Adding mirror clauses within the European Green Deal: Hype or hope?

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Abstract:

With the Green Deal, Europe intends to increase the sustainability of its food system. However the proposed reductions of farm input uses may further penalize European farm productions and incomes while increasing environmental leakages to foreign countries where production may expand. These expected impacts have led to an ex ante unlikely alliance between farm organisations and environmental NGOs calling for a more restrictive trade policy with mirror clauses. The European Commission responds with a cautious report on these clauses, arguing that cost benefit analysis should first be performed on case studies. The purpose of this paper is to contribute to this general objective, considering a potential ban of glyphosate in vegetable and fruits productions as a first case study. We develop an original computable general equilibrium model with endogenous adoption of new European production standards by foreign producers on currently latent markets. The results obtained from our original model significantly differ from those obtained from a standard approach. We find in our case study that the addition of mirror clauses to the Green Deal will marginally improve the European farm income and the global environmental footprint of food. We also find that foreign producers as a whole will gain from these clauses and not lose as a standard analysis does quantify. European households will mostly support these clauses by paying higher food bills while enjoying glyphosate-free vegetables and fruits.

Keywords: Green Deal, Trade Policy, Glyphosate

The European Green Deal and its implementation in the agro-food sector, the Farm to Fork and associated strategies, sets ambitious targets to reduce agricultural Greenhouse Gas emissions and increase carbon sequestration. It also intends to reduce use of chemical inputs and associated pollutions, and to reverse the decline in biodiversity by setting aside agricultural area for nature and encouraging more extensive forms of farming such as organic agriculture.

Several impact studies have already assessed the consequences for agricultural productions and farm incomes in Europe as well as the impacts on global markets of several of the measures making up the Farm to Fork Strategy (Wesseler, 2022). While these studies have been criticised for their partial implementation of the measures that make up the Strategy or for failing to adequately capture potential productivity gains due to redirecting innovation (Barreiro-Hurle et al. 2021; Candel 2022), there is a broad consensus that fully implementing the Strategy by 2030 would mean lower EU production relative to a baseline. There is also consensus on a higher level of net EU imports and thus the potential for environmental leakages to those countries where production will expand. On the other hand, there is greater disagreement among these studies over the likely impacts on farm incomes, depending on whether price effects compensate for quantity effects.

These likely impacts have led to an ex ante unlikely alliance between farm organisations and environmental NGOs calling for a more restrictive trade policy with mirror clauses to accompany implementation of the Green Deal (Baldon et al., 2021). The principal aim of mirror measures is to make market access conditional to compliance with domestic environmental, animal welfare or health standards and regulations. Farm organisations likely seek to offset the potential loss of competitiveness vis à vis third country exporters by calling for a level playing field, where imports would be required to meet the same standards as applied to EU producers. Environmental NGOs also support a more restrictive trade policy because it would help to avoid an increase in imports and thus the export of the environmental footprint of production to countries where it is assumed lower standards are in place. Environmental leakage of this kind could even lead to an increase in global emissions, in the use of polluting chemical inputs or in the global quantum of animal suffering despite the raising of standards in the EU.

While the idea of introducing mirror clauses was already debated in the EU during the last reform of the Common Agricultural Policy (CAP) and during EU bilateral trade negotiations, it gains significant impetus with the publication of the Green Deal roadmap. The French presidency of the European Union during the first semester of 2022 ranked these clauses as the top priority for the agricultural sector. Following a previous request by the European Council and Parliament, the European Commission (EC, 2022) delivers a cautious view on these clauses. On one hand, it argues that "*there is some scope to extend to imported products EU production standards*". On the other hand, it immediately mentions that this is possible "*provided this is done in full respect of the relevant WTO rules*." Mirror measures can be introduced in bilateral free trade agreements or imposed unilaterally through EU domestic laws. In this last case, these mirror measures can be challenged by other countries under the WTO dispute settlement system if these countries consider them to be illegitimate or protectionist and inconsistent with the EU's international obligations. Moreover, the EC warns that "*In addition to the question of WTO compatibility, the case-by-case analysis of possible measures needs also to take into account the technical and economic feasibility of control mechanisms. Since it is the methods of production or processing in the third country that are being regulated, the feasibility and proportionality of adequate means to control and enforce their application must be assessed in relation to costs and benefits of doing so.*" In other words, the EC recommands performing ex ante legal and economic Cost Benefit Analysis (CBA) of potential mirror clauses, which is a position also shared by academics/experts (Lamy et al., 2022 ; Matthews, 2022). To our knowledge, no such CBA have been conducted so far on potentially new production standards implemented in the EU.

