Assessing locally defined environmental policies in the agricultural sector: a multiregional CGE modelling approach

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FIRST DRAFT

ABSTRACT

Most environmental issues related to agricultural activities arise at a local scale and need to account for the spatial dimension of processes. We present a multiregional computable general equilibrium model which, by dropping out the classical Armington assumption on trade while explicitly introducing transport costs, is in contrast with the present modelling tradition. It is implemented as a mixed complementarity program using the GAMS software. Simulations are run with an 8–region version of the model, but successful experiments have been carried out with up to 35 regions. We also adopt an original two-step calibration method which permits the endogenous calculation of the multiregional benchmark equilibrium. An unconditional systematic sensitivity analysis regarding elasticity parameters concludes to a satisfactory robustness of the model. Finally, two stylised agricultural policy alternatives with an underlying environmental objective demonstrate the relevance of the multiregional framework for the comparison of scenarios which are defined at different local scales.

KEYWORDS: Computable General Equilibrium, multiregional spatial modelling, agricultural activity location, environmental policies

JEL CODE: D58, Q18, R13

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1. INTRODUCTION

Most environmental issues related to agricultural activities arise at a local scale. In particular water diffuse pollution, which has become a major concern, is strongly related to local phenomena such as soil properties, water drainage network and especially the distribution of activities in space.

In turn, policies which aim at reducing pollution emissions from the agriculture tend to be designed so as to take these local specificities into account. Perhaps the most recent example in the European Union is the Framework Directive 2000/60/EC published in December 2001 which explicitly defines sub– or trans–national "river basin districts" as the suitable scale to produce a "management plan and programme of measures".

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Agricultural economists have a long tradition in farm modelling, for example using linear programming, which permits the study of the impact of environmental policies at the firm scale. Unfortunately, such policies have wider impacts that these farm–level designed models fail to capture: in general, the aggregate effect at the regional scale is not just the sum of individual effects. On the other hand, nationwide defined models fail to exhibit locally differentiated impacts of policy measures. There is therefore a need for tools which can efficiently deal with this intermediate, regional scale while taking into account local specificities and spatial issues.

Multiregional Computable General Equilibrium (CGE) models offer a suitable modelling framework to meet these two objectives. However, since they are traditionally used to deal with international issues, these models do not offer a satisfying treatment of space for our purpose. Namely, trade relations between regions are most often modelled under the Armington assumption of imperfect substitutability between commodities from different origins (Kraybill, 1993; Hertel, 1997; Partridge and Rickman, 1998). Trade patterns then remain fixed throughout simulations to the configuration they had in the benchmark equilibrium used to calibrate the model. Meanwhile, the use of Constant Elasticity of Substitution (CES) functions in production technologies implies the same kind of rigidity on the regional production side. In other words, there is no possible regime shifts neither in production nor in trade (Löfgren and Robinson, 1999). Therefore, in line with the approaches recently developed by (Löfgren and Robinson, 1999) and (Isard and Azis, 1998) while in a more general way, we propose a multiregional CGE model which permits to explicitly account for the spatial dimension of economic processes in a more satisfying way.

This paper is organised as follows. The next section describes the model while section 3 introduces the two–stage procedure used to calibrate the model and determine the multiregional reference equilibrium. Then, after having described the studied system (a 8-region stylised vision of the French department Charente), section 4 offers a brief assessment of the model sensitivity to elasticity parameters uncertainty and reports an example of application of our model for the comparison of two environmentally targeted agricultural policy alternatives.

2. THE MODELLING FRAMEWORK

In this section, we briefly present the structure of our model. Appendix 1 introduces the underlying endogenous variables, parameters and equations. In particular, equation numbers refer to this appendix. We use a mixed complementarity programming (MCP) format which has been shown to be highly efficient in implementing and solving CGE models (Mathiesen, 1985; Rutherford, 1995; Löfgren and Robinson, 1997).

2.1. SET DEFINITIONS

The studied economic system is divided into several elementary regions, denoted by the subscript r; the results reported here have been obtained with an 8-region version of the model, but successful runs have been carried out with up to 35 regions[2]. Two more external regions (subscripted e) are identified, the first one representing the rest of France (RDF) and

[2] This figure corresponds to the 35 administrative units "cantons" of the French department "Charente" (South-West of France). See section 4.

the second one representing the rest of the world (ROW). Each "domestic" region is endowed with three primary factors, labour (LAB), capital (CAP) and land (TER), denoted *f*. Seven production activities, denoted *j*, among which three are agricultural activities (VEGE, ANIM and POLY) and four are non–agricultural (AIAA, AIND, ASER and ATRS), can produce ten final commodities, denoted *i*. Six of them are agricultural goods (GDC, VIG, OCV, BOV, LAI and ENB) and the remaining are industrial goods (IAA and IND) and services (SER and TRS). (Refer to Appendix 2 for a description of this nomenclature). Finally, each elementary region hosts a representative agent for private final consumption (ARC), and a local government (GOV) ; both are denoted by the subscript *h*.

2.2. PRODUCTION

In each elementary region, production in all sectors is modelled as a three-stage technology (see Fig. 1). In the first nest, labour and capital are combined as imperfect substitutes into an added-value aggregate through the use of a piecewise linear approximation of a CES function in the "activity analysis" tradition, resulting into a series of co-existing Leontief technologies. The added-value aggregate is then further combined with the remaining primary production factor, land, and other intermediate consumptions using a Leontief technology. At the last level, this activity aggregate is transformed, with fixed coefficients too, into one or several output commodities. In reality, the agricultural sector is the only one where multi-product activities are specified.

Under the assumption of constant returns to scale, profit maximisation at the different production levels leads to the first order conditions given by Eqs. (1) to (3) for input and output quantities and the zero-profit condition given by Eq. (4). Finally, Eq.(7) calculates the total production supply of commodity *i* in region *r* by summing over activities *j* and Eq. (8) defines the relationship between producer and market prices.

