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MIRAGE, Updated Version of the Model for Trade Policy Analysis.

Focus on Agriculture and Dynamics

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MIRAGE, Updated Version of the Model for Trade Policy Analysis *
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Abstract

MIRAGE is a multi-region, multi-sector computable general equilibrium model, devoted to trade policy analysis. It incorporates imperfect competition, horizontal and vertical product differentiation, and foreign direct investment, in a sequential dynamic set-up where installed capital is assumed to be immobile. Adjustment inertia is linked to capital stock reallocation. MIRAGE draws upon a very detailed measure of trade barriers and of their evolution under given hypotheses, thanks to the MAcMap database. The most recent version, presented in this document, offers improvements in the modelling of agriculture policy and dynamics.

JEL Classification: D58; F12; F13.

Key words: computable general equilibrium model, trade policy, dynamics, foreign direct investment, imperfect competition.

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Introduction

The recent failure of Doha negotiation Round emphasized how complex and controversial the stakes of trade policies are. Numerous new preferential agreements are in project, while the future of multilateral liberalisation remains unclear. In this context, delivering a rigorous and detailed quantitative analysis of a large scope of trade agreements is most useful, for policy-makers as well as for the public debate. This is the reason why the CEPII has decided to develop and to maintain a multi-sector, multi-region computable general equilibrium (CGE) model, nicknamed MIRAGE,[1] devoted to trade policy analysis.

Trade agreements can involve substantial changes in prices, in allocated resources and in income, that are frequently strongly contrasted across sectors and countries. Based on a robust and widely accepted modelling of agents' behaviour, CGE models are able to provide a detailed description of the impact of such shocks on the economy. A number of robust and well-identified mechanisms are quantified in a single, rigorous and consistent framework. Such an analysis makes it possible to put forward the main mechanisms, to give their sign and their order of magnitude.

During the last two decades, an extensive literature has been devoted to applying CGE modelling to the study of trade policies. Compared to the pure walrasian tradition models,[2] several major improvements have been achieved, in particular thanks to the studies about the expected impact of the European Single Market, the NAFTA, or the Uruguay Round. Since Harris (1984), imperfect competition and horizontal product differentiation are commonly incorporated, notably based on the formalisations proposed by Smith and Venables (1988), and by Harrison, Rutherford and Tarr (1997). Numerous studies have also gone beyond the static framework, in order to be able to describe adjustment periods, and the corresponding dynamic effects, notably after Baldwin (1989). Lastly, the nineties witnessed the increasing spreading of the GTAP database (Global Trade Analysis Project, Purdue University), that marked the sharing of the heavy data work required for this kind of models, making their access far easier.

The MIRAGE model builds on this literature, and intends to take a new step toward a better analysis of trade policies. It describes imperfect competition and horizontal product differentiation in a rather standard fashion, but with an original calibration procedure, allowing the available information to be used more efficiently. The modelling is done in a sequential dynamic set-

[1] MIRAGE stands for *Modelling International Relationships in Applied General Equilibrium.*

[2] Such as, for instance, the one used by the World Bank for a global and prospective analysis of development issues, more than twenty years ago (World Bank, 1981).

up, where installed capital is assumed to be immobile, even across sectors. Therefore, capital reallocation only results from the combined effect of depreciation and investment. It makes it possible to describe the adjustment lags of capital stock, and the associated costs. The model uses the GTAP 6.x database (see Dimaranan and Mac Dougall, 2005). In order to improve the description of trade policies main transmission channels, MIRAGE has three main distinctive features:

- FDIs are explicitly described, with a modelling both theoretically consistent (with agents' behaviour and with domestic investment setting), and consistent with the empirical results about FDIs' determinants and their order of magnitude.
- A notion of vertical product differentiation is introduced by distinguishing two quality ranges. Even though it remains rudimentary, this assumption is a first step toward taking advantage, in applied modelling, of the empirical progresses achieved in this domain during the last decade.
- Trade barriers are described by the MAcMap database (see Bouët, Decreux, Fontagné, Jean and Laborde, 2004), that provides with a measure of ad-valorem tariffs, ad-valorem equivalent of specific tariffs, tariff quotas and anti-dumping duties, at the bilateral level, for 137 countries with 220 partners. Preferential agreements are taken into account in a quasi-exhaustive way. This information, available at the level of the 5,113 products of the HS6 classification, is used to describe the initial level of trade barriers, but also to build scenarios. Assumptions concerning the changes in these barriers can thus be made at the product level. Only then are these data aggregated in the model's nomenclature, according to a procedure designed to limit the extent of the endogeneity bias. As a result, MIRAGE is based on a description of trade barriers that, besides its precision, preserves the bilateral dimension of the information.

The present version of the model includes a few more specific features concerning agricultural sectors to adequately reflect trade policy changes: export subsidies variations in the European Union are computed considering the intervention price mechanism. Production quotas, land imperfect allocation across different crops, capital and land subsidies are also modelled. Labour forces are distinguished between agricultural and non agricultural labour types and supposed imperfectly mobile. The modelling of such mobility depends on the level of development of a region and on the share of agricultural labour.

The dynamic framework has also been improved. The reservoir of labour is adjusted with respect to the United Nations forecast and the growth of the total factor productivity is computed to match the World Bank economic growth forecast. For developing countries, the transfer from rural areas to urban areas enable to take into effect the migrations occuring in these regions. These features should enable to better assess trade policy effects, especially in agricultural sectors.

The MIRAGE model

MIRAGE is a multiregional and multisectoral model, the regional and sectoral aggregation of which can be adapted to each application. This Section describes the structure of the model and focuses on a few key assumptions, namely those dealing with products quality ranges, imperfect competition, FDI and dynamic aspects. The model's equations are displayed at the end of the document.

The demand side

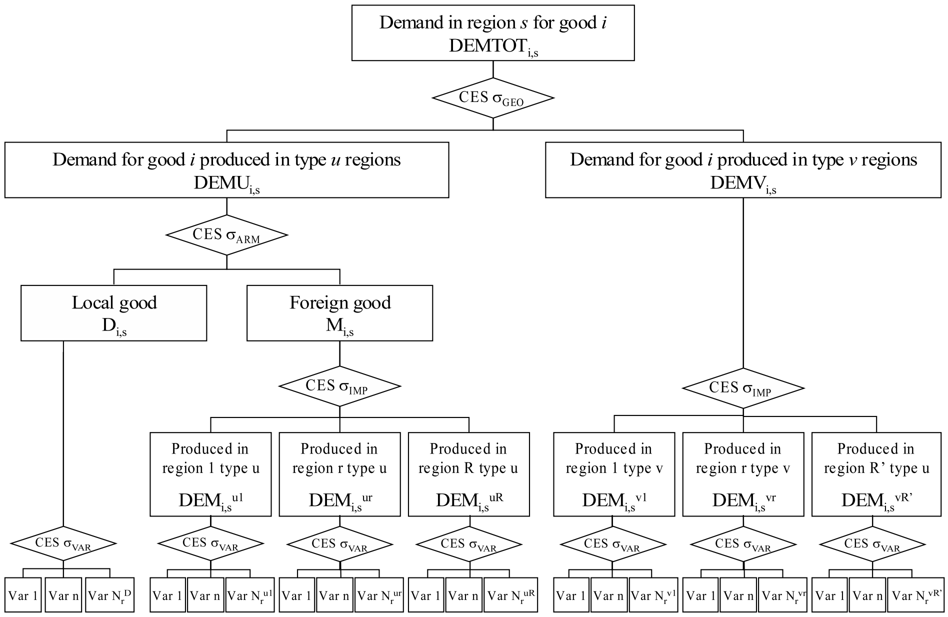
Final consumption is modelled in each region through a representative agent,[3] whose utility function is intratemporal. A fixed share of the regional income is allocated to savings,[4] the rest is used to purchase final consumption goods. Below this first-tier Cobb-Douglas function, the preferences across sectors are represented by a LES-CES (*Linear Expenditure System - Constant Elasticity of Substitution*) function. Without excessive complexity, this allows to account for the evolution of the demand structure of each region as its income level changes. With this kind of utility function, the elasticity of substitution is constant only across the sectoral consumptions over and above a minimum level.[5] As far as consumption choices within each sector are concerned, a nesting of CES functions such as the one used in Harrison, Rutherford and Tarr (1997) allows the particular status of domestic goods, together with product differentiation according to geographical origin (the so-called Armington assumption) and horizontal product differentiation between varieties to be taken into account (see the 'Local good'/'Foreign good' level in figure 1). Such a standard, nested Armington - Dixit-Stiglitz, subutility function does not account for vertical differentiation nor for specialisation across quality ranges, although their importance in trade has been widely illustrated by now (see e.g. Abd-El-Rahman, 1991; Fontagné and Freudenberg, 1997; Fontagné, Freudenberg and Péridy, 1997; Freudenberg, 1998; Greenaway and Torstensson, 2000). Even though it is not easy to model nor quantify, this is an important device as far as analysing the nature and intensity of competition is concerned. This is why a further CES nesting level is added to the subutility function for some sectors of the aggregation, distinguishing be-

[3]This assumption can be thrown out to study the impact of a decision on poverty (see for instance Hertel *et alii*, 2001), but it requires detailed survey data, which are available only on a country by country basis.