Accordingly, our main objective in this paper is to provide quantitative figures to perform such CBA of a potential new EU production standard. We consider the potential ban of glyphosate use in the vegetable and fruit (v&f) sectors. The choice of this case study is motivated in the immediately following section. The next section provides a targeted literature review of economic studies and methodologies assessing the effects of production standards. This section reveals some methodological gaps, justifying the development of an original economic model. The third section explains the specification of our original model and its calibration to our case study. The fourth section is devoted to scenario analyses.

1. Our case study: glyphasote use in the vegetable and fruit sectors

Glyphosate is the most frequently used active substance, both worldwide and in the EU, to combat weeds that compete with cultivated crops. Glyphosate-based pesticides are also used as a pre-harvest treatment to facilitate better harvesting by regulating plant growth and ripening. The main benefits of glyphosate-based pesticides advanced by their proponents (see https://www.glyphosate.eu/) are to facilitate better growth of crops and hence contribute to food security, as well as to eliminate or minimise the use of ploughing, thereby reducing soil erosion and carbon emissions (conditionally on current crop acreages). On the other hand, opponents of glyphosate-based pesticides (see https://www.pan-europe.info/) highlight their damaging impacts on human health and ecosystems (directly and indirectly by favouring current crop acreages towards grain production to the detriment of pastures).

The current EU approval of glyphosate expires end of 2022. Glyphosate is recognized as an active substance which can cause serious eye damage to glyphosate applicants and is toxic to aquatic life but it is not deemed to be carcinogenic. Moreover, when used according to good agricultural practices, it does not pose an unacceptable risk to the environment. Accordingly, this active substance is currently approved at the EU level while EU Member States are responsible for the authorisation and use on their territories of glyphosate-based pesticides. This division of responsibility is based on the principle of subsidiarity and reflects differences in climatic, agronomic and environmental conditions in Member States. It should be added that for a non approved active substance, a Member State can still authorize its use for a limited period of 120 days by way of derogation. Imports of foods with residues of this active substance by way of import tolerances can also be permitted. Such import tolerances can be granted provided the reason for non-approval in the EU is not related to the protection of consumer health and provided a risk assessment is undertaken by the European Food Safety Agency (EFSA) to show that the proposed import tolerance is not a risk to consumer health.

So far, only Luxembourg implements a complete ban on glyphosate use in its farming sectors from 2020. The Austrian parliament voted a similar ban in 2019 but the government did not implement it. France defined in 2017 the ambitious goal of banning glyphosate from 2020 onwards. This objective was later softened, with only some new restrictions on farm and non-farm applications. This decision was justified by the fear of competitiveness loss of French farmers with respect to their European competitors.

Active substances are normally approved at the EU level for a 15 year period. Glyphosate use was approved in 2017 for a 5 year period only, in order to take later into account the insights of newly launched studies assessing its health and environmental effects. This literature is so vast and growing so fast that the EFSA requires more time to review it, delaying by minimum one year the decision on the eventual re-approval of glyphosate at the EU level. In addition to scientific uncertainties, there are also policy uncertainties linked to the future positions of the different policy makers, both at the EU and member state levels. So far only the European parliament officially asked in 2021 for a complete phase out of glyphosate use in farm sectors.

Glyphosate use is under scrutiny not only in EU countries but in most countries in the world. This is partly linked to the declaration in 2015 by the International Agency for Research on Cancer (IARC) that glyphosate is a possible human carcinogen. Focusing on the US case, glyphosate-based Roundup manufacturer Monsanto (then purchased by Bayer) has since been battling thousands of lawsuits alleging that the product caused non-Hodgkin's lymphoma. Similar to the EU case, a growing number of US states and cities have been restricting or outright banning the use of glyphosate but the US federal government currently maintains that glyphosate can be used. There is the additional concern in the US that the resistance of weeds to glyphosate increases, lowering the private and social values of glyphosate (Van Deynze et al., 2022).

We are not in position to anticipate which countries will move first to a potential ban on glyphosate, if any. With the Green Deal, the EC indicates that it wants to lead the change towards greening our economies, with the hope that other regions will follow the EU example. In this context, an ex ante analysis of a first EU glyphosate ban is therefore appropriate.