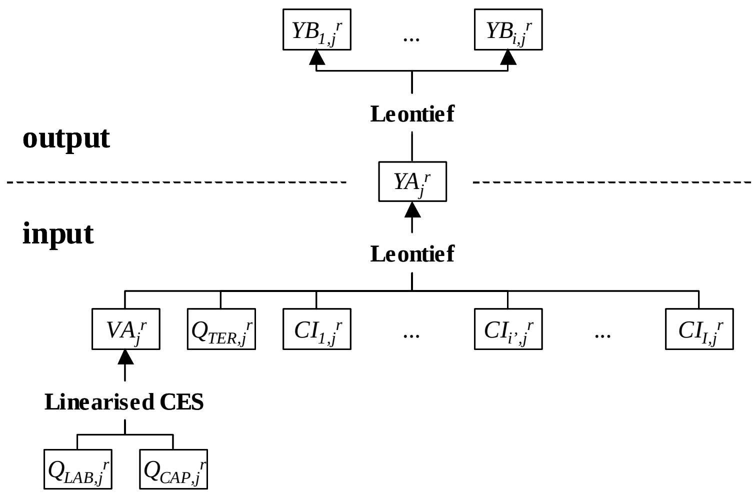


Fig. 1: A graphical presentation of the production technology.

2.3. CONSUMPTION

Consumers in each region maximise their utility, which is modelled through a Cobb-Douglas function, subject to an income constraint. The corresponding first order conditions defining the level of final consumption demands are given by Eq. (5). Consumers total income originates from factor endowment payments plus (minus) net transfers from (to) other consumption institutions (government and other households). Savings, which represent a fixed part of the total income, are then subtracted to give the disposable income allocated to consumption.

Basically, consumers total income corresponds to factor endowment payments augmented with (diminished from) net transfers from (to) other consumption institutions (Eq. (6)). In the particular case of government, tax revenues and subsidy expenditure must be further taken into account, resulting in Eq. (6').

2.4. *TRADE RELATIONS*

Fig. 2 proposes a graphical representation of commodity flows and market structure. Multiregional trade among system regions and import/export with external regions follow different processes and will be therefore treated separately.

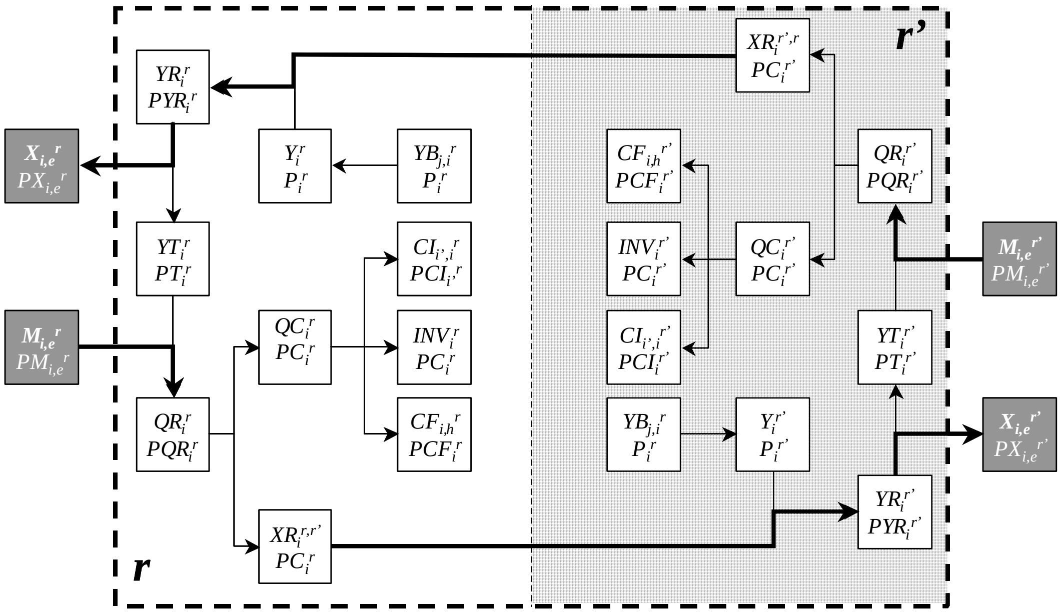


Fig. 2: A graphical presentation of commodity flows and market structure.

Domestic trade relations (Eqs. (9) to (14)). Every commodity but transport can be traded among domestic elementary regions under the Heckscher-Ohlin assumption of perfect substitution. Then, the total supply of a particular region in each commodity is the sum of its own total production plus "imports" from other domestic regions (Eq. (9)) ; similarly, the quantity remaining available for local consumption in a particular region can be deduced from its total disposable quantity by subtracting interregional "exports" (Eq. (10)). Homogeneity also implies two price equalities given by Eqs. (11) and (12).

Nevertheless, a certain degree of product differentiation is taken into account through the explicit introduction of transport costs. These are supported by the importer region but represent a demand for intermediate consumption in the exporter region. In Eqs. (13) and (14), $ttrs_{i',i}^{r',r}$ thus represents the unit amount of commodity *i'* consumed in region *r'* to "export" commodity *i* from *r'* to *r*. In fact, $ttrs_{i',i}^{r',r}$ is non zero only when *i'* represents the transport good (*i.e.* $ttrs_{i',i}^{r',r} = 0$ for any $i' \neq TRS$). This unit transport cost is broken down into three components, the first of which corresponds to a concentration cost within the exporting region, the second one to the transport cost itself and the third one to a distribution cost within the importing region. Each component is based on a "Samuelson's-like iceberg" formalism of the type :

$$t_{TRS,i}^{r',r} = \tau_i . e^{\omega^{r',r} . d^{r',r}}$$

where τ_i represents the relative transportability of the transported commodity *i*, $\omega^{r',r}$ is a coefficient depending only on the transport infrastructure between *r'* and *r*, and $d^{r',r}$ is the distance between the two regions. Note that $d^{r',r}$ needs not to be the Euclidian distance , but should be viewed in a very broad sense : it can be defined as a Manhattan distance or more generally as a *p*-distance[3], or, with even more generality, as a "functional distance" (*e.g.* a time-based distance) and may be non-symmetric and/or non-transitive.

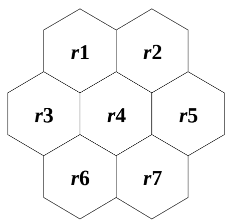
Trade relations between regions are restricted by specifying a contiguity matrix which defines the permitted bilateral connections[4]. There again, contiguity is defined in a broad sense since two regions can be said contiguous even though they do not share a neighbouring border in the geographical reality. In Fig. 3(a) and 3(b) which give two examples of possible contiguity matrices in the 7-region case of Fig. 3(c), $m_{r,r'} = 1$ if *r* and *r'* are connected or 0 otherwise.

r	*r*1	*r*2	*r*3	*r*4	*r*5	*r*6	*r*7
*r*1	0	1	1	1	1	1	1
*r*2	1	0	1	1	1	1	1
*r*3	1	1	0	1	1	1	1
*r*4	1	1	1	0	1	1	1
*r*5	1	1	1	1	0	1	1
*r*6	1	1	1	1	1	0	1
*r*7	1	1	1	1	1	1	0

(a)

r	*r*1	*r*2	*r*3	*r*4	*r*5	*r*6	*r*7
*r*1	0	1	1	1	0	0	0
*r*2	1	0	0	1	1	0	0
*r*3	1	0	0	1	0	1	0
*r*4	1	1	1	0	1	1	1
*r*5	0	1	0	1	0	0	1
*r*6	0	0	1	1	0	0	1
*r*7	0	0	0	1	1	1	0

(b)



(c)

Fig. 3: Two examples of contiguity matrices in the 7-region case. (a) complete contiguity, (b) nearest neighbouring contiguity, (c) regions in the "geographical" space.

External trade relations (Eqs. (15) to (22)). Trade relations with the two external ("foreign") regions are governed by the Armington assumption of imperfect substitution between the different origins of a particular commodity. Traditionally implemented through the use of a CES function on the import side and a CET function on the export side, this assumption is here modelled using piecewise linear approximations of these functions, in a similar way to what was previously presented for the labour/capital substitution in the production

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[3] The *p*-distance between points *a* and *b* is defined by: $d_p(a,b) = \left(|x_a - x_b|^p + |y_a - y_b|^p \right)^{1/p}$ with $p > 0$. The Manhattan distance is defined by $p = 1$ while the Euclidian distance corresponds to $p = 2$.

[4] We could have used the term *graph* to describe the definition of permitted trade relations. As such, the contiguity matrix exemplified at Fig. 3(a) represents the *complete graph* that can be drawn in the 7-region case.

technology. Furthermore, each elementary region is assumed to be a Small Open Economy with respect to both external regions, and may or may not be allowed to enter into trade with them through contiguity restrictions, as presented just before. Eqs. (15) to (22) constitute the resulting set of equilibrium conditions on import and export markets.

2.5. MACROECONOMIC RULES

Eq. (23) ensures that the locally available quantity of commodity *i*, which remains after all trade exchanges have been fulfilled, is fully employed through intermediate consumption, final consumption and investment[5]. Eqs. (24) and (25) define the price of a commodity on the intermediate consumption market and final consumption market respectively. Factors are supposed mobile across sectors while immobile across regions. Thus, equilibrium on factor markets in each region is achieved by specifying that the total factor consumption of production activities should be less than or equal to total local endowments. This condition, Eq. (26), is associated in a complementary slackness way to a constraint on factor prices, allowing for underemployment of a factor when its equilibrium price would fall under an exogenous minimum level.

Equilibrium on the market of investment and savings is achieved in a neoclassical way by specifying that total investments equal total savings at the system's level (Eq. (27)). Eq. (28) and (29) respectively define the level of investment for each commodity and the level of savings for each consumer. Eq. (30) specifies the market clearing condition regarding trade relations with both external regions. Two variables are used to ensure equilibrium: on the one hand the real exchange rate for the "truly" foreign region ROW ; on the other hand, the balance deficit (or surplus if positive) for the RDF region. Consequently, Eq. (31) defines the balance deficit/surplus with ROW and the "exchange rate" with RDF as exogenous variables.

Finally, the resolution of the system of simultaneous equations constituted by Eqs. (1) through (31) provides with the quantities and prices that ensure an equilibrium on every market, *i.e.* the general equilibrium point. This way, one can only calculate a system of relative prices. It is therefore a tradition to select one particular price or to define a price-index as a numeraire to which all other prices are expressed in a relative way. Here, we choose the numeraire as an index of average regional production prices, as specified by Eq. (32). By doing so, the system is over determined from one equation. Then, a usual way of validating the internal coherence of the model consists in withdrawing one particular equation from the system and to verify *ex-post* that the corresponding constraint is actually fulfilled. This process represents a verification of the so-called Walras law which specifies that, in an n-market economy, if $n - 1$ markets are at equilibrium, so does the n^{th} market. Here, we choose to withdraw the investments/savings equilibrium condition, that is Eq. (27).

3. THE BENCHMARK EQUILIBRIUM: A TWO-STAGE PROCESS

Obviously, it would be desirable to construct the benchmark database which is used to calibrate the CGE model directly in the form of a multiregional equilibrium. Unfortunately, even in countries like France where a larger amount of statistical data is available, it is most often difficult if not impossible to gather such exhaustive statistics that building a

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[5] The intermediate consumption of commodity *i* as a transport input should also be accounted for, but it is non zero only in the case of the transport commodity TRS (see above).

multiregional SAM at a very local scale would be possible. We therefore propose a two-stage procedure which permits to calibrate the model at the system level and then endogenously compute the multiregional reference equilibrium.

3.1. Calibration at the system level

A balanced benchmark Social Accounting Matrix (SAM) is first constructed at the national level for France for the reference year 1995. To do so, we use data which are provided by the European statistical institute Eurostat. These data use the European system of national accounting SEC 95 and an aggregated version of the NACE Rev. 1 nomenclature for activities and goods. We further disaggregate the agricultural sector, a unique branch under this classification, with the help of statistics provided by the European Farm Accounting Data Network (FADN).

This national SAM is then disaggregated at the system's level thanks to a ratio based method. Though not the same, our method may be related to those used in the regional Input/Output modelling tradition, like the location quotient technique (Miller and Blair, 1985). Key data that appear relevant for one or several variables of the national SAM are selected among local databases available at the French statistical institute INSEE, the French institute for agricultural statistics SCEES and some local administrative agencies (such as the customs) in order to compute the relative part of the system in the national total values. This process usually leads to a system level SAM which is not balanced anymore. Equilibrium is then restored for each account by introducing compensating economic flows from and to the external "foreign" region RDF.

At this stage, we need to exogenously specify substitution and transformation elasticities to determine, *at the system level*, the values of all other parameters, but unit transport cost coefficients, appearing in the model just like a single country CGE model is now usually calibrated. Elasticity values used here are reported and discussed in the next section. Then, in order to check for its internal coherence, we verify that the model properly replicates the benchmark system level SAM by setting the number of regions to 1, *i.e.* as if the system were not spatially disaggregated.

3.2. Endogenous computation of the benchmark equilibrium and replication

In order to compute the multiregional reference equilibrium to which counterfactual equilibriums will be compared, two types of parameters need to be further specified. First, as just mentioned above, unit transport cost coefficients have to be fixed for each commodity and bilateral route. This task should obviously rely on an empirical econometric work. In this paper which reports a not yet fully operational model and preliminary results, we content ourselves with arbitrary values which we view as good starting point estimates for these parameters.

Second, we need to gather data on factor endowments for each elementary region. In fact, we do not seek to estimate the absolute quantity of factors attributable to a region; rather we compute the relative weight of each region for every factor on the basis of suitable variables which are also available in the local databases mentioned above and in other statistical sources. Table 1 gives an example of such a computation in the case of labour endowments for the 8-region version of the model which is described with more details in the next section.

	r001	r002	r003	r004	r005	r006	r007	r008	System
Active population by branch $(a_{j,r})$									
Agriculture	2480	1776	1996	660	60	2288	4264	1768	15292
Industries	2241	4624	8372	9365	3600	3552	4182	1640	37576
Construction	1152	1168	1472	1944	848	812	1204	752	9352
Trade	1488	1656	3144	3428	2096	1032	2064	860	15768
Services	4304	5060	9308	14048	9476	3556	5360	2956	54068
Average annual wage by branch in Francs (b_j)									
Agriculture	97910	97910	97910	97910	97910	97910	97910	97910	97910
Industries	108200	108200	108200	108200	108200	108200	108200	108200	108200
Construction	90100	90100	90100	90100	90100	90100	90100	90100	90100
Trade	104600	104600	104600	104600	104600	104600	104600	104600	104600
Services	114700	114700	114700	114700	114700	114700	114700	114700	114700
Total value in million Francs $(c_r = \sum_j a_{j,r} \times b_j)$									
	12380	1533	2630	3223	1778	1197	1809	847	14257
Regional percentage $(d_r = c_r / \sum_r c_r)$									
	0.0869	0.1075	0.1845	0.2261	0.1247	0.0840	0.1269	0.0594	1.0000

Table 1: Labour endowment ratio computation for each elementary region in the 8-region case. Sources : (INSEE, 1997; INSEE, 1998) and (SCEES; 2000).

Finally, an assumption has to be made which states that the elasticity parameters and technical coefficients previously established at the system aggregated level are also valid in each and every elementary region. By doing so we assume that the system is geographically homogeneous with respect to production technologies, consumer preferences, etc.[6]

The multiregional benchmark equilibrium is then computed by the model. In particular, optimal production locations, active trade routes and bilateral flows endogenously derive from equilibrium conditions. If even basic information regarding the distribution of activities in the geographical space were available for the reference year, this endogenous computation of the multiregional benchmark equilibrium would permit an *a priori* validation of the model.

4. COUNTERFACTUAL RESULTS

4.1. BENCHMARK MULTIREGIONAL EQUILIBRIUM

Experimental results reported in the following paragraphs are based on an 8-region version of the model. The studied system is the "department" of Charente, South-West of France. Each elementary region is an aggregation of one to up to five "*cantons*", an administrative subdivision of the department (see Fig. 4(a)). Centres of regions which are used as a support for the computation of distances and transport costs are defined as the most inhabited county-towns. Contiguity is defined as the complete graph that may be drawn in the 8-region case. Fig. 4(b) presents the corresponding contiguity matrix, while Fig. 4(c) gives a stylised vision of possible trade routes. Factor endowments of each region, calculated as mentioned in the previous section, are reported in Table 2.

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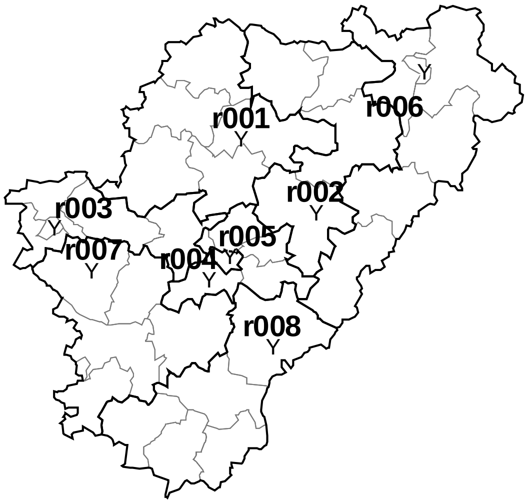
[6] Though certainly questionable, note that this assumption is the one implicitly underlying any single country CGE model. At least, in our modelling framework do we have the opportunity to let these parameters vary across regions. The various impacts of such a modelling strategy should be further investigated in a future work.

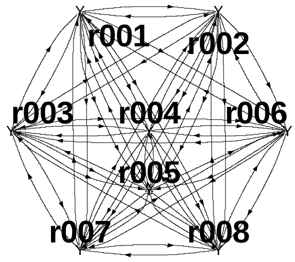
Region	LAB	CAP	TER
*r*001	8.69%	8.03%	16.07%
*r*002	10.75%	9.16%	7.57%
*r*003	18.45%	20.88%	19.71%
*r*004	22.61%	22.25%	2.71%
*r*005	12.47%	14.57%	0.02%
*r*006	8.40%	6.94%	9.45%
*r*007	12.69%	12.94%	35.36%
*r*008	5.94%	5.23%	9.12%
System	100.0%	100.0%	100.0%

Table 2: Relative endowment in each factor in the 8-region case.
Computed from INSEE (1997, 1998) and SCEES (2000).



	*r*001	*r*002	*r*003	*r*004	*r*005	*r*006	*r*007	*r*008
*r*001	0	1	1	1	1	1	1	1
*r*002	1	0	1	1	1	1	1	1
*r*003	1	1	0	1	1	1	1	1
*r*004	1	1	1	0	1	1	1	1
*r*005	1	1	1	1	0	1	1	1
*r*006	1	1	1	1	1	0	1	1
*r*007	1	1	1	1	1	1	0	1
*r*008	1	1	1	1	1	1	1	0

(b)



(a) (c)

Fig. 4: An 8-region vision of the Charente *department (South-West of France).*
(a) Elementary regions definition, (b) contiguity definition and
(c) permitted trade routes stylised representation.

In such a configuration, the model comprises 25 212 equations[7] and is solved in round 40 seconds[8] by GAMS/PATH (Dirkse and Ferris, 1995, Ferris and Munson, 1998; Brooke *et al.*, 1998). Describing part of the multiregional reference equilibrium which derives from this standard version, Fig. 5(a) and (c) present the regional distribution of the aggregated output value for agricultural and non–agricultural activities respectively, while Fig. 5(b) and (d) show the corresponding multiregional trade flows.

[7] And of course as many variables.

[8] Unfortunately this quite reasonable computation time for the reference case can increase to hours in some counterfactual studies.

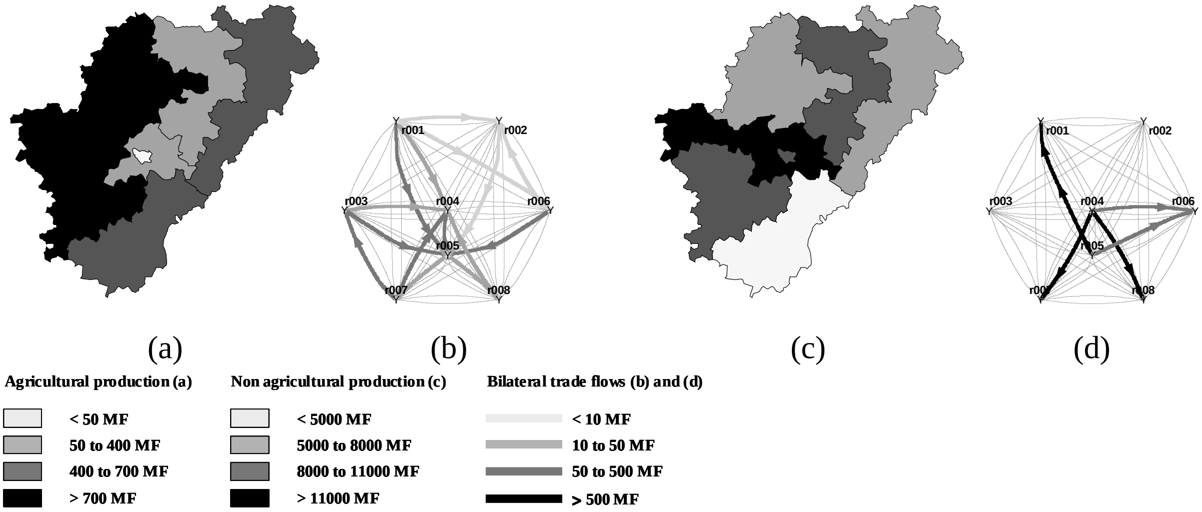


Fig. 5: Production and bilateral trade in the multiregional reference equilibrium.
(a) Agricultural output value, (b) agricultural commodities trade flows,
(c) non–agricultural output value and (d) non–agricultural commodities trade flows.

4.2. *SYSTEMATIC SENSITIVITY ANALYSIS*

Alike many CGE modelling examples, substitution and transformation elasticity parameters (which characterise the linearised CES and CET functions appearing in production and foreign trade) do not derive from empirical econometric data, but rather represent "guesstimates" (Table 3). It is then necessary to undertake an analysis of the sensitivity of the model regarding the underlying uncertainty. With the passing years, several authors have proposed different methodologies for such an analysis (Harrison; 1986; Whalley, 1986; Harrison and Vinod, 1992; Tembo *et al.*, 1999). It appears that the unconditional systematic sensitivity analysis (USSA) is the most rigorous approach and is therefore highly recommended (Wigle, 1991).

Activity	σ^{VA}
VEGE	0.8
ANIM	0.8
POLY	0.8
AIAA	0.9
AIND	1.1
ATRS	1.9
ASER	1.9

(a)

Commodity	σ_i^{IMP}	σ'^{EXP}_i
GDC	3.0	3.0
VIG	3.0	3.0
OCV	3.0	3.0
BOV	3.0	3.0
LAI	3.0	3.0
ENB	3.0	3.0
IAA	3.0	3.0
IND	1.5	1.5
TRS	1.5	1.5
SER	1.5	1.5

(b)

Table 3: Subsitution and transformation elasticities used in the model.
(a) labour/capital substitution in production technologies, (b) Armington eslasticities for domestic/foreign origin distinction on imports and exports.

It is also the most computing time consuming solution though, since the number of runs the model has to be solved for may reach very high numbers. In effect, elasticity parameters, for which several values (typically 3 or 5) are assumed plausible, are simultaneously deviated from their central "guesstimate" point, so that any combination should be investigated ; then, with n parameters taking 3 possible values, the number of repetitions is 3^n, which leads to an exploding level for sure as the number of parameters to be tested for increases. Approximations of the USSA have therefore been investigated[9] over the years. (DeVuyst and Preckel, 1997) show that the Gaussian Multivariate Quadrature (GMQ) is a powerful statistical technique for approaching an exhaustive USSA.

Here, we adopt the GMQ solution presented by (Arndt, 1996), where $2n$ repetitions of the model have to be computed. In our case, the sensitivity analysis affects all of the 27 elasticities introduced above so that 54 repetitions are needed, to which we add a 55th one corresponding to the central point case. Each elasticity is assumed to follow an independent normal distribution of which the mean is the central guesstimate of Table 3 and the standard deviation is arbitrarily set to 20% of the mean value.

The sensitivity of the model is first assessed regarding the computation of the multiregional benchmark equilibrium. This first step aimed at verifying whether the reference point was stable in itself or not (recall that it is endogenously calculated here unlike in other classical CGE models). With most variables exhibiting small variations around their average value (not exciding 10% for a vast majority), we conclude to a satisfactory robustness of the model. Likewise, counterfactual experiments can be considered as robust, though exhibiting larger confidence intervals. In the following, we therefore only report results corresponding to the central case.

4.3. COMPARING TWO ALTERNATIVES OF AN AGRI-ENVIRONMENTAL POLICY

The counterfactual experiments reported here seek to demonstrate the usefulness of the multiregional framework for the assessment of agricultural policy reforms, especially these which have an environmental objective. Here, we make the (oversimplifying !) assumption that the production technology undertaken by the producers of activity VEGE generates water diffuse pollution and that this pollution is somehow proportional to the activity aggregate output. Moreover, we assume that this problem is especially sensitive in only a sub-area of Charente, corresponding to region *r*007. A decrease in the production level of this activity in this particular area would then lead to direct environmental benefits.

The first scenario therefore consists in raising to 50% the tax rate affecting the agricultural activity VEGE in region *r*007 only; at the same time, this rate is held constant in the other seven regions. The computation of the counterfactual equilibrium reveals that while activity VEGE is abandoned in region *r*007, its output declines from round 15% at the system level. The second option consists in endogenously finding the tax rate to be applied uniformly to every region so that the same reduction of 15% in activity VEGE output is reached at the system level[10]. Then, it appears that the optimal tax rate is 10.3%. Now the multiregional

[9] See (Wigle, 1991) for an approximation example which uses an interpolation technique.

[10] This implies a slight modification of the model as introduced above. First, the tax rate becomes an endogenous variable and loses its multiregional dimension. Then the following supplementary complementary equation is

framework allows us to compare both reforms either at the system level or at the elementary regions level.

First, we conclude from Table 4 that the impacts of both scenarios are always consistent in tendency if not in magnitude at the system level. This observation is also valid for the great majority of the other variables. The difference in magnitude is especially obvious for welfare impacts when the second scenario implies far larger compensating variations for both private and public institutions.

	Activity output (% change)								Welfare change (MF) [11]			
	scenario 1				*scenario 2*				*scenario 1*		*scenario 2*	
	VEGE	ANIM	POLY	AIAA	VEGE	ANIM	POLY	AIAA	ARC	GOV	ARC	GOV
***r*001**	+16	-100	-0	-24	-8	-51	APP	+6	+9.4	-5.7	-22.9	+35.7
***r*002**	+23	-42	-100	-3	-10	-2	+90	+2	+0.5	+0.5	-21.2	+12.5
***r*003**	APP	-23	-90	+1	+0	-87	+14	+3	+20.7	+14.0	-32.7	-6.8
***r*004**	+0	+0	+0	-5	+0	+0	+0	-20	-11.5	-5.2	-15.5	-18.0
***r*005**	+0	+0	+0	+0	+0	+0	+0	-0	-7.2	+0.0	-7.3	-1.8
***r*006**	+12	-100	+0	-25	-4	+2	+0	-1	+3.2	-0.1	-15.0	+23.7
***r*007**	-100	+21	APP	+47	-26	-20	APP	+43	-104.7	+10.2	-46.5	+71.6
***r*008**	+15	-100	+0	-21	-3	+17	+0	+0	+9.3	-0.9	-13.2	+22.0
System	-16	-44	+47	+0	-15	-34	+70	+1	-83.4	+12.8	-174.3	+139.0

Table 4: Comparison of the impacts of both scenarios on selected variables. "APP" stands for the apparition of an activity which was not active in the reference equilibrium.

Meanwhile, it appears that the impacts are quite different in their regional dimension, either in magnitude or even sometimes in tendency. There again, this is true for most other variables. While on the one hand the first scenario fully reaches its initial environmental objective by stopping activity VEGE in region *r*007 and decreasing its output at the system level, we also notice that it implies in return an increase of round 15% of activity VEGE production level in fairly all other regions. On the other hand, if scenario 2 has a more homogenous impact across regions, it fails to completely discourage activity VEGE in region *r*007, where the decrease only reaches –25%. Moreover, indirect impacts on other activities (especially agricultural ones) are also brought into light, which may have unexpected implications regarding water pollution. Further investigations from an environmental point of view should therefore be carried out to ascertain which scenario would be effectively the most efficient.

Finally, the multiregional framework adopted here has enabled us to show that two environmentally driven policy options that would generate similar aggregated changes would in reality exhibit a fairly different distribution of their impacts over the geographical space,

specified: $\sum_r \sum_t YA_j^{t,r} \leq M_j \quad \perp \quad ttax_j \geq 0$, where is a large upper bound except for activity VEGE for which $M_{VEGE} = 0.15 \times \sum_r \sum_t \left(YA_{VEGE}^{t,r}\right)^0$. We also impose the two following conditions: $ttax_{VEGE} \leq 1$ and $ttax_{j \neq VEGE} = \left(ttax_{j \neq VEGE}\right)^0$.

[11] Welfare impact of the reforms are evaluated as the compensating income variations.

not only in terms of magnitude but worse in terms of tendency. A "classical" approach in the tradition of single country CGE models would have missed such an issue.

5. CONCLUSIONS AND FUTURE WORK

The model presented in this paper has to be viewed as a grounding work towards the development of a more operational one. In many ways, it is still a toy–model, especially in its oversimplifying representation of economic policy instruments (*ad–valorem* taxes and subsidies). In the near future, we plan to reach a more realistic modelling of such instruments as these of the European Common Agricultural Policy (CAP): direct "decoupled" income support, intervention price, variable restitutions on export, compulsory set–aside, etc. The mixed complementarity format adopted here appears to be most suitable for such developments, since it allows for the modelling of both equality and inequality constraints required by the explicit modelling of such instruments. New measures aiming at a better environmentally friendly and durable agriculture such as Best Management Practices and other eco-condition principles should also be implemented to allow the assessment of environmentally designed policies.

Furthermore, future work will aim at coupling this economic model with a hydrological one so as to produce a real cost–effectiveness assessment of such policies, one of the major objectives of the European Water Framework Directive. Recent attempts have been made in this direction (Conrad, 1999; Coxhead, 2000; Wiig *et al.*, 2001), but it is still a challenge in the field of water diffuse pollution originating from the agriculture, especially when the spatial dimension of processes has to be taken into consideration. We think that the multiregional economic approach adopted here is a relevant framework for coupling a CGE model with spatially distributed agronomical and hydrological models (Piet, 1999). Only then shall we be able to assess the impacts of locally defined environmental policies in the agricultural sector in an operational and integrated, *i.e.* truly satisfying way.

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APPENDIX 1 : MATHEMATICAL STATEMENT

Sets

r, r'	Domestic regions	i, i'	Commodities
f	Primary factors	h, h'	Consumption institutions
j	Production activities	e	External regions

Variables

$QF^{r}_{f,j}$	Primary factor consumption	W^{r}_{f}	Primary factor price
$CI^{r}_{i',j}$	Intermediate consumption	PCI^{r}_{i}	Intermediate consumption price
$YA^{t,r}_{j}$	Activity aggregate output	PP^{r}_{i}	Producer price
$YB^{r}_{j,i}$	Commodity output	P^{r}_{i}	Market price
Y^{r}_{i}	Total commodity output	PYR^{r}_{i}	Regional supply price
$YR^{t,r}_{i}$	Total regional supply	PT^{r}_{i}	Regional supply price after exports
YT^{r}_{i}	Regional supply after exports	PQR^{r}_{i}	Regional demand price after imports
$QR^{t,r}_{i}$	Regional demand after imports	$PM^{r}_{i,e}$	Import price
$XR^{r',r}_{i}$	Multiregional bilateral trade	$PX^{r}_{i,e}$	Export price
$CT^{r',r}_{i',i}$	Transport cost	PC^{r}_{i}	Regional demand price
$M^{r}_{i,e}$	Imports	PCF^{r}_{i}	Final consumption price
$X^{r}_{i,e}$	Exports	I	Total investments
QC^{r}_{i}	Total regional demand	EPA^{r}_{h}	Savings
$CF^{r}_{i,h}$	Final consumption	REV^{r}_{h}	Consumer total income
INV^{r}_{i}	Investments	TC_{e}	Real exchange rate
		BF_{e}	Balance deficit or surplus

Parameters

$a^{t,r}_{*,*}$	Input/Output technical coefficients	$\overline{DOT}^{r}_{f}$	Regional factor endowments
$\alpha^{r}_{i,h}$	Cobb-Douglas technical coefficient	$tepa^{r}_{h}$	Savings rates
$ttrs^{r',r}_{i',i}$	Unit transport cost	$ttrf^{r}_{*,*}$	Transfers rates
$ttax^{r}_{*}$	Tax rates	$tinv^{r}_{i}$	Investment rate
$tsub^{r}_{*}$	Subsidy rates	$\overline{IX}_{e}$	Foreign investments
$ttva^{r}_{i}$	Value–added tax rate	$\overline{PW}_{i,e}$	World price
$tddm^{r}_{i,e}$	Tax rate on imports		

Equations

(1) $$Q^{r}_{f,j} = \sum_{t} a^{t,r}_{f,j}.YA^{t,r}_{j} \qquad \perp \quad QF^{r}_{f,j}$$

(2) $$CI^{r}_{i',j} = \sum_{t} a^{t,r}_{i',j}.YA^{t,r}_{j} \qquad \perp \quad CI^{r}_{i',j}$$

(3) $YB_{j,i}^{r} = \sum_{t} a_{j,i}^{t,r} . YA_{j}^{t,r}$ $\perp$ $YB_{j,i}^{r}$

(4) $\sum_{f} a_{f,j}^{t,r} . W_{f}^{r} + \sum_{i'} a_{i',j}^{t,r} . PCI_{i'}^{r} \geq \left(1 - ttax_{j}^{r} + tsub_{j}^{r}\right) . \sum_{i} a_{j,i}^{t,r} . PP_{i}^{r}$ $\perp$ $YA_{j}^{t,r}$

(5) $PCF_{i}^{r} . CF_{i,h}^{r} = \alpha_{i,h}^{r} . \left(1 - tepa_{h}^{r}\right) . REV_{h}^{r}$ $\perp$ $CF_{i,h}^{r}$

(6) $$REV_{h}^{r} = \left(1 + \sum_{e}\left(ttrf_{e,h}^{r} - ttrf_{h,e}^{r}\right) + \sum_{h'}\left(ttrf_{h',h}^{r} - ttrf_{h,h'}^{r}\right)\right) . \sum_{f}\sum_{j} tdot_{h,f}^{r} . W_{f}^{r} . Q_{f,j}^{r} \Big/ \left(1 + \sum_{e}\left(ttrf_{e,f}^{r} - ttrf_{f,e}^{r}\right)\right)$$ $\perp$ REV_{h}^{r}

(7) $Y_{i}^{r} = \sum_{j} YB_{j,i}^{r}$ $\perp$ PP_{i}^{r}

(8) $PP_{i}^{r} = P_{i}^{r} . \left(1 - ttax_{i}^{r} + tsub_{i}^{r}\right)$ $\perp$ Y_{i}^{r}

(9) $YR_{i}^{r} = Y_{i}^{r} + \sum_{r'} XR_{i}^{r',r}$ $\perp$ P_{i}^{r}

(10) $QR_{i}^{r} = QC_{i}^{r} + \sum_{r'} XR_{i}^{r,r'}$ $\perp$ PQR_{i}^{r}

(11) $PYR_{i}^{r} = P_{i}^{r}$ $\perp$ YT_{i}^{r}

(12) $PQR_{i}^{r} = PC_{i}^{r}$ $\perp$ QC_{i}^{r}

(13) $CT_{i',i}^{r',r} = ttrs_{i',i}^{r',r} . XR_{i}^{r',r}$ $\perp$ $CT_{i',i}^{r',r}$

(14) $PC_{i}^{r'} + \sum_{i'} ttrs_{i',i}^{r',r} . PCI_{i'}^{r'} \geq P_{i}^{r}$ $\perp$ $XR_{i}^{r',r}$

(15) $YT_{i}^{r} = \sum_{t} a_{i,DOM}^{t,r} . QR_{i}^{t,r}$ $\perp$ PT_{i}^{r}

(16) $M_{i,e}^{r} = \sum_{t} a_{i,e}^{t,r} . QR_{i}^{t,r}$ $\perp$ $PM_{i,e}^{r}$

(17) $a_{i,DOM}^{t,r} . PT_{i}^{r} + \sum_{e} a_{i,e}^{t,r} . PM_{i,e}^{r} \geq PQR_{i}^{r}$ $\perp$ $QR_{i}^{t,r}$

(18) $YT_{i}^{r} = \sum_{t} a_{DOM,i}^{t,r} . YR_{i}^{t,r}$ $\perp$ PYR_{i}^{r}

(19) $X_{i,e}^{r} = \sum_{t} a_{e,i}^{t,r} . YR_{i}^{t,r}$ $\perp$ $PX_{i,e}^{r}$

(20) $PYR_{i}^{r} \geq a_{DOM,i}^{t,r} . PT_{i}^{r} + \sum_{e} a_{e,i}^{t,r} . PX_{i,e}^{r}$ $\perp$ $YR_{i}^{t,r}$

(21) $\overline{PW}_{i,e} . TC_{e} . \left(1 + tddm_{i,e}^{r}\right) \geq PM_{i,e}^{r}$ $\perp$ $M_{i,e}^{r}$

(22) $PX_{i,e}^{r} \geq \overline{PW}_{i,e} . TC_{e}$ $\perp$ $X_{i,e}^{r}$

(23) $QC_{i}^{r} = \sum_{j} CI_{i,j}^{r} + \sum_{h} CF_{i,h}^{r} + INV_{i}^{r} + \sum_{r'}\sum_{i'} CT_{i,i'}^{r,r'}$ $\perp$ PC_{i}^{r}

(24) $PCI_i^r = PC_i^r$ $\perp$ PCI_i^r

(25) $PCF_i^r = PC_i^r.(1 + ttva_i^r)$ $\perp$ PCF_i^r

(26) $\overline{DOT}_f^r.\left(1+\sum_e\left(ttrf_{f,e}^r - ttrf_{e,f}^r\right)\right) \geq \sum_j QF_{f,i}^r$ $\perp$ W_f^r

(27) $I + \sum_e TC_e.\overline{IX}_e = \sum_r \sum_h EPA_h^r + \sum_e TC_e.\overline{BF}_e$

(28) $INV_i^r = tinv_i^r.I$ $\perp$ INV_i^r

(29) $EPA_h^r = tepa_h^r.REV_h^r$ $\perp$ EPA_h^r

(30) $TC_e.BF_e = \sum_r \sum_i \overline{PW}_{i,e}.TC_e.M_{i,e}^r - \sum_r \sum_i \overline{PW}_{i,e}.TC_e.X_{i,e}^r$ $\perp$ TC_e

$-\sum_r \sum_f \left(ttrf_{e,f}^r - ttrf_{f,e}^r\right).\sum_j W_f^r.Q_{f,j}^r \Big/ (1+\sum_e\left(ttrf_{e,f}^r - ttrf_{f,e}^r\right))$

$-\sum_r \sum_h \left(ttrf_{e,h}^r - ttrf_{h,e}^r\right).\sum_f \sum_j tdot_{h,f}^r.W_f^r.Q_{f,j}^r \Big/ (1+\sum_e\left(ttrf_{e,f}^r - ttrf_{f,e}^r\right))$

(31) $TC_{RDF} = \overline{TC}_{RDF}$ and $BF_{ROW} = \overline{BF}_{ROW}$ $\perp$ BF_e

(32) $\dfrac{\frac{1}{R}\cdot\sum_r \sum_i P_i^r Y0_i^r}{\sum_i P_i^{SYS} Y0_i^{SYS}}$ $\perp$ I

APPENDIX 2 : NOMENCLATURE DESCRIPTION

Activities	Commodities
Crop agriculture (VEGE)	Main crops (GDC)
Cattle raising agriculture (ANIM)	Vineyards (VIG)
Mixed agriculture (POLY)	Other crops (OCV)
	Beef cattle (BOV)
	Milk (LAI)
	Other cattle and animal products (ENB)
Food industries (AIAA)	Food products (IAA)
Other industries (AIND)	Other industrial products (IND)
Service activities (ASER)	Services (SER)
Transport activities (ATRS)	Transport (TRS)