[4]This simplifying assumption does not allow to consider the indirect impact of liberalisation on savings, through a variation of the return rate of capital, though it can significantly alter the impacts of opening in a dynamic framework (Baldwin 1992, Francois *et alii* 1995; this point is discussed below).

[5]The minimum consumption is supposed to be one third of the initial consumption in developed countries, and two thirds in developing countries.

tween two quality ranges, defined on a geographical basis: goods produced in a developing economy are assumed to belong to a different quality range than those produced in a developed economy (this nesting level is displayed at top level in Figure 1). The choice of substitution elasticities (the one between qualities is inferior to the Armington elasticity) implies that goods that do not belong to the same quality range are less substitutable than goods from the same quality range. This means for instance that, within a given sector, goods from a developing country compete more directly with goods from any other developing country than with goods from any developed country. Even though it remains rudimentary, this formulation is a first step toward taking vertical differentiation into account in applied modelling. Such an assumtion can also represent the fact that the composition of each sector in terms of elemetary products often differs more between a developed economy and a developing one than between two economies of the same development level, which also leads to a lower substitutability between those aggregate products in the first case.



Notes:

- Good i refers to the output of sector i
- In order to make the figure clearer, parameter t has been omitted in variables
- Type u regions correspond to regions exporting products of the same quality as those from the region s. Type v regions correspond to regions exporting products of different quality.
- Local demand refers to demand of products on the local markets of countries in the region r. Trade between countries within a region r is considered in $DEMU_{i,r,r,t}$
- Substitution elasticities are linked by the following relationships $\sigma_{ARM} - 1 = \sqrt{2}(\sigma_{GEO} - 1)$; $\sigma_{IMP} - 1 = \sqrt{2}(\sigma_{ARM} - 1)$; $\sigma_{VAR} - 1 = \sqrt{2}(\sigma_{IMP} - 1)$

Figure 1: Demand nesting for good i

Total demand is made up of final consumption, intermediate consumption and capital goods. Sectoral demand of these three compounds follows the same pattern as final consumption. The regional representative agent includes the government. He therefore both pays and earns taxes, and no public budget constraint has to be taken into account explicitly: this constraint is implicit to meeting the representative agent's budget constraint. Unless otherwise indicated (modelling a distorsive replacement tax does not raise any technical problem), this implicitly assumes that any decrease in tax revenues (for example as a consequence of a trade liberalisation) is compensated by a non-distorsive replacement tax. However, the magnitude of the tax revenue losses is an interesting information, to be considered when analysing results.

The supply side

Production makes use of five factors: capital, skilled labour, unskilled labour, land and natural resources. Factor endowments are assumed to be fully employed and their growth rates are exogenous (zero for Natural Resources, based on demographic forecast provided by the World Bank for Labour), except for Land and Capital: even though saving rates are exogenous, total incomes vary and the regional and sectoral allocation of savings depends on capital returns as will be explained later. The possibility of extending arable land is considered, thanks to a global supply function for land, characterised by a constant elasticity to land return. This global factor is distributed across productions on the basis of the assumption that it is a Constant Elasticity of Transformation (CET) function of lands used in the different sectors; this assumption introduces an imperfect mobility of land across uses. Installed capital and natural resources are sector-specific, so that their rates of return may vary across sectors and regions. Labour is perfectly mobile within two sets of sectors in each country, corresponding to agricultural production on the one hand and non agricultural production on the other hand. It is imperfectly mobile between these two sets of sectors and is immobile across countries.[6] In the standard version of the model, labour mobility across the two sets of sectors is represented through the assumption that total labour is a CET bundle of two labour types.

The production function is described in Figure 2. In a standard fashion, perfect complementarity is assumed between value added and the intermediate consumptions. The sectoral composition of the intermediate consumption aggregate stems from a CES function, with the same elasticity as in the corresponding CES-LES for final consumption. For each sector of origin, the nesting is exactly the same as for final consumption, meaning that the sec-

[6] Factor market rigidity, particularly Labour market rigidity, can affect the impact of liberalisation processes (McKibbin, 1999).

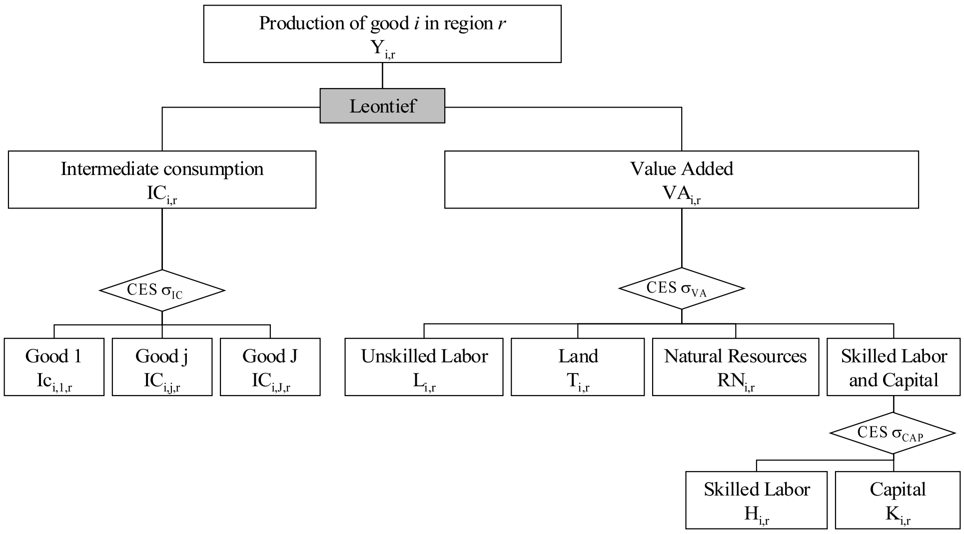


Figure 2: Structure of sector's i production function

tor bundle has the same structure for final and intermediate consumption.[7] Value added is a CES function of land, natural resources, unskilled labour and a CES bundle of capital and skilled labour. This structure is intended to take into account the well-documented skill-capital relative complementarity. The elasticity of substitution within the capital and skilled labour bundle is assumed to be lower (0.6) than the elasticity between this bundle and all other factors (1).[8]

Imperfect competition

The need to consider imperfect competition and economies of scale when assessing the consequences of trade liberalisation episodes has been widely documented (see for instance Norman, 1990). However, some sectors, such as agriculture and transport,[9] are generally considered to be perfectly competitive with constant returns to scale.

[7]Based on the idea that firms collect information about products more easily than consumers, Mercenier (1992) assumes that substitution elasticities are higher within intermediate consumption than they are in final consumption. However the lack of empirical basis has led us not to adopt this assumption.

[8]Value added is thus a Cobb-Douglas function of the bundle and the other factors. However, it can be replaced by a general CES formulation for sensitivity analysis purposes.

[9]The transport sector plays a specific role: it covers both regular transport activities, that are demanded and can be traded like any other service, and international transport of commodities. The latter is a Cobb-Douglas bundle of regional supplies, and it accounts for the difference between fob and cif values of traded goods. The same bundle is used for any route. It is employed in fixed proportions with the volume of each good shipped along each route.

Oligopolistic competition is thus assumed to hold in the other sectors, with horizontal differentiation of products and increasing returns to scale, in the line of Krugman's (1979) theoretical model and of Smith and Venables' (1988) applied partial equilibrium model. The specification in MIRAGE is very close to that used by Harrison, Rutherford and Tarr (1997). Each firm produces its own and unique variety. The marginal production cost is constant at given factor prices, and production involves each year a fixed cost, expressed as a fixed quantity of output. Within each sector of each region, firms are assumed to be symmetrical. They compete in a Cournot-Nash way, i.e. they suppose that their decisions of production do not affect the volume of production of their competitors. Moreover they rule out the possibility that their production decision may affect the global level of demand through a revenue effect (the so-called Ford effect). However, firms take into account their market power, that is the influence they may exert on the sectoral or infra-sectoral price index (given the above-defined demand structure). It follows from the absence of strategic interaction implied by the Cournot-Nash hypothesis, that the mark-up is given by the Lerner formula:

$$\mu_{i,r,s} = \frac{P_{i,r,s}}{MC_{i,r}} = \frac{1}{1 - \frac{1}{\varepsilon^P_{i,r,s}}}$$

Where $\mu_{i,r,s}$ is the mark-up applied in region s by each sector i's firm producing in region r, P is the corresponding price, MC is the marginal cost of production (which does not depend on the market). Time subscript t has been omitted for all variables, for greater convenience. $\varepsilon^P_{i,r,s}$ is the price-elasticity of demand, as perceived by the firm based on the above-mentioned assumptions (see formula at the end of the document); it increases with the elasticity of substitution between good i varieties produced in country r (this elasticity is a higher bound for $\varepsilon^P_{i,r,s}$) and with the elasticity of substitution between good i baskets from region r and from other regions; it is a decreasing function of the number of firms in sector i of region r, and of the global market share of region r's producers taken together in the region s's market for good i. This endogenous determination of firms' mark-up (already present, in a generic form, in Krugman, 1979), allows the pro-competitive effect of trade shocks to be accounted for.

This formulation requires three types of parameters, describing respectively products substitutability, scale economies and competition intensity. Since these parameters are linked by the zero-profit condition in each sector, only two of them are usually drawn from external sources, and the third one is calibrated. This method is not fully satisfactory, either in terms of consistency or of robustness. This is why a different method is used in MIRAGE, that takes advantage of the whole available information for these three sets of parameters, not only about their value, but also concerning their variance. Once external estimates are collected for the three parameters, their calibrated values are jointly determined such as to minimise their distance from these estimates, subject to the consistency constraints imposed by the model. The inverted variance is used as a weight in calculating this distance, so as to make the adjustment borne more strongly by parameters which estimates have the greatest variance.

Changes in the number of firms are also an important matter: it affects competition and therefore will have an impact on markup rates, particularly when the number of firms / varieties is small, and is also important through the preference of firms and final consumers for variety. In MIRAGE, the number of varieties adjusts at each period to match a zero profit condition.

Capital, investment and macroeconomic closure

Whatever its origin, a unit of capital invested in a given region is a bundle, obtained using the same CES nesting as for intermediate consumption. However, the distribution coefficients of the CES functions are different, according to the data. As for intermediate consumption, no factor service is required.

Installed capital is assumed to be immobile. This *putty-clay* hypothesis is important, because it implies that capital stock adjustment is gradual. [10] The sectoral allocation of investment can thus be sub-optimal, and the corresponding loss can be interpreted as an adjustment cost for the economy. In addition, this putty-clay assumption implies that the rate of return to capital may vary across sectors.

This confers investment an important role, as the only adjustment device for capital stock. As soon as trade policies are concerned, investment is also important through its cross-border component, that is FDI. In many models, among which the GTAP one (see Hertel, 1997), international financial flows are the results of the assumptions of perfect capital mobility and of cross-country equalisation in the rate of return to capital (including risk premium). This modelling is micro-funded, but it induces unplausibly high cross-border capital flows. On the other hand, using directly the results of econometric estimates for parameterising an ad-hoc relationship would give more realistic results, but it would lack theoretical consistency.

This is why an original modelling of FDI is used here, aiming at combining empirical realism and theoretical consistency. The latter objective requires, in particular, that domestic investment's setting is consistent with FDI's one, and that savings allocation behaviour is rational. In this context, the rate of return to capital is a natural determinant of investment sharing across sectors and countries. It is noteworthy that this rate of return incorporates

[10] Note, however, that there is no technological difference between capital generations.

the influence of many FDI determinants identified in the empirical literature, (see for example Chakrabarti, 2001, for a recent survey) such as market size, growth rate or market potential.[11] As a consequence, these determinants need not be taken into account, over and above the sectoral rate of return to capital. Practically, a single generic formalisation is used for setting both domestic and foreign investment. It stems from allocating savings across sectors and regions, as a function of the initial savings pattern, of the present capital stock and of the sectoral rate of return to capital, with an elasticity α:

$$\frac{P_s^K I_{i,r,s}}{S_r} = \frac{A_{i,r,s} P_s^K K_{i,s} \mathrm{e}^{\alpha W_{i,s}^K}}{\sum_{i,s} A_{i,r,s} P_s^K K_{i,s} \mathrm{e}^{\alpha W_{i,s}^K}}$$

where P_s^K stands for the price of capital good in region s, S_r for country r savings, $I_{i,r,s}$ for country r representative agent's investment in the sector i of country s, $K_{i,s}$ for installed capital stock, $A_{i,r,s}$ for a calibrated parameter, $W_{i,s}^K$ for the capital remuneration rate in sector i of country s. Parameter α sets the adjustment speed of capital stock.[12] The capital good used in a given region is the same, whatever the capital's origin.

Equivalently, for the sake of clarity, introducing an endogenous variable B_r allows the problem to be rewritten as follows:

$$I_{i,r,s} = B_r A_{i,r,s} P_s^K K_{i,s} \mathrm{e}^{\alpha W_{i,s}^K}$$

$$\sum_{i,s} P_s^K I_{i,r,s} = S_r$$

B_r can therefore be written as:

$$B_r = \frac{S_r}{\sum\limits_{i,s} A_{i,r,s} P_s^K K_{i,s} P_s^K I_{i,r,s}} \mathrm{e}^{-\alpha R_r}$$

Where R_r can be interpreted as the shadow price of capital (including the depreciation rate) in region r.

Foreign owned firms are treated as domestic firms in all respects. The only difference is that the capital revenue goes back to the source country. By changing the number of firms, FDI may have an influence on productive efficiency. Nevertheless, it is worth emphasizing that FDI is not assumed to originate any technological spillover here. Although some empirical studies

[11] Tariff jumping issues are left aside, because this mechanism cannot be modeled consistently without relying on a model of the multinational firm (see for instance Markusen and Venables, 2000).

[12] Since α cannot be calibrated, two static models were built, corresponding to a short run and a long run version of Mirage. We applied the same shocks to both of them and chose α so that half the adjustment of capital stocks towards the long run would be made in around 4 years, for a variety of small commercial shocks. It gave the value $\alpha = 40$.

have shown that such spillovers may arise, they are not systematic nor robust enough to be taken into account in a model aimed at studying a large scope of trade policy shocks.

It is noteworthy, in addition, that product quality is assumed to depend only on the region of production. This contrasts for example with Petri (1997), who assumes that foreign affiliates produce the same quality as their parent company. In this framework, also adopted by Hanslow and alii (2000), and Lee and van der Mensbrugghe (2001), FDI liberalisation induces quality upgrading in developing countries, originating significant gains. Though interesting, this mechanism is not supported by robust enough empirical results.

Labour market

An optional feature enables to consider developing countries as dual economies, with an urban labour market that is distinct from a "traditional" market in rural areas (Lewis, 1954; Harris and Todaro, 1970). The modern sector (industry and services) pays an efficiency wage to unskilled workers, above their marginal productivity. This wage is independent from labour supply and is indexed on price inflation, after being adjusted with tax change effect in order to guaranty constant purchasing power to workers.

The primary sector (i.e., agriculture), in contrast, pays a competitive wage with a totally elastic supply of unskilled labour. The supply of unskilled labour available for the primary sector is set as a residual, once the "modern" sector has set its unskilled labour employment level. The specification provides a simple way to account for a hidden unemployment in developing countries, and to depart from the standard assumption of balanced labour markets used in CGE models, in spite of its obvious inappropriateness in the developing countries case.

In developed countries, labour is considered imperfectly mobile between agricultural activities and other sectors, and substitution is represented by a Constant Elasticity of Transformation function with an elasticity of 0.5.

Agriculture market specific features

This updated version of MIRAGE includes new features implemented for a better description of the agricultural sector specificities.

Farm support: Subsidies are introduced either on output, land or capital. They are assumed proportional to the volume of output or factor. Market price support is explicitly modeled, through the combination of tariffs and of export subsidies. The WTO ceilings cap the corresponding subsidized exports, and reaching the ceiling entails an endogenous adjustment of the market price that can be supported. Production quotas are also explicitly modeled, and originate rents. Some of the (semi-decoupled) EU direct payments are treated as subsidies to the animal capital. Some others are treated as subsidies to land. The fully decoupled ones are treated as a return to self-employed labour and have therefore an indirect effect on production, by pulling some of the primary factor into the sector, reflecting that no payment is fully decoupled in agriculture. Set-aside is taken into account in the US and the EU.

Export subsidies: In order to model changes in the European Union trade policy, intervention prices have been introduced for agricultural exports. When activated, intervention prices make exportation subsidies endogenous with three possible behaviours on the market:

1. when the internal price is higher than the intervention price, no export subsidies are used.

2. when the internal price becomes lower than the intervention price, subsidies are given to producers in order to sustain production prices at the intervention level. Export subsidies distribution is kept same across regions as in the reference year. If there was no subsidy in the baseline, this distribution is homogenous. In actual facts, the EU also increases inventories, but inventories are not accounted for in Mirage.

3. when subsidized exports from the European Union come to exceed a sectorial WTO limit, the model ensures exports are contained at the WTO level.

For countries other than the EU or for sectors not concerned by intervention prices, the subsidy rate is set exogenous.

Land imperfect mobility: Land mobility across agricultural sector is assumed to be imperfect. Land supply behaves as an isoelastic function of the real return to land (Lee and van der Mensbrugghe, 2001). Regions are accordingly classified either as land-constrained or not, and different values of supply elasticities are assumed.[13]

[13] The values of the elasticities are similar to those used in the LINKAGE model, i.e. 0.25 for land constrained countries and 1 for other countries. We thank Dominique van der Mensbrugghe for providing us information and advice on this point. The transformation elasticity of land mobility across sectors is set to 0.5.

Dynamic set-up

Adapting to a trade policy shock is neither immediate nor costless. Dynamics are thus useful, in order to be able to study the corresponding adjustment period, i.e. the short- and medium-run impacts. In addition, a number of effects are dynamic, in the sense that they are intrinsically linked to an accumulation or evolution process. Such effects are difficult to take into account in a static framework. They are mainly twofold: on the one hand, trade policy may modify the capital stock in the economy, through its impact on income or on the savings rate (see e.g. Baldwin, 1989); on the other hand, it may influence human capital and technology. Each of these two kinds of effects is likely to reach far higher orders of magnitude (for gains as well as for losses) than static effects, as evidenced for example by the results of Baldwin (1989, 1992) or of Francois, Mac Donald and Nordström (1995) concerning capital accumulation, and those of Baldwin and Forslid (1999) or of the World Bank (2001) as to introducing a technological externality linked to trade openness.

Now, empirical studies do not allow a definitive and robust conclusion to be reached about the existence of such growth effects (see e.g. Fontagné and Guérin, 1997, for a survey of this literature). In this context, a cautious approach is necessary, in order to prevent results from depending overwhelmingly on dubious (or at least not well-grounded) assumptions. This is why no technological externality linked to trade is introduced in MIRAGE, and why the savings rate is assumed to be constant over time in each region. Note, however, that capital accumulation is still influenced by income changes, that are proportionately transmitted to savings, and by the net balance of FDIs, which can be affected by the trade policy scenario.

The model's dynamics is exclusively of a sequential nature: the equilibrium can be solved successively for each period. Time span can be freely chosen, usually around 15 to 20 years. Except for capital, the growth rate of production factors is set exogenously and the technical progress is calibrated in order to fit GDP forecast.

At each period, labour, land and the number of varieties adjust instantaneously to match the objectives assumed in the model. By contrast, capital stocks only adjust through investment, so that rates of returns vary across sectors after the base year. Even though the model does not include any explicit adjustment cost, capital allocation may become strongly unoptimal in the case of a strong shock applied to the economy. Then, the relative rigidity of the capital distribution across sectors induces implicit adjustment costs, as compared to what come out of a perfect capital mobility assumption.

Baseline

In order to compute more precisely the effects of trade policy changes, a baseline has been constructed for the model. Basically, population and GDP projections are used to compute the trajectory of the technological progress in this baseline. To determine this parameter, other data are taken as exogenous:

- the initial levels of skilled and unskilled labour force in each region of the model are those of the GTAP 6.1 database,
- the structure of the labour force (ratio of skilled to unskilled) is assumed to be constant over time as default for all regions,
- the growth rate of the labour force in each region is taken from the World Bank projections of population,
- the annual growth of GDP in each region is taken from the World Bank projections. The annual growth of the different TFP is first computed endogenously. The figures are then taken as exogenous variables and put into the model.

Conclusion

The MIRAGE model makes a synthesis of the main recent developments of CGE models applied to trade policy analysis, and it proposes several innovations. It describes competition imperfections, horizontal product differentiation, delays and costs of adjustment. It introduces a notion of product quality, in order to improve the analysis of competition, and of trade diversion when necessary. It proposes an explicit, consistent and realistic description of FDIs. It provides adequate tools to model specificities of the agricultural sectors. Lastly, it is based on a very detailed and complete measure of trade barriers. However, the model has been conceived for a variety of applications, the specificities of which may call for modifications, additions or subtractions, to the database as well as to the specification of the model.

A number of further developments would be useful, in the near future:

- the description of quality is rudimentary. More in-depth work would help taking advantage of the empirical studies about vertical product differentiation in trade and country specialisation along quality ranges;
- FDIs modelling received special attention, in order to combine theoretical and empirical consistency. It is an important step, but it would be worth trying to incorporate in the model some recent developments of the multinational firm theory (e.g. Markusen et Venables, 2000);
- similar structural models are applied to different economies. Doing otherwise would be difficult, in a world-wide model devoted to varied applications. Nonetheless, this is a very strong hypothesis, and it could be worth using a different model, in particular for developing countries;

This list is far from exhaustive, given the wide variety of trade policy topics and of the methodological problems they raise. MIRAGE aims at constituting an efficient tool devoted to the quantitative analysis of trade policy shocks, taking into account in a satisfactory and robust way their main systematic transmission channels, in order to enlighten the public debate, as well as policy makers. Doubts are frequently expressed as to the adequacy of CGE models to such objectives, this kind of model being accused of providing an oversimplified, if not oriented, vision of the economies, and in particular of the consequences of a trade liberalisation. But a model is no more than the quantified expression of a number of well-identified, robust mechanisms. The relevant point is about the way it is used. CGE models simulations are not an ending point, that would give a definitive answer to the question of the impact of a given trade policy decision. It is on the contrary a starting point making it possible, based on (often complex) protection scheme changes, to deliver a synthetic numbering of their main impacts. The interpretation then requires a well-suited analysis, taking into account the problems tackled, and the important mechanisms not included in the model.

This is the reason why the choices made in conceiving MIRAGE were guided by the willingness to take into account only those mechanisms that proved to be robust and systematic. This cautious choice allows the simulation results to be considered as a solid working basis, the ins and outs of which are well identified.

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Elements on the structure of the model

1 Notations

The i and j indices refer to sectors, r and s refer to regions, t to periods.
Superscripts for prices P refer to the related variable.
$U(s)$ is the subset of countries in the same development level as region s and
$V(s)$ is the subset of countries with a different level of development.
$Agri(i)$ is the subset of sectors from agriculture.
i_{TrT} refers to transport sectors and r_{EU} refers to the European Union regions.
The reference year is indexed with t_0.

2 Parameters definition

$\sigma_{ARM_i}, \sigma_{IMP_i}, \sigma_{VAR_i}$, $\sigma_{VA_j}, \sigma_{CAP_j}, \sigma_C$, $\sigma_{IC}, \sigma_{KG}, \sigma_{GEO_i}$,	Substitution elasticities of factors and goods demand
$cmin_{i,r}$	Minimal consumption of good i in the final demand of region r
epa_r	Saving rate in region r
$\mu_{i,r,s}$	Transport demand per volume of good
θ_r	Value share of region r transport sector in the world production of transport
$DD_{i,r,s,t}$	*Ad-valorem* tariff rate applied by regions s on its imports from region r
$MaxExpSub_{i,r,t}$	Maximum level of subsidized exports authorized by WTO
$taxp_{i,r}$, $taxcc_{i,s}$, $taxicc_{i,s}$, $taxkgc_{i,s}$	Tax rate applied on production, final consumption, intermediate consumption and capital good
$taxAMF_{i,r,s}$	Export tax rate equivalent to the Multifiber Arrangement
$TsubK_{i,r}$	Subsidy rate on capital
$TsubTE_{i,r}$	Subsidy rate on land
$cf_{j,r}$	Fixed cost per unit of output in imperfectly competitive sectors
$mmoy_{i,r}$	Mark-up average
$Quota_{i,r,t}$	Maximum production in sectors where quotas hold
α	Elasticity of investment to capital return rate
$\gamma^L_{i,r}, \gamma^Q_{i,r}, \gamma^{TE}_{i,r}, \gamma^{RN}_{i,r}$	Value share of factors in value added (Cobb-douglas)
δ	Depreciation of capital
$\rho_{r,t}$	Population growth rate of region r (World Bank data)
a_{XXX}	Various share and scale coefficients in CES or Cobb-Douglas functions
$PGF_{r,t}$	Total factor productivity

3 Variables definition

Production

$Y_{i,r,t}$	Output of sector i firms
$VA_{i,r,t}$	Value added
$CNTER_{i,r,t}$	Aggregate intermediate consumption

Factors

$Q_{i,r,t}$	Aggregate of human capital and physical capital
$L_{i,r,t}$	Unskilled labour
$L^{Agri}{}_{i,r,t}$	Total Unskilled labour in agriculture
$L^{notAgri}_{i,r,t}$	Total Unskilled labour in sectors other than agriculture
$TE_{i,r,t}$	Land
$RN_{i,r,t}$	Natural resources
$H_{i,r,t}$	Skilled labour
$K_{i,r,s,t}$	Capital stock from region r to region s in sector i
$KTOT_{i,r,t}$	Total capital stock in sector i and region r
$\overline{L}_{r,t}$	Total supply of unskilled labour
$\overline{TE}_{r,t}$	Total supply of land
$\overline{H}_{r,t}$	Total supply of skilled labour
$\overline{K}_{r,t}$	Total supply of capital

Demand

$BUDC_{r,t}$	Budget allocated to consumption
$UT_{r,t}$	Utility
$P_{r,t}$	Price of utility
$C_{i,r,t}$	Aggregated consumption
$IC_{i,j,r,t}$	Intermediate consumption of good i used in the production of sector j
$INVTOT_{r,t}$	Total investment in region r
$INV_{i,r,s,t}$	Investment from region r to sector i in region s
$B_{r,t}$	Investment scale coefficient
$KG_{i,r,t}$	Capital good demand of sector i in region r
$DEMTOT_{i,r,t}$	Total demand
$DEMU_{i,r,t}$	Total demand, in region r, of good originating from regions with the same development level than region r (including local demand in region r)
$DEMV_{i,r,t}$	Total demand, in region r, of good originating from regions with a different development level than region r
$D_{i,r,t}$	Domestic demand of good i
$DVAR_{i,r,t}$	Domestic demand of good i produced by each firm of region r

$M_{i,r,t}$	Total demand, in region r, of good i originating from regions with the same development level than region r other than region r
$DEM_{i,r,s,t}$	Demand, in region s, of good i originating from region r
$DEMVAR_{i,r,s,t}$	Demand of good i produced by each firm of region r

Transportation sector	
$TRADE_{i,r,s,t}$	Exports to region s of industry i in region r
$TR_{i,r,s,t}$	Transport demand
$MONDTR_t$	Transport aggregate
P_t^T	Transport of commodities price
$TRM_{i,r,t}$	Supply of international transportation sector i in region r

Monopolistic competition	
$EP_{i,r,s,t}$	Perceived price elasticity of total demand
$EPD_{i,r,t}$	Perceived price elasticity of domestic demand
$NB_{i,r,t}$	Number of varieties in imperfectly competitive sectors
$SDU_{i,s,t}$	Market share of domestic demand in demand of regions with the same level of development than region r
$SDT_{i,s,t}$	Market share of domestic demand in total demand
$SE_{i,r,s,t}$	Market share of imports from region r in imports of region s originating from regions with the same level of development
$SU_{i,r,s,t}$	Market share of imports from region r in demand of region s for goods from regions with the same level of development
$SV_{i,r,s,t}$	Market share of imports from region r in imports of region s originating from regions with a different level of development
$ST_{i,r,s,t}$	Market share of imports from region r in demand of region s

Tax revenue	
$RECPROD_{i,r,t}$	Revenue of production tax
$RECDD_{i,r,t}$	Revenue of tariff
$RECCONS_{i,r,t}$	Revenue of consumption tax
$RECEXP_{i,r,t}$	Revenue of exports tax
$RECTAX_{r,t}$	Total tax revenue
$RQUOTA_{i,r,s,t}$	Implicit transfers due to quotas
$REV_{r,t}$	Regional revenue
$SOLD_{r,t}$	Current account balance
$PIBMVAL_t$	Total GDP in value
$GDPVOL_{r,t}$	Regional GDP

Prices and taxes	
P^{XXX}	Generic notation to indicate the price of the variable XXX
$P^{CIF}_{i,r,s,t}$	CIF price
$P^{Int}_{i,t}$	Intervention price (European Union only)
$\overline{W^{K}_{r,t}}$	Capital return rate in region r
$W^{K}_{i,r,t}$	Capital return paid to the investor
$\overline{W^{TE}_{r,t}}$	Land return rate in region r
$W^{TE}_{i,r,t}$	Land return rate paid to the owner
$TAXEXP_{i,r,s,t}$	Export tax rate
$TAXREF_{i,r,s,t}$	Auxiliary variable to adjust TAXMOY to its proper level while keeping unchanged the distribution across destinations
$TAXMOY_{i,r,t}$	Average export tax rate across the various destinations

4 Equations of the model

4.1 Supply

Determination of supply results from the following optimization programs:

Leontieff relation between value added and intermediate consumption:

Imperfect competition

$$\min NB_{i,r,t} P^{Y}_{i,r,t}(Y_{i,r,t} + cf_{i,r}) = P^{VA}_{i,r,t} VA_{i,r,t} + P^{CNTER}_{i,r,t} CNTER_{i,r,t} \tag{1}$$

$$\text{s.t.} \quad NB_{i,r,t}(Y_{i,r,t} + cf_{i,r}) = a^{VA}_{i,r} VA_{i,r,t} = a^{CNTER}_{i,r} CNTER_{i,r,t} \tag{2}$$

Perfect competition

$$\min P^{Y}_{i,r,t} Y_{i,r,t} = P^{VA}_{i,r,t} VA_{i,r,t} + P^{CNTER}_{i,r,t} CNTER_{i,r,t} + P^{Quota}_{i,r,t} Quota_{i,r,t} \tag{3}$$

$$\text{s.t.} \quad Y_{i,r,t} = a^{VA}_{i,r} VA_{i,r,t} = a^{CNTER}_{i,r} CNTER_{i,r,t} \tag{4}$$

For sectors where quotas hold (perfect competition only):

$$Y_{i,r,t} = Quota_{i,r,t} \tag{5}$$

Factor demand

$$\min P^{VA}_{i,r,t} VA_{i,r,t} = P^{L}_{i,r,t} L_{i,r,t} + P^{Q}_{i,r,t} Q_{i,r,t} + P^{TE}_{i,r,t} TE_{i,r,t} + P^{RN}_{i,r,t} RN_{i,r,t} \tag{6}$$

s.t. (CES option)

$$\left(\frac{VA_{i,r,t}}{PGF_{r,t}}\right)^{1-\frac{1}{\sigma_{VA_i}}} = a^{L}_{i,r} L_{i,r,t}^{1-\frac{1}{\sigma_{VA_i}}} + a^{Q}_{i,r} Q_{i,r,t}^{1-\frac{1}{\sigma_{VA_i}}} + a^{RN}_{i,r} RN_{i,r,t}^{1-\frac{1}{\sigma_{VA_i}}} + a^{TE}_{i,r} TE_{i,r,t}^{1-\frac{1}{\sigma_{VA_i}}} \tag{7}$$

or s.t. (Cobb-Douglas option)

$$VA_{i,r,t} = A_{i,r} PGF_{r,t} L_{i,r,t}^{\gamma^{L}_{i,r}} Q_{i,r,t}^{\gamma^{Q}_{i,r}} TE_{i,r,t}^{\gamma^{TE}_{i,r}} RN_{i,r,t}^{\gamma^{RN}_{i,r}} \tag{7'}$$

and

$$\min P^{Q}_{i,r,t} Q_{i,r,t} = P^{K}_{i,r,t} KTOT_{i,r,t} + P^{H}_{i,r,t} H_{i,r,t} \tag{8}$$

$$\text{s.t.} \quad Q_{i,r,t}^{1-\frac{1}{\sigma_{CAP_i}}} = a^{K}_{i,r} KTOT_{i,r,t}^{1-\frac{1}{\sigma_{CAP_i}}} + a^{H}_{i,r} H_{i,r,t}^{1-\frac{1}{\sigma_{CAP_i}}} \tag{9}$$

The capital stock in region s is described by:

$$KTOT_{i,s,t} = \sum_{r} K_{i,r,s,t} \tag{10}$$

Comment: in this model, production quotas have been introduced. For the associated sectors, production is equal to the quota and an additional income, equal to $P^{Quota}_{i,r,t} Quota_{i,r,t}$, is drawn from the quota.

4.2 Demand

Determination of supply results from the following optimization programs:

LES-CES (first stage)

$$\min P_{r,t} UT_{r,t} = \sum_{i} P^{C}_{i,r,t} (C_{i,r,t} - cmin_{i,r}) \tag{11}$$

$$\text{s.t.} \quad UT_{r,t}^{1-\frac{1}{\sigma_C}} = \sum_{i} a^{C}_{i,r} (C_{i,r,t} - cmin_{i,r})^{1-\frac{1}{\sigma_C}} \tag{12}$$

$$BUDC_{r,t} = \sum_{i} P^{C}_{i,r,t} C_{i,r,t} \tag{13}$$

$$P^{C}_{i,r,t} = P^{DEMTOT}_{i,r,t} (1 + taxcc_{i,r}) \tag{14}$$

$$P^{KG}_{i,r,t} = P^{DEMTOT}_{i,r,t} (1 + taxkgc_{i,r}) \tag{15}$$

$$DEMTOT_{i,r,t} = C_{i,r,t} + \sum_{j} IC_{i,j,r,t} + KG_{i,r,t} \tag{16}$$

Groups of regions (second stage)

$$\min P^{DEMTOT}_{i,r,t} DEMTOT_{i,r,t} = P^{DEMU}_{i,r,t} DEMU_{i,r,t} + P^{DEMV}_{i,r,t} DEMV_{i,r,t} \tag{17}$$

$$\text{s.t.} \quad DEMTOT_{i,r,t}^{1-\frac{1}{\sigma_{GEO_i}}} = a^{DEMU}_{i,r} DEMU_{i,r,t}^{1-\frac{1}{\sigma_{GEO_i}}} + a^{DEMV}_{i,r} DEMV_{i,r,t}^{1-\frac{1}{\sigma_{GEO_i}}} \tag{18}$$

Armington (third stage)

$$\min P^{DEMU}_{i,r,t} DEMU_{i,r,t} = P^{D}_{i,r,t} D_{i,r,t} + P^{M}_{i,r,t} M_{i,r,t} \tag{19}$$

$$\text{s.t.} \quad DEMU_{i,r,t}^{1-\frac{1}{\sigma_{ARM_i}}} = a^{DEM}_{i,r} D_{i,r,t}^{1-\frac{1}{\sigma_{ARM_i}}} + a^{M}_{i,r} M_{i,r,t}^{1-\frac{1}{\sigma_{ARM_i}}} \tag{20}$$

Regions (fourth stage)
For foreign regions with the same level of development:

$$\min P^{M}_{i,s,t} M_{i,s,t} = \sum_{r \in U(s)} P^{DEM}_{i,r,s,t} DEM_{i,r,s,t} \tag{21}$$

$$\text{s.t.} \quad M_{i,s,t}^{1-\frac{1}{\sigma_{IMP_i}}} = \sum_{r \in U(s)} a^{IMP}_{i,r,s} DEM_{i,r,s,t}^{1-\frac{1}{\sigma_{IMP_i}}} \tag{22}$$

For foreign regions with different levels of development:

$$\min P^{DEMV}_{i,s,t} DEMV_{i,s,t} = \sum_{r \in V(s)} P^{DEM}_{i,r,s,t} DEM_{i,r,s,t} \tag{23}$$

$$\text{s.t.} \quad DEMV_{i,s,t}^{1-\frac{1}{\sigma_{IMP_i}}} = \sum_{r \in V(s)} a^{IMP}_{i,r,s} DEM_{i,r,s,t}^{1-\frac{1}{\sigma_{IMP_i}}} \tag{24}$$

Varieties (fifth stage)

$$DEMVAR_{i,r,s,t} = DEM_{i,r,s,t} NB_{i,r,t}^{1-\frac{1}{\sigma_{VAR_i}}} \tag{25}$$

$$P^{DEM}_{i,r,s,t} = P^{DEMVAR}_{i,r,s,t} NB_{i,r,t}^{1-\frac{1}{\sigma_{VAR_i}}} \tag{26}$$

$$DVAR_{i,s,t} = D_{i,s,t} NB_{i,s,t}^{1-\frac{1}{\sigma_{VAR_i}}} \tag{27}$$

$$P^{D}_{i,s,t} = P^{DVAR}_{i,r,t} NB_{i,s,t}^{1-\frac{1}{\sigma_{VAR_i}}} \tag{28}$$

Intermediate consumption

$$P^{IC}_{i,j,r,t} = P^{DEMTOT}_{i,r,t}(1 + taxicc_{i,j,r}) \tag{29}$$

$$\min P^{CNTER}_{j,r,t} CNTER_{j,r,t} = \sum_{i} P^{IC}_{i,j,r,t} IC_{i,j,r,t} \tag{30}$$

$$\text{s.t.} \quad CNTER_{j,r,t}^{1-\frac{1}{\sigma_{IC}}} = \sum_{i} a^{IC}_{i,j,r} IC_{i,j,r,t}^{1-\frac{1}{\sigma_{IC}}} \tag{31}$$

Capital good

$$\min P^{INVTOT}_{r,t} INVTOT_{r,t} = \sum_{i} P^{KG}_{i,r,t} KG_{i,r,t} \tag{32}$$

$$\text{s.t.} \quad INVTOT_{r,t}^{1-\frac{1}{\sigma_{KG}}} = \sum_{i} a^{KG}_{i,r} KG_{i,r,t}^{1-\frac{1}{\sigma_{KG}}} \tag{33}$$

Commodity market equilibrium

Imperfect competition

$$Y_{i,r,t} = DVAR_{i,r,t} + \sum_s DEMVAR_{i,r,s,t} \tag{34}$$

$$TRADE_{i,r,s,t} = NB_{i,r,t} DEMVAR_{i,r,s,t} \tag{35}$$

Perfect competition

$$Y_{i,r,t} = D_{i,r,t} + \sum_s DEM_{i,r,s,t} \quad (i \notin TrT) \tag{36}$$

$$Y_{i_{TrT},r,t} = D_{i_{TrT},r,t} + \sum_s DEM_{i_{TrT},r,s,t} + TRM_{i_{TrT},r,t} \tag{37}$$

$$TRADE_{i,r,s,t} = DEM_{i,r,s,t} \tag{38}$$

Transport sector

Transport demand

$$TR_{i,r,s,t} = \mu_{i,r,s} TRADE_{i,r,s,t} \tag{39}$$

$$MONDTR_t = \sum_{i,r,s} TR_{i,r,s,t} \tag{40}$$

Transport supply

$$P^Y_{i_{TrT},r,t}(1 + taxp_{i_{TrT},r})\, TRM_{i_{TrT},r,t} = \theta_{i_{TrT},r} P^T_t MONDTR_t \tag{41}$$

$$MONDTR_t = a^T \prod_r TRM_{i_{TrT},r,t}{}^{\theta_{i_{TrT},r}} \tag{42}$$

4.3 Factor market

Labour market

Developed countries: labour allocation between agricultural and non agricultural sectors

$$L^{Agri}_{r,t} = b^{L^{Agri}}_r \overline{L}_{r,t} \left(\frac{P^{L^{Agri}}_{r,t}}{P^{\overline{L}}_{r,t}} \right)^{\sigma_L} \tag{43}$$

$$L^{notAgri}_{r,t} = b^{L^{notAgri}}_r \overline{L}_{r,t} \left(\frac{P^{L^{notAgri}}_{r,t}}{P^{\overline{L}}_{r,t}} \right)^{\sigma_L} \tag{44}$$

Developing countries: dual labour market

$$P^{L^{Agri}}_{r,t}\left(1+\frac{RECTAX_{r,t}-RECTAX_{r,t_0}}{REV_{r,t}-RECTAX_{r,t}}\right)=P^{L^{Agri}}_{r,t_0}\prod_i\left(\frac{P^C_{i,r,t}}{P^C_{i,r,t_0}}\right)^{\frac{P^C_{i,r,t_0}C_{i,r,t_0}}{\sum_j P^C_{j,r,t_0}C_{j,r,t_0}}} \tag{45}$$

$$L^{Agri}_{r,t}+L^{notAgri}_{r,t}=\overline{L}_{r,t} \tag{46}$$

Labour market (both cases)

$$P^{\overline{L}}_{r,t}\overline{L}_{r,t}=P^{L^{Agri}}_{r,t}L^{Agri}_{r,t}+P^{L^{notAgri}}_{r,t}L^{notAgri}_{r,t} \tag{47}$$

Land market

$$W^{TE}_{i,r,t}=P^{TE}_{r,t}+P_{r,t}\,TsubTE_{i,r,t} \tag{48}$$

Land supply

$$W^{\overline{TE}}_{r,t}\overline{TE}_{r,t}=\sum_i W^{TE}_{i,r,t}TE_{i,r,t} \tag{49}$$

$$\overline{TE}_{r,t}=\overline{TE}_{r,t_0}\left(W^{\overline{TE}}_{r,t}\right)^{\sigma_{\overline{TE}}}\quad (\mathrm{NB}: W^{\overline{TE}}_{r,t_0}=1) \tag{50}$$

Land allocation

$$TE_{i,r,t}=b^{TE}_{i,r}\overline{TE}_{r,t}\left(\frac{W^{TE}_{i,r,t}}{W^{\overline{TE}}_{r,t}}\right)^{\sigma_{TE}} \tag{51}$$

Full use of factor endowments

$$L^{Agri}_{r,t}=\sum_{j\in Agri(j)}L_{j,r,t} \tag{52}$$

$$L^{notAgri}_{r,t}=\sum_{j\notin Agri(j)}L_{j,r,t} \tag{53}$$

$$\overline{TE}_{r,t}=\sum_j TE_{j,r,t} \tag{54}$$

$$\overline{H}_{r,t}=\sum_j H_{j,r,t} \tag{55}$$

Comments:

- In comparison to the standard model, the agricultural version distinguishes between two types of unskilled labour: agricultural labour and non agricultural labour. A partial mobility between these two types of labours is allowed through a Constant Elasticity of Transformation supply function. Within each category, labour is perfectly mobile.
- A duality of labour has been assumed in developing countries: an efficiency wage scheme determines the level of wages in non agricultural sectors and the corresponding labour demand, and labour supply in agricultural sectors is computed as a residual. The efficiency wage is set such that the purchasing power of non agricultural wages, including tax receipts so that fiscal policy do not affect the results, remains unchanged after the shock.

4.4 Revenues

For imperfectly competitive sectors:

$$\begin{aligned} 0 =& P^{Y}_{i,r,t}\left(NB_{i,r,t}\sum_{s}\frac{DEMVAR_{i,r,s,t}}{1+EP_{i,r,s,t}}+\frac{NB_{i,r,t}DVAR_{i,r,t}}{1+EPD_{i,r,t}}\right) \\ &-(P^{VA}_{i,r,t}VA_{i,r,t}+P^{CNTER}_{i,r,t}CNTER_{i,r,t}) \end{aligned} \quad (56)$$

Comment: this corresponds to the zero profit condition allowing to compute the number of firms.

Tax revenue from imperfectly competitive sectors

$$RECPROD_{i,r,t} = taxp_{i,r}P^{Y}_{i,r,t}\left(NB_{i,r,t}\sum_{s}\frac{DEMVAR_{i,r,s,t}}{1+EP_{i,r,s,t}}+\frac{NB_{i,r,t}DVAR_{i,r,t}}{1+EPD_{i,r,t}}\right) \quad (57)$$

$$\begin{aligned} RECEXP_{i,r,t} =& (1+taxp_{i,r})P^{Y}_{i,r,t}NB_{i,r,t} \\ &*\sum_{s}(TAXEXP_{i,r,s,t}+taxAMF_{i,r,s,t})\frac{DEMVAR_{i,r,s,t}}{1+EP_{i,r,s,t}} \end{aligned} \quad (58)$$

Tax revenue from perfectly competitive sectors

$$RECPROD_{i,r,t} = taxp_{i,r}P^{Y}_{i,r,t}Y_{i,r,t} \quad (59)$$

$$\begin{aligned} RECEXP_{i,r,t} =& (1+taxp_{i,r})P^{Y}_{i,r,t} \\ &*\sum_{s}(TAXEXP_{i,r,s,t}+taxAMF_{i,r,s,t})TRADE_{i,r,s,t} \end{aligned} \quad (60)$$

For both sectors

$$RECDD_{i,r,t} = \sum_r DD_{i,r,s,t} P^{CIF}_{i,r,s,t} TRADE_{i,r,s,t} \tag{61}$$

$$RQUOTA_{r,s,t} = \sum_{i \in TQUOTAO} TQUOTA_{i,r,s,t} P^{CIF}_{i,r,s,t} TRADE_{i,r,s,t} \tag{62}$$

$$\begin{aligned} RECCONS_{i,s,t} = {} & P^{DEMTOT}_{i,s,t}(taxcc_{i,s} C_{i,s,t} + taxkgc_{i,s} KG_{i,s,t} \\ & + \sum_j taxicc_{i,j,s,t} IC_{i,j,s,t}) \end{aligned} \tag{63}$$

$$\begin{aligned} RECTAX_{r,t} = {} & \sum_i RECPROD_{i,r,t} + RECEXP_{i,r,t} \\ & + RECDD_{i,r,t} + RECCONS_{i,r,t} \end{aligned} \tag{64}$$

Savings

$$BUDC_{r,t} = (1 - epa_r) REV_{r,t} \tag{65}$$

Factor mobility

$$P^L_{i,r,t} = P^{L^{Agri}}_{r,t} \qquad (i \in Agri(i)) \tag{66}$$

$$P^L_{i,r,t} = P^{L^{notAgri}}_{r,t} \qquad (i \notin Agri(i)) \tag{67}$$

$$P^{TE}_{i,r,t} = P^{\overline{TE}}_{r,t} \tag{68}$$

$$P^H_{i,r,t} = P^{\overline{H}}_{r,t} \tag{69}$$

4.5 Prices definition

Sale price (imperfect competition)

$$P^{DEMVAR}_{i,r,s,t} = P^{CIF}_{i,r,s,t}(1 + DD_{i,r,s,t}) \tag{70}$$

$$P^{DVAR}_{i,r,t} = \frac{P^Y_{i,r,t}(1 + taxp_{i,r})}{1 + EPD_{i,r,t}} \tag{71}$$

CIF price (imperfect competition)

$$P^{CIF}_{i,r,s,t} = (1 + taxp_{i,r})(1 + TAXEXP_{i,r,s,t} + taxAMF_{i,r,s,t}) \frac{P^Y_{i,r,t}}{1 + EP_{i,r,s,t}} + \mu_{i,r,s} P^T_t \tag{72}$$

Sale price (perfect competition)

$$P^{DEM}_{i,r,s,t} = P^{CIF}_{i,r,s,t}(1 + DD_{i,r,s,t}) \tag{73}$$

$$P^{D}_{i,r,t} = P^{Y}_{i,r,t}(1 + taxp_{i,r}) \tag{74}$$

CIF price (perfect competition)

$$P^{CIF}_{i,r,s,t} = (1 + taxp_{i,r})(1 + TAXEXP_{i,r,s,t} + taxAMF_{i,r,s,t})P^{Y}_{i,r,t} + \mu_{i,r,s}P^{T}_{t} \tag{75}$$

4.6 Imperfect competition

Determination of market shares

$$SDU_{i,s,t} = \frac{P^{D}_{i,s,t}D_{i,s,t}}{P^{DEMU}_{i,s,t}DEMU_{i,s,t}} \tag{76}$$

$$SDT_{i,s,t} = \frac{P^{D}_{i,s,t}D_{i,s,t}}{P^{DEMTOT}_{i,s,t}DEMTOT_{i,s,t}} \tag{77}$$

$$SE_{i,r,s,t} = \frac{P^{DEM}_{i,r,s,t}DEM_{i,r,s,t}}{P^{M}_{i,s,t}M_{i,s,t}} \tag{78}$$

$$SU_{i,r,s,t} = \frac{P^{DEM}_{i,r,s,t}DEM_{i,r,s,t}}{P^{DEMU}_{i,s,t}DEMU_{i,s,t}} \tag{79}$$

$$SV_{i,r,s,t} = \frac{P^{DEM}_{i,r,s,t}DEM_{i,r,s,t}}{P^{DEMV}_{i,s,t}DEMV_{i,s,t}} \tag{80}$$

$$Sh_{i,r,s,t} = \frac{P^{DEM}_{i,r,s,t}DEM_{i,r,s,t}}{P^{DEMTOT}_{i,s,t}DEMTOT_{i,s,t}} \tag{81}$$

Mark-up in domestic markets

$$NB_{i,r,t}(EPD_{i,r,t} + \frac{1}{\sigma_{VAR_i}}) = \left[\frac{1}{\sigma_{VAR_i}} - \frac{1}{\sigma_{ARM_i}}\right] + \left[\frac{1}{\sigma_{ARM_i}} - \frac{1}{\sigma_{GEO_i}}\right] SDU_{i,r,t} + \left[\frac{1}{\sigma_{GEO_i}} - \frac{1}{\sigma_{C_i}}\right] SDT_{i,r,t} \tag{82}$$

Mark-up in foreign markets in countries with the same level of development

$$NB_{i,r,t}(EP_{i,r,s,t} + \frac{1}{\sigma_{VAR_i}}) = \left[\frac{1}{\sigma_{VAR_i}} - \frac{1}{\sigma_{ARM_i}}\right] + \left[\frac{1}{\sigma_{IMP_i}} - \frac{1}{\sigma_{ARM_i}}\right] SE_{i,r,s,t} + \left[\frac{1}{\sigma_{ARM_i}} - \frac{1}{\sigma_{GEO_i}}\right] SU_{i,r,s,t} + \left[\frac{1}{\sigma_{GEO_i}} - \frac{1}{\sigma_{C_i}}\right] Sh_{i,r,s,t} \tag{83}$$

Mark-up in foreign markets in countries with different levels of development

$$NB_{i,r,t}(EP_{i,r,s,t} + \frac{1}{\sigma_{VAR_i}}) = \left[\frac{1}{\sigma_{VAR_i}} - \frac{1}{\sigma_{ARM_i}}\right] + \left[\frac{1}{\sigma_{IMP_i}} - \frac{1}{\sigma_{GEO_i}}\right] SV_{i,r,s,t} + \left[\frac{1}{\sigma_{GEO_i}} - \frac{1}{\sigma_{C_i}}\right] Sh_{i,r,s,t} \quad (84)$$

4.7 Intervention price scheme (European Union)

Mode 0: no subsidy change

$$TAXEXP_{i,r,s,t} = TAXEXP_{i,r,s,t_0} \quad (85)$$

Mode 1: no subsidy

$$TAXEXP_{i,r,s,t} = 0 \quad (86)$$

Mode 2: perfect competition

$$P^{Y}_{i,r_{EU},t} = P^{Int}_{i,r,t} \quad (87)$$

Mode 2: imperfect competition

$$\sum_s \frac{P^{Y}_{i,r,t}}{1 + EP_{i,r,s,t}} TRADE_{i,r,s,t} = P^{Int}_{i,t} \sum_s TRADE_{i,r,s,t} \quad (88)$$

Mode 3: subsidized exports ceiling

$$\sum_{s \neq r} TRADE_{i,r,s,t} = MaxExpSub_{i,r,t} \quad (89)$$

Mode 2 or 3, or subsidy change and subsidy for at least one destination before the change

$$TAXEXP_{i,r,s,t} = TAXREF_{i,r,t}\, TAXEXP_{i,r,s,t_0} \quad (90)$$

Mode 2 or 3, or subsidy change and no subsidy for all destinations before the change

$$TAXEXP_{i,r,s,t} = TAXMOY_{i,r,t} \quad (91)$$

Mode 2 or 3, or subsidy change

$$TAXMOY_{i,r,t} \sum_{s \neq r} TRADE_{i,r,s,t} = \sum_{s \neq r} TAXEXP_{i,r,s,t}\, TRADE_{i,r,s,t} \quad (92)$$

Comments:

The intervention price scheme in the EU is modeled as follows: as soon as the internal price becomes lower than the intervention price, the EU subsidies exports so as to raise the internal price to the level of the intervention price. In actual facts, the EU also increases inventories but inventories are not accounted for Mirage.

In practice, the price scheme is divided into 4 possible modes:

- For countries other than the EU or sectors not concerned by intervention prices, the subsidy rate is exogenous.
- When the intervention price is lower than the internal price, there is no export subsidy.
- When the intervention price would be higher than the internal price, the export subsidy rate is endogenous. The distribution across importers is the same as in the baseline. If there was no subsidy in the baseline, this distribution is homogenous.
- The subsidization of exports is limited by a maximum of subsidized exports from the WTO. If this limit is reached, then this constraint replaces the price constraint.

When a simulation is complete, the model checks if the constraints defining a mode still hold. If they do not, then the mode is changed automatically until there is no more necessary change.

4.8 Investment

$$INV_{i,r,s,t} = a_{i,r,s} B_{r,t} KTOT_{i,s,t}\, \mathrm{e}^{\alpha W^K_{i,s,t}} \tag{93}$$

$$W^K_{i,r,t} = P^K_{i,r,t} + P_{r,t}\, TsubK_{i,r,t} \tag{94}$$

$$INVTOT_{s,t} = \sum_{i,r} INV_{i,r,s,t} \tag{95}$$

4.9 Regional equilibrium

$$GDPVOL_{r,t} * P^{CIndex}_{r,t} = REV_{r,t} + PIBMVAL_t * SOLD_{r,t} \tag{96}$$

$$\text{with} \quad P^{CIndex}_{r,t} = \prod_i \left(\frac{P^C_{i,r,t}}{P^C_{i,r,t_0}} \right)^{\frac{P^C_{i,r,t_0} C_{i,r,t_0}}{\sum_j P^C_{j,r,t_0} C_{j,r,t_0}}} \tag{97}$$

$$\begin{aligned} GDPVOL_{r,t} * P^{CIndex}_{r,t} = & \sum_s (RQUOTA_{r,s,t} - RQUOTA_{s,r,t}) \\ & + RECTAX_{r,t} + \sum_i P^{RN}_{i,r,t} RN_{i,r,t} + \sum_{i,s} (P^K_{i,r,s,t} K_{i,r,s,t}) \\ & + \overline{L}_{r,t} P^{\overline{L}_{r,t}} + \overline{TE}_{r,t} P^{\overline{TE}}_{r,t} + \overline{H}_{r,t} P^{\overline{H}}_{r,t} \end{aligned} \tag{98}$$

$$epa_r REV_{r,t} = \sum_{i,s} P^{INVTOT}_{s,t} INV_{i,r,s,t} \tag{99}$$

$$PIBMVAL_t = \sum_{i,r} PVA_{i,r,t} VA_{i,r,t} \tag{100}$$

4.10 Dynamics

$$K_{i,r,s,t} = K_{i,r,s,t-1}(1 - \delta) + INV_{i,r,s,t} \tag{101}$$

$$\overline{L}_{r,t} = \rho_r \overline{L}_{r,t-1} \tag{102}$$

$$\overline{H}_{r,t} = \rho_r \overline{H}_{r,t-1} \tag{103}$$