0}}}{p_{X_{i_0}}}\, \frac{p_{Xi}}{p_{Mi}} \right)^{\sigma_{X_{p_i}}} \tag{62}$$

The different treatment of imports and exports merely reflects the assumption that, notwithstanding the evolution of the terms of trade, import volumes rise in proportion to economic activity (domestic production), while exports do not (global demand is assumed constant). It implies, however, that improved terms of trade do not necessarily mean an improvement in the trade balance, depending on the concomitant variations of activity. In the versions calibrated on France an exception to these treatments is the import of raw fossil fuels: to account for the paucity in natural resources these are assumed to mechanically balance the market on the resources′ side, assuming fixed domestic production (negligible in recent times).

8.5.2 Capital flows and self-financing capacity

Capital flows from and to the ROW are not assigned a specific behaviour, but are simply determined as the balance of capital flows of the three national institutional sectors (households, firms, public administrations) to ensure the balance of trade accounting. This assumption determines the self-financing capacity of the ROW, which in turn determines the evolution of $D_R OW$, its net financial debt:

$$AFC_{ROW} = \sum_{i=1}^{n} p_{M_i} M_i - \sum_{i=1}^{n} p_{X_i} X_i + \sum_{K=H,S,G}^{n} i_K D_K - \sum_{K=H,S,G}^{n} OT_K \tag{63}$$

$$D_{ROW} = D_{ROW_0} + \frac{t_{REF}}{2} \left(AFC_{ROW_0} - AFC_{ROW} \right) \tag{64}$$

By construction the self-financing capacities (*AFC*) of the four agents clear (sum to zero), and accordingly the net positions, which are systematically built on the AFCs, change from a position in which they are strictly compensating each other to another such position. Indeed a nil condition on the sum of net positions could be substituted to equation (64) without impacting the results of the model. The hypothesis of a systematic 'compensation' by the ROW of the property incomes of national agents without any reference to its debt D_{ROW} may seem crude, but in fine only replicates the method of construction of the economic account table. Indeed, in the no-policy equilibrium the effective interest rate of the ROW (ratio of net debt to its property income), which ultimately results from a myriad of debit and credit positions and from the corresponding capital flows, is negative, so unworkable for modelling purposes.

To conclude, as previously mentioned other transfers *OT* ("other current transfers " and "capital transfers ", aggregates D7 and D9 of the economic account table) are defined as a fixed share of *GDP* :

$$\frac{OT}{GDP} = \frac{OT_0}{GDP_0} \tag{65}$$

8.6 Market balances

8.6.1 Goods markets

Goods market clearing is a simple accounting balance between resources (production and imports) and uses (households and public administrations' consumption, investment, exports). Thanks to the process of hybridisation, this equation is written in *Mtoe*for energy goods and consistent with the 2010 energy balance of the IEA (the

G and I of these goods are nil by definition).

$$Y_i + M_i = C_i + G_i + I_i + X_i \tag{66}$$

8.6.2 Investment and capital flows

The effective interest rates i_H , i_S and i_G faced by households, firms and public administrations, vary to balance capital markets: their shift from a common point differential δ_i (equation (67)) impacts the households' and firms' disposable incomes R_{GD_H} and R_{GD_S} , and hence their investment decisions $GFCF_H$ and $GFCF_S$, in order to match the supply of capital they constitute, completed by the public $GFCF$, $GFCF_G$, to the demand for investment goods $p_{I_i} I_i$ (equation (68)). This demand is in turn constrained by the assumption that the ratio of each of its real components I_i to total fixed capital consumption (the sum of $k_i\,Y_i$) is constant. In other words, the capital immobilised in all productions is supposed homogeneous, and all its components vary as the total consumption of fixed capital.

$$\forall\ K \in [H, S, G] \quad i_K = i_{K_0} + \delta_i \tag{67}$$

$$\sum_{K=H,S,G} GFCF_K = \sum_{i=1}^{n} p_{I_i} I_i \tag{68}$$

$$\frac{I_i}{\sum_{j=1}^{n} k_j\,Y_j} = \frac{I_{i_0}}{\sum_{j=1}^{n} k_{j_0}\,Y_{j_0}} \tag{69}$$

Therefore the closure of the model is fundamentally made on the investment supply of agents, which mechanically adapts to the investment demand from productions. Through an adjustment of interest rates it leads to fluctuations in financial flows between creditors and debtors, and eventually in some evolution of their net financial positions. In most versions of the model, where the budgetary option retained for public accounts implies some control of the debt, a feedback effect is obtained through the necessary adjustment of the taxes designated as control variables (social contributions in the central hypothesis).

8.6.3 Employment

The labour market results from the interplay of labour demand from the production systems, equal to the sum of their factor demands $l_i\,Y_i$, and of labour supply from households. The labour endowment of households L is assumed constant (calibrated on the total full-time equivalent of the active population in the no-policy equilibrium), but the model allows a strictly positive unemployment rate u and the market clearing condition writes:

$$(1-u)\,\overline{L}=\sum_{i=1}^{n} l_i\,Y_i \tag{70}$$

Rather than explicitly describe labour supply behaviour, the model infers changes in u following a wage curve, which describes an empirical correlation between the average real wage w and the unemployment rate u, characterised by an constant elasticity σ_{w_u} :

$$\frac{w}{CPI}=w_0\left(\frac{u}{u_0}\right)^{\sigma_{wu}} \tag{71}$$

The underlying intuition is that any increase in unemployment creates a downward pressure on wages, which is indeed interpretable in terms of either bargaining power, or efficiency wage. Changes in employment corresponding to the evolution of u are then split between the household classes according to their specific unemployment u_h :

$$u_h=u_{h_0}\,\frac{u}{u_0} \tag{72}$$

Hence N_{U_h} the number of unemployed in each class follows:

$$N_{U_h}=u_h\,\overline{L_h} \tag{73}$$

N_{L_h} the number of employed in class h (defined as $L_h-N_{U_h}$) allows moreover to determine the share ω_{L_h} of total labour income that accrues to class h:

$$\omega_{L_h}=\frac{\frac{N_{L_h}}{N_{L_{h_0}}}\,\omega_{L_{h_0}}}{\sum_{h=1}^{m}\frac{N_{L_h}}{N_{L_{h_0}}}\,\omega_{L_{h_0}}} \tag{74}$$

9 Appendix D: Notation of Imaclim-S France

Calibration consists in providing a set of values to all variables and then determining the values that should be given to the parameters so that the set of equations defining the model holds. The exercise is therefore to determine what values the parameters must take in order for the values drawn from national accounts to be linked by the set of equations. However, all parameters do not receive their values from the calibration: the carbon tax, for instance, is a purely exogenous parameter; other parameters have their values set according to some econometric estimation on data superseding the national accounts as described by the input-output table and the economic account table. As a result of these distinctions, the notations below are presented in three categories, (i) the variables of the model properly speaking, (ii) the parameters of the model that are calibrated on statistical data, and (iii) the exogenous parameters. Within each of these categories the notation are listed in alphabetical order (the Greek letters are classified according to their English name rather than according to their equivalent in the Latin alphabet).

9.1 Variables of Imaclim-S France

Variable Name	**Description**
α_{ij}	Technical coefficient, quantity of good *i* entering the production of one good *j*
OT	Other transfers (equivalent of accounts D7 and D9 of the economic account table)
OT_H	Other transfers to the households
OT_S	Other transfers to firms
OT_G	Other transfers to the public administrations
AFC_H	Self-financing capacity of class *h*
AFC_S	Self-financing capacity of firms
AFC_G	Self-financing capacity of the public administrations
AFC_{ROW}	Self-financing capacity of the rest of the world
C_{i_h}	Final consumption of good *i* by household class *h*
D_h	Net debt of class *h* - Calibrated on the net financial assets (patrimoine financier net) of the INSEE Comptes de patrimoine
D_S	Net debt of firms - Calibrated on the net financial assets (patrimoine financier net) of the INSEE Comptes de patrimoine
D_G	Net public debt - Calibrated on the net financial assets (patrimoine financier net) of the INSEE Comptes de patrimoine

D_{ROW}	Net debt of the rest of the world - Calibrated on the net financial assets (patrimoine financier net) of the INSEE Comptes de patrimoine
d_i	Reform-induced interest rate differential
GOS_H	Gross operating surplus accruing to households
GOS_S	Gross operating surplus accruing to firms
GOS_G	Gross operating surplus accruing to public administrations
$GFCF_h$	Gross fixed capital formation of household class h
$GFCF_S$	Gross fixed capital formation of firms
$GFCF_G$	Gross fixed capital formation of administrations publiques
$\gamma_{IC_{ij}}$	CO2 emissions per unit of good i consumed in the production of good j
γ_{FC_i}	CO2 emissions per unit of good i consumed by households
G_i	Final public consumption of good i
i_H	Effective interest rate on the net debt of ménages
i_S	Effective interest rate on the net debt of sociétés
i_G	Effective interest rate on the net debt of administrations publiques
I_i	Final consumption of good i for the investment
IPC	Consumer price index (Fisher)
k_i	Capital intensity of good i
l_i	Labour intensity of good i
ω_{L_h}	Share of labour income accruing to household class h
M_i	Imports of good i
M_S	Sum across goods and uses of the specific sale margins
N_{L_h}	Employed population of household class h (full time equivalent)
p_{M_i}	Import price of good i
p_i	Average price of the resource in good i (domestically produced and imported)
$p_{IC_{ij}}$	Price of good i for the production of good j
p_{C_i}	Consumption price of good i
p_{G_i}	Public price of good i
p_{I_i}	Investment price of good i
Φ_i	Endogenous technical progress coefficient applying to the production of good i
p_K	Cost of capital input (weighted sum of investment prices)
p_{L_i}	Cost of labour input in the production of good i
p_{X_i}	Export price of good i

p_{Y_i}	Production price of good i
R_{PGD_h}	Before-tax gross disposable income of household class h
R_{GD_h}	Gross disposable income of household class h
R_{GD_S}	Gross disposable income of sociétés
R_{GD_G}	Gross disposable income of administrations publiques
R_h	Consumed income of household class h
R_O	Social transfers to households not elsewhere included
R_U	Sum of unemployment benefits
R_P	Sum of retirement pensions
ρ_{O_h}	Average per capita not-elsewhere-included transfers of household class h
ρ_{P_h}	Average per capita pensions of household class h
ρ_{U_h}	Average per capita unemployment benefits of household class h
σ_{Θ_i}	Elasticity of the decreasing returns coefficient of production i to its output.
T	Total taxes and social contributions
T_{LT}	Sum of social contributions of the employer and the employee
T_{EnT}	Fiscal revenues from tax on energy products (so called "Taxe intérieure de consommation sur les produits énergétiques", TICPE)
T_{OPT}	Fiscal revenues of excise taxes other than the energy product tax
T_{VAT}	VAT revenues
T_F	Corporate tax revenues
T_{I_h}	Household class h income tax payments
T_{D_h}	Other direct taxes paid by household class h
T_{CARB}	Carbon tax revenues
Θ_i	Decreasing returns coefficient for the production of good i
τ_{LT}	Social contribution rate applicable to net wages
$\tau_{CM_{COM}}$	Commercial mark-up on the commercial good or on the aggregate encompassing it
$\tau_{CM_{TRANS}}$	Transport mark-up on the transport good or on the aggregate encompassing it
u	Unemployment rate
u_h	Household class h unemployment rate
ω_i	Average net wage in the production of good i
ω	Average net wage across productions
X_i	Good i exports
Y_i	Good i production

Table 10: Variables for solving IMACLIM-S FRANCE

9.2 Parameters calibrated on statistical data

Variable Name	**Description**
$\overline{L}$	Total active population in full-time equivalents (INSEE data)
$\overline{L_h}$	Active population of household class h in full-time equivalents. Calibrated by applying to total L the shares of active population drawn from the m-class aggregation of the 10305 households of the Budget des Familles 2001 survey by INSEE.
λ_{ij}, λ_{L_i}, λ_{K_i}	Coefficients of the CES production function governing the variables shares of conditional factor demands. Calibrated on the first order conditions of cost minimisation applied to the no-policy equilibrium (functions of prices $p_{IC_{ji_0}}$, $p_{L_{i_0}}$ and $p_{K_{i_0}}$, of quantities α_{ji_0}, l_{i_0} and k_{i_0}, and of basic need shares β_{ji}, β_{K_i} and β_{L_i}).
$\overline{N_h}$	Total population of household class h. Calibrated by applying to total 2004 population the shares of total population drawn from the m-class aggregation of the 10305 households of the Budget des Familles 2001 survey by INSEE.
$\overline{N_{P_h}}$	Number of retirees of household class h. Calibrated by applying to the 2004 retiree population the shares of retiree population drawn from the m-class aggregation of the 10305 households of the Budget des Familles 2001 survey by INSEE.
$\overline{\omega_{OT_h}}$	Share of the other transfers accruing to households devoted to household class h. Calibrated as the share accruing to household class h of revenues other than those of labour, in the m-class aggregation of the 10305 households of the Budget des Familles 2001 survey by INSEE.
$\overline{\omega_{OT_H}}$	Share of other transfers accruing to households (all classes together). Calibrated on the economic account table.
$\overline{\omega_{OT_S}}$	Share of other transfers accruing to firms. Calibrated on the economic account table (aggregate of financial and non financial firms, and of non-profit organisations).
$\overline{\omega_{OT_G}}$	Share of other transfers accruing to public administrations. Calibrated on the economic account table.
$\overline{\omega_{K_h}}$	Share of the capital income of households accruing to household class h. Calibrated as the share accruing to household class h of revenues other than those of labour, in the m-class aggregation of the 10305 households of the Budget des Familles 2001 survey by INSEE.
$\overline{\omega_{K_H}}$	Share of capital income accruing to households (all classes). Calibrated on the economic account table.

$\overline{\omega_{K_S}}$	Share of capital income accruing to firms. Calibrated on the economic account table (aggregate of financial and non financial firms, and of non-profit organisations).
$\overline{\omega_{K_G}}$	Share of capital income accruing to public administrations. Calibrated on the economic account table
$\overline{\pi_i}$	Mark-up rate (rate of net operating surplus) in the production of good i. Calibrated as the ratio of net operating surplus to distributed output (input-output table and more broadly INSEE data).
$\overline{t_{OPT_i}}$	Excise taxes other than the energy product tax per unit of consumption of good i. Calibrated as the ratio of the corresponding fiscal revenue of each good i (input-output table data after subtraction of the energy product tax) to total domestic consumption in the no-policy equilibrium $Yi0 + Mi0 - Xi0$ (exports are assumed to be exempted).
$\overline{t_{EnT_{FC_i}}}$	energy product tax per TOE of automotive fuel of household consumption. The energy product tax is isolated from other excise taxes and split between goods GG15 and GG2B of the input-output table: refined petroleum products and natural gas. The split between energy product tax on intermediate vs. final sales is calibrated on data from the Comité Professionnel Du Pétrole (CPDP).
$\overline{t_{EnT_{IC_i}}}$	energy product tax per TOE of automotive fuel of intermediate consumption. The energy product tax is isolated from other excise taxes and split between goods GG15 and GG2B of the input-output table: refined petroleum products and natural gas. The split between energy product tax on intermediate vs. final sales is calibrated on data from the Comité Professionnel Du Pétrole (CPDP).
$\overline{\tau_{IT_h}}$	Effective income tax rate of household class h. Calibrated as the ratio of income tax payments to the before-tax gross disposable income. Both aggregates are distributed among household classes based on the shares observed in the m-class aggregation of the 10305 households of the Budget des Familles 2001 survey by INSEE.

$\overline{\tau_{FT}}$	Effective corporate tax rate. Calibrated as the ratio of the corporate tax fiscal revenue, to the share of the gross operating surplus accruing to firms.
$\overline{\tau_{SMIC_{ij}}}$	Specific mark-up rate on intermediate energy consumptions (if i is not an energy good then the rate is nil). Defined during the hybridisation procedure.
$\overline{\tau_{SMC_i}}$	Specific mark-up rate on household energy consumptions (if i is not an energy good then the rate is nil). Defined during the hybridisation procedure.
$\overline{\tau_{SMG_i}}$	Specific mark-up rate on public energy consumptions (if i is not an energy good then the rate is nil). Defined during the hybridisation procedure. Under the convention that public energy consumptions are nil (see footnote 5) this parameter is pointless.
$\overline{\tau_{SMX_i}}$	Specific mark-up rate on energy exports (if i is not an energy good then the rate is nil). Defined during the hybridisation procedure.
$\overline{\tau_{S_h}}$	Savings rate of household class h. Calibrated as the ratio of the savings of class h to its gross disposable income, with the data being derived from all the main data sources (input-output table, economic account table, data from the Budget des Familles survey aggregated in m classes).
$\overline{\tau_{VAT_i}}$	VAT rate applying to the final consumption of good i. Calibrated on input-output table data by treating the VAT as a simple sales tax levied indifferently on C, G and i.

Table 11: Calibrated parameters for Imaclim-S France

9.3 Exogenous parameters

Variable Name	**Description**
β_{i_h}	Share of the good i consumption of household class h that corresponds to a basic need. Set for each good i at a level that defines a basic need equal to 80% of the real consumption of the class for which it is the lowest.
β_{ji}	Technical asymptote of the technical coefficient α_{ij} .
β_{K_i}	Technical asymptote of the capital intensity of good i.
β_{L_i}	Technical asymptote of the labour intensity of good i.
σ	Substitution elasticity of the variable shares of production factors.
σ_{CR_i}	Income-elasticity of household consumption of good i. An econometric estimate over aggregate 1985-2006 data.

σ_{CP_i}	Price-elasticity of household consumption of good i. An econometric estimate over aggregate 1985-2006 data.
$\sigma_{M_{p_i}}$	Elasticity of the ratio of imports to domestic production of good i, to the corresponding terms of trade.
σ_{Θ_i}	Elasticity of the technical progress coefficient of production i to its fixed capital consumption (whose variations are taken as a proxy of those of cumulated investment).
$\sigma_{X_{p_i}}$	Elasticity of good i exports to the corresponding terms of trade.
σ_{w_u}	Elasticity of the average net wage (nominal or real, see supra) to the unemployment rate.
t_{IC}	Carbon tax on the carbon emissions of intermediate consumptions.
t_{FC}	Carbon tax on the carbon emissions of household consumptions.
$tREF$	Time of development of the reform (years).

Table 12: Exogenous parameters for Imaclim-S France

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