Glyphosate is used for many crop productions but we focus our analysis on the vegetable and fruit sectors for the following reasons. First, imposing a ban on an active substance requires the ability to control its effective absence in products sold on the internal market. The EU Regulation (EC) No. 396/2005 on pesticides residues defines how maximum residue levels (MRLs) for active substances are set . MRLs are established solely on health grounds and do not consider environmental risks (which is required when approving an active substance). Each year, the EFSA and related Member States agencies control for the presence of approved and unapproved active substances. This procedure is performed particularly on vegetable and fruit products because they are often directly consumed by households and past controls reveal that samples can exceed the relevant MRL. This means that the technical feasibility mentioned by the EC in its cautious view on mirror clauses should not be a problem.

Second, there are growing pressures across all EU Member States to increase vegetable and fruits consumption and to reduce animal protein consumption (see e.g. https://www.tappcoalition.eu/). This shift in consumption is presented as a way to improve the sustainability of the food system, tackling simultaneously the climate, environmental and public health challenges. Even if the Green Deal roadmap does not explicitly include provisions to encourage plant-based diets, assuring EU consumers of the absence of residues of controversial active substances in these products could be one way to encourage consumption. Residues from all pesticides are currently detected in around 45 per cent of controlled samples of food products and MRLs are not satisfied in 5 per cent of these samples (EFSA, 2020). Among all active substances, glyphosate residues are currently detected in around 2 per cent of the controlled food products, with exceedance of the MRL by less than 0.6 per cent. The highest occurrence of exceedance is observed on dry lentils which are a flagship product of the green transition. Banning the use of glyphosate in vegetable and fruit production may be a measure implemented to sustain the consumption of these products and may be a compromise between a simple renewal of glyphosate authorisation and a complete ban of glyphosate.

The choice of our case study is finally also dictated by data considerations. Other mirror clauses are also under scrutiny, such as the antibiotic uses in animal productions and neonicotinoid insecticides in many crop productions (see https://capreform.eu/). But technical and economic data required to perform CBA for these potential mirror clauses are currently less available.

2. Literature review

The economic literature assessing the market effects of agricultural production standards and associated trade measures is large and vivid. We can first split the numerous studies between ex post and ex ante analyses. The former are relevant to identify the causal effects of policy measures, which eventually lead policy makers to alter their initial policy decisions. Many ex post analyses rely on public trade data, such as Karemera et al. (2020) who focus on the trade flows of vegetables and fruits between the US and EU, taking into account their current differences in food safety standards and sanitary and phytosanitary regulations. These authors deployed micro-econometric gravity models and probit equations and found that if both regions endorse the international MRLs, this would boost US exports of fruits and vegetables to the EU by 14 per cent. These ex post analyses are also useful to understand the political economy of the production standards and associated trade measures. In this respect, Karemera et al. (2021) find that countries spending more on public health set more restrictive MRLs. These authors also show that countries possessing comparative advantage in fruits and vegetables adopt more lenient MRLs. Finally, products subject to lower tariffs are generally traded with tougher MRLs.

One main challenge of these ex post analyses is to get sufficient detailed time series data to estimate the causal, short and long run, effects of standards on many crucial economic variables. Ex ante analyses are generally less intensive in time series data and consider more economic variables, such as detailed input uses by sectors, farm incomes or consumer expenditures. By definition, these ex ante analyses can only provide simulated, short and long run, effects whose robustness is assessed by performing sensitivity analysis of results to crucial modelling choices.[1]

In the context of our paper, a crucial modelling choice concerns the explicit modelling of the different production standards and related commodity markets upon which economic agents operate. All economic models mobilised to assess the market effects of the Green Deal assume fixed numbers of production technologies and commodity markets[2]. By mostly relying on aggregated data, these models cannot precisely represent the current diversity of production technologies that farmers may implement in their particular (soil, climate) conditions, nor the diversity of farm products sold on differentiated markets. One prominent example is the absence of explicit distinction of the markets of organic products and related technologies in

[1] We underline that ex ante analyses are usually separated between those using Partial Equilibrium (PE) models and those using Computable General Equilibrium (CGE) models. Both types of models are generally built on the same microeconomic economic principles (similar to ex post analyses mentioned above) and mostly diverge on their implementation choices: PE models consider a limited but detailed set of markets and sectors while generally ignoring macroeconomic feedbacks, such as endogenous income effects. The market effects simulated by these two approaches can be indeed similar, depending on the contemplated scenarios.

[2] Hereafter, production technologies and production standards are used interchangeably.

these models, due to the difficulty to gather relevant macroeconomic data. Even more, they are not designed to allow new production standards that may lead to differentiated products valued by consumers, hence new commodity markets.

Economic models simulate the ex ante market and welfare effects of the targeted input reductions of the Green Deal by introducing endogenous levels of input taxes. Simulating input taxes makes sense with these models, provided that parameters of the aggregate production technology are well calibrated (Hertel et al., 1996). But this implementation with input taxes of the Green Deal does not ensure that some undesirable inputs (such as unapproved active substances) are no longer used: the taxes may simply reduce their uses, not removing them. Moreover, the eventual introduction of mirror clauses due to potentially new EU production standards is not a policy measure that requires comparable input taxes in foreign countries who wants to export to the EU. Rather, a mirror clause can be implemented only if the standards can be controlled (such as the absence of a particular active substance in some food products). This means that not all producers in foreign countries may need to comply with the new EU standards, only those willing to export to the EU markets. This likely leads to additional certification and segregation costs in the food chain, as well as different production costs for the different active technologies that are ultimately reflected in different output prices and/or different factor returns.

These different costs have been collected by Beckman et al. (2021) to analyse the trade dispute between the US and EU on cattle fed with growth hormones, a prohibited practice in the EU. These authors simulate the market and welfare effects of the removal of this mirror clause with the Global Trade Analysis Project (GTAP) CGE model. However this model does not differentiate the production technologies used for beef sold on the US market and as exports to the EU. Accordingly they develop an imperfect solution by converting all additional observed costs as export and import taxes between the US and EU. This approach is imperfect as it does not explicitly recognize that the feed efficiencies are different across the two technologies, nor that some US households (as well as households in other countries) may also value and consume hormone free beef cuts (Drouillard, 2018).

Beckman et al. (2022) use the same GTAP model to analyse the choices of non-EU countries to adopt or not the new standards that the EU may implement with the Green Deal. Again these authors do not recognize the possibility that only some producers in non EU countries adopt the new standards and that some non EU households also want to consume products offered by the new production standards. Rather they assume a fixed number of technologies and commodities, and that adopting foreign countries implement input taxes such as to reduce their aggregate input usage while non-adopting ones face a purely ad hoc increase of import taxes to the EU by 50 per cent.

It is possible to overcome this limitation of fixed numbers of technologies and commodities, as is obviously done in the economic literature on new farm technologies. For instance, Sobolevsky et al. (2005) develop a PE model to assess the impacts of regulations on Genetically Modified (GM) crops. They focus on the soybean complex (soybeans, soy oil and soil meal) and examine the market and welfare impacts of a technological innovation that is cost reducing and yield increasing but involves new segregation costs and intellectual property rights. These authors find that, depending on the levels of segregation costs, farmers produce only GM soybeans or both GM and conventional soybeans following the technological innovation. Two types of commodity markets (conventional and GM free) co-exist while only the conventional markets are active before the innovation. The numbers of technologies/markets are endogenous in their model, thanks to the specification of virtual (or "choke") prices in their food demand system.

To our knowledge, this approach with the specification of virtual prices leading to endogenous numbers of both technologies and markets has been implemented to date only in PE settings. Komen and Peerlings (2001) developed a CGE model of the Dutch economy where the number of milk production technologies is endogenous but there is only one single milk market as they all produce a homogenous good. These authors also introduce virtual prices in their milk production specification but assume no substitution between inputs for each of the three potential technologies, thus constraining the supply responses to price. In the next section, we show how to generalize the approach in a CGE setting accounting for endogenous numbers of both technologies and markets and with flexible price responses. The CGE setting allow us to capture cross market and income effects that may be important to consider depending on the simulated policy scenarios.

3. Modelling framework

Our starting modelling framework is the widely used GTAP framework to assess the ex ante market and welfare effects of many policy scenarios (such as trade, environmental, climate, agriculture, climate, fiscal policies). Like Beckman et al. (2021, 2022), we elaborate on the static version, assuming perfect competition in all markets, that producers maximize their profits subject to market and technological constraints, and that households maximise their utility subject to budget constraints. We adopt a medium term horizon, assuming that physical capital is fixed in each sector while other primary factors (whose total supply are fixed) are perfectly mobile across sectors.[3]

We implement this CGE model using the GTAP10A database, which gathers economic flows of the 2014 year. We aggregate the 141 regions in that database in 3 regions only (the EU, US and Rest of the World), which is the maximal aggregation level allowing us to quantify the potential contrasting impacts of mirror clauses while requiring the minimal amount of external data on new standards. We aggregate the 65 sectors/products as Beckman et al. and accordingly only consider the aggregate of v&f.[4] Importantly the GTAP database includes an aggregate "chemical" sector that does not differentiate mineral fertilizers, pesticides and antimicrobials. It means that this database does not provide the amounts of nitrogen or glyphosate or other pesticides that are used in a particular crop activity in a particular region, as these data are not publicly collected in any region. Still some previous authors examine the contribution of glyphosate to agriculture using this framework (Brookes et al., 2017) and we will partly follow their example.

[3] As regards the macroeconomic closures, we assume that per region government expenditures are exogenous, total investment and net capital account per region are fixed (consistently with the assumption of fixed capital in each sector), so that private savings adjust to ensure macroeconomic equilibrium. These assumptions have negligible consequences on the results reported in this paper (Kilkenny and Robinson, 1990).

[4] Chepeliev et al. (2021) develop a supplemental database where the v&f commodity is disaggregated in 79 commodities. The production technology and cost of these commodities are not available, preventing us to analyze the effects of new standards on particular v&f.

3.1. Supply modelling

3.1.a. Issues with the standard approach

The standard approach of crop supply modelling in CGE models is to assume the existence of an aggregate mono-product technology, usually specified with nested Constant Elasticity of Substitution (CES) functions. The choice of substitution elasticities between pairs of inputs is obviously crucial, as it governs price responses of crop supply. This aggregate approach may seem at odds with the diversity of crop management practices that farmers may implement on their farms, which diversity is generally captured in individual farm microeconomic models. However the economic consistency of the aggregate approach was theoretically demonstrated more than half a century ago. Houthakker (1955), then followed by Levhari (1968) and Sato (1969), demonstrates that a CES function at the national level is fully compatible with fixed technologies at the field level. The condition is that one production factor is heterogeneous. This idea has been investigated in the agricultural economic literature. For instance, Hertel *et al.* (1996) show that the aggregate substitution elasticity between land and fertilizer can be significant, even if it is limited at the field level, with soils and climate being heterogeneous factors.

Accordingly this aggregate approach is consistent with the existence of farmers applying different production techniques on their particular (soil/climate) conditions. It captures that some farmers use significant/no amount of a controversial active substance and that they switch from one crop management practice to another one depending on price incentives. On the other hand, this aggregate approach does not fully recognize the potential different qualities of the delivered crop products because they are sold on the same price on domestic/foreign markets. This price is usually an average of the market prices of the different crop qualities. The implicit assumption is that the price differences across these qualities (for instance, between organic and conventional crops) does not change with the contemplated policy scenario. This assumption is unlikely in our case study of a new standard leading to a new product, whose price is initially unknown. We underline that a glyphosate-free v&f is not an organic one, in particular as we do not prohibit the use of other synthetic pesticides or mineral fertilizers.

3.1.b. Our approach

We thus need to develop a more detailed crop supply modelling to account for new production standards delivering new differentiated products. We develop a new specification, inspired by the structural microeconomic approach of Carpentier and Letort (2014). It has already been partly implemented in a reduced form manner in the Global Change Analysis Model (GCAM) PE model (Sands et Leimbach, 2003).and in structural form manner by Bareille and Gohin (2020) in their CGE model, but assuming that the numbers of commodities and technologies are fixed. We extend it to allow for latent production standards and commodity markets, using virtual prices. Below we explain it focusing on the v&f sector, even if it can be implemented for any sector.

We specify a multi-output, multi-input technology for the v&f sector in each country. In the application, we consider only two outputs or activities, hereafter named conventional v&f (short name is conv v&f) and glyphosate-free v&f (short name is gly-free v&f). The first is initially produced in positive quantities while the production of second is initially null in all countries. Two inputs (chemicals and a composite factor used for mechanical weeding) are assumed allocable while other inputs are not. These non allocable inputs are combined (with a standard structure of nested CES functions) by an assembly subprocess to produce an assembly output that is used as intermediate inputs by our two activities. This kind of separability assumptions has already been specified in CGE models (Peterson et al., 1994), capturing that some (mixed) farms offer many products and some inputs are specific to some activities. For instance, a single farm may produce both conventional and organic products using the same accounting services or the same farm machine (Peterson et al. consider labor, buildings and non-feed inputs that can be used in many livestock operations).

The originality of our crop supply modelling lies in the specification of the functional forms that govern the substitution pattern between allocable inputs at the activity level and the allocation of the assembly output between the two activities. More precisely, we first specify a flexible quadratic yield function for each v&f activity (while this is a leontief function in Sands and Leimer as well Komen and Peerlings). Yield per hectare depends on the application of chemicals and mechanical weeding factors per hectare. Maximizing the margin per hectare leads to optimal chemical input use, mechanical weeding, yields and returns per hectare for both activities. Formally, we solve the following programs:

$\pi_j = max_{x_j,y_j}\ p_j.y_j - w'.x_j$

Subject to: $y_j = a_j - 0.5.(b_j - x_j)'\nabla_j^{-1}(b_j - x_j)$

With p_j the price of the output offered by the activity j, y_j the yield per hectare, w the vector of input prices, x_j the vector of input use per hectare, a_j, b_j, ∇_j the deep parameters of the yield function. Optimal input use, yield and return per hectare are given by:

$$x_j = b_j - \mathrm{p}_j^{-1}\nabla_j w \qquad (1)$$
$$y_j = a_j - 0.5.p_j^{-2}w'\nabla_j w \qquad (2)$$
$$\pi_j = p_j a_j - w'b_j + 0.5.p_j^{-1}w'\nabla_j w \qquad (3)$$

These functions satisfy the usual properties, in terms of curvature and homogeneity, if ∇_j is a positive semidefinite matrix. One important property of this specification is the possibility to rely on agronomic functions to calibrate the deep parameters (Femenia and Letort, 2016). This is obviously important in our case where the glyphosate-free technology is not yet implemented by farmers.[5]

Second we determine the amount of the assembly output (that incorporates land) allocated to each v&f activity by maximizing the total return (sum of returns per hectare times the optimal acreage) minus an entropic cost function and total land allocated to the v&f sector. This cost function implicitly captures the different reasons why v&f farmers (at the individual level or at the aggregate level) do not fully specialize in the most profitable activity (for example due to dynamic agronomic constraints, management of labor peak loads, risk management, heterogeneity of land qualities). Formally, the optimal v&f acreages solve the following program in each region:

$$max_{s_j \geq 0}\ \sum_j \pi_j.s_j - \sum_j c_j.s_j - \frac{1}{\alpha}\sum_j s_j.ln(s_j)$$

[5] We again underline that our new technology is different from an organic one, as we do not prohibit other chemical inputs. Moreover, same farmers may already not rely on glyphosate some years. Yet they have the possibility in the following years to use again glyphosate if they encounter weeding issues.

Subject to $\sum_j s_j = s_{v\&f}$, j=conv v&f, gly-free v&f

With s_j the acreage devoted to activity j, π_j the return per hectare for activity j determined in the first step, $s_{v\&f}$ the total land devoted to veg&fruit production, c_j and α the deep parameters of the entropic cost function. The optimal acreage devoted to each activity is then given by:

$$s_j = s_{v\&f}.\frac{e^{\alpha\left(\pi_j+\mu_j-c_j\right)}}{\sum_{j'} e^{\alpha\left(\pi_{j'}+\mu_{j'}-c_{j'}\right)}} \quad (4)$$

With μ_j the endogenous lagrangian multipliers associated with the non-negativity conditions. As explained by Carpentier and Letort (2014), this specification is widely used in microeconometric analyses (with the log ratio of acreages being linear in returns). The deep parameter α is crucial as it controls the price responses of acreage. If it tends to zero, then acreage are fixed, with farmers always cropping the same amount of land. The c_j parameters of the entropic cost function have no real economic interpretation but ensure perfect calibration at the initial point.

These optimal acreages also serve to determine the amount of the assembly output allocated to each sector and its total amount (the price is implicitly given by the zero profit condition of the assembly sector and the standard nested structure of CES function between the non allocable inputs):

$$IC_{\text{asse},j}.P_{\text{asse}} = \pi_j.s_j \quad (5)$$
$$\sum_j IC_{\text{asse},j} = Q_{\text{asse}} \quad (6)$$

With $IC_{\text{asse},j}$ the intermediate consumption of the assembly output by the activity j, P_{asse} the price of the assembly output and Q_{asse} the total amount of the assembly output. All these equations ensure that profits are distributed to primary factors of production.

Our multi-production technological specification allows activities/commodities to appear or disappear according to economic incentives. This is a generalization over CGE models specifying multi-product technologies with usual functional forms, the prominent one being the Constant Elasticity of Transformation (CET). In that alternative approach, the number of active activity is exogenously controlled by the modeler (by changing the distribution parameters of the CET function). Our approach also preserves the physical land area (see Zhao et al., 2020) while taking into account the economic incentives to change the productive capacity of land (captured in our static approach with the substitution elasticity between land and other non allocable inputs).

3.1.c. Calibration

The implementation of our original v&f supply modelling (equations 1 to 6) requires the calibration of the deep parameters of the yield functions and of the entropic cost function. The usual practice in CGE modelling is to combine initial economic data (gathered in social accounting matrix) with external supply price elasticities to calibrate the technology parameters of an active technology. One first challenge with this procedure is that such elasticities are often computed for main farm products/sectors, few are available for the v&f products/activities. One second challenge with this procedure is the unknown external validity of these elasticities, when they are available. They are usually econometrically estimated with past data where prices and quantities did not significantly change during a long period (see for instance Guyomard et al. 2020 on the stability on pesticides and nitrogen use in EU farming sectors). A third challenge is that initial data are not always sufficiently detailed. For our case study, the GTAP database does not distinguish the composite factor used for mechanical weeding, only the total labor and capital used by the conv v&f. To cope with the last challenge, we will only introduce the additional composite factor used for mechanical weeding required for the gly-free v&f technology, an information available in the economic literature. To cope with the elasticity issue, we rely on the survey conducted by Bremmer et al. (2021). These authors ask agronomic experts of the yield effects of reducing fertilizers, then pesticides (without distinguishing the different pesticides) for different crops. For apples, tomatoes and grapes, they report yield reductions between 14 and 20 per cent when reducing mineral fertilizers by 20 per cent, between 10 and 20 per cent when reducing pesticides by 50 per cent. They also indicate that there are no significant interactions between these effects. Accordingly we calibrate the parameters of the European yield functions of the conv v&f using the initial economic data of the GTAP database (on conv v&f production, acreage, yield and chemical use) and assuming that a 30 per cent reduction of chemical use leads to a 30 per cent reduction of conv v&f. We proceed similarly for the other regions, again assuming this relationship.

As regards the calibration of the parameters of the yield function of the gly-free v&f technology, an expanding literature on arable crops assess the impacts on yields, other herbicide uses and additional weeding costs of a glyphosate ban (Bocker et al., 2020, Ye et al., 2021). The literature is less developed on v&f crops. According to Jacquet et al. (2019; 2021), a glyphosate ban may induce a yield decrease between 5 and 40 per cent for French apple and plum trees while negligible impacts on French vineyard productivity. Garcia Perez et al. (2022) confirm a small impact on vineyard productivity (3 per cent), compared to potatoes (close to 20 per cent) due to a glyphosate ban. Jacquet et al. also compute the additional mechanical weeding costs, assuming that the glyphosate ban does not lead to additional use of other (more expensive) herbicides. These additional costs represent on average 2.6 per cent of current revenue, with great diversity across time, French regions and v&f commodities. We combine these information as follows. First we assume that the gly free v&f yield response to chemical inputs is the same as the conv v&f technology (this is captured by assuming the same ∇_j parameters). This first assumption implies for instance, that reducing mineral fertilisers has the same yield impact on gly free and conv v&f. Second we assume that for the same values of aggregate chemical use, the gly-free yield is 10 per cent lower than the conv v&f yield (we capture this by decreasing the a_j parameter by 10 per cent and unchanging the b_j parameter). This second assumption intends to reflect that other herbicides are less efficient than glyphosate in the control of weeds. Third, we assume that the gly-free v&f technology requires more labor time, without any substitution between this additional labor and chemicals. We calibrate the relevant input output coefficient to 3 per cent. This third assumption intends to capture the additional non-chemicals costs of alternatives to the systemic glyphosate (either in mechanical weeding control or more time to apply other selective herbicides). Again we proceed similarly for the other regions, assuming the same figures. The only difference concerns the segregation/identity costs that will appear in our simulations. An European glyphosate ban implies that European producers do not need to identify their v&f products while foreign producers needs to do so if part of them want to export their products to the European markets. We assume that these additional segregation/identity costs are supported by producers and amount to 1 per cent of current output values for US producers (based on the small amounts reported in Beckman et al., 2021). We simplify the analysis by assuming that other countries have prohibitive segregation/identity costs, an assumption that can be explored in further researches.

As regards the calibration of the parameters of the entropic cost function, we also need external information, such as the amount of land that can be converted into gly-free technology in function of returns per hectare. Jacquet et al. (2021) find that the additional costs due to a glyphosate ban on French vineyards range from 0.3 to 4.4 per cent of current output values, with an average value of 2.6 per cent. Accordingly our calibration procedure targets a 5 per cent difference between i/ the virtual price of the gly-free v&f that leads first farmers to adopt the gly-free technology and ii/ the virtual price of the gly-free v&f that leads all farmers to abandon glyphosate. To be consistent with the above assumption of a 10 per cent decrease of the gly-free v&f yield, we thus assume that the first virtual price is 13 per cent higher than the current price of the conv v&f and the second virtual price is 18 per cent higher than the current price of v&f. With these two points and a normalization rule[6], we are then able to calibrate all parameters of the entropic cost function.

Our calibration approach shares similarities with Brookes et al. (2017) who assess the combined contribution of glyphosate to agriculture and GM crops (Bt corn). Like these authors, we introduce farm level impacts as productivity shocks to our CGE model. But we have one major difference in that we allow coexistence of conventional and glyphosate free technologies in non EU regions. On the other hand, Brookes et al. ban glyphosate and Bt corn globally.

3.2. Demand modelling

3.2.a. Issues with the standard approach

The GTAP model distinguishes five types of demand for each commodity: i/ intermediate demands by domestic firms, ii/ demands by public institutions, iii/ final demand by households, iv/ stock variation and v/ import demands by foreign agents. These different demands are usually specified using nested homothetic CES functions (eventually with zero substitution elasticities,), the exception being for the final demand with potentially more flexible non-homothetic forms (such as the Constant Difference of Elasticity). These specifications are globally regular and contribute to the existence of a unique general equilibrium. But they are only partially flexible in their price/expansion/income effects. More importantly, these specifications do not allow initial latent demands to become effective depending on economic conditions. They do not allow as well initial existing demands to disappear. For our case study, it means that the European final demand of conv v&f will never disappear, even if the price of conv v&f reaches high level. It also implies that a potential demand for gly-free v&f does not exist.

This "zero" issue is a long lasting issue in trade policy analysis (Romer, 1994). The predominant CES modelling of trade flows, also called the standard Armington approach reflecting national product differentiation, has long been criticized for prohibiting new trade flows and leading to high terms of trade effects of trade policy scenarios (Brown, 1987). Three main solutions have been implemented so far to solve this issue. The first consists in the exogenous modification of the parameters of the CES function in the CGE model (Philippidis et al., 2014). This solution implicitly assumes a change of preferences by households (over domestic/foreign goods), at least making difficult welfare analysis. The second consists in

[6] As explained by Carpentier and Letort, the c_j parameters are not fully identified. We assume that the denominator of the acreage function (equation 4) equals one in the initial situation. This normalization also applies when a CET function is implemented.

removing the product differentiation assumption captured with the CES and replacing it by the assumption of perfectly homogenous products (Britz et al., 2022). This second solution does not capture the two-way trade that are often observed at aggregate (time, space, product) levels. The third solution consists in specifying more flexible functions. This has already been implemented by Witzke et al. (2005) and Gohin and Laborde (2006). Witzke et al. (2005) replace the CES function with a Linear Expenditure System (LES) with negative commitments. This approach is not fully flexible in price effects. Gohin and Laborde (2006) instead implement the Normalised Quadratic Expenditure System (NQES) which is flexible and globally regular when virtual prices are introduce to deal with zero trade flows. We follow this approach.

3.2.b. Our approach

We specify a NQES at the import demand side, permitting European imports of conv v&f to cease if a glyphosate ban coupled with a mirror clause is implemented. We also implement this NQES at the final demand side, permitting households to start consuming gly-free v&f when economic conditions are favorable. As regards intermediate demands of v&f by processing firms, we assume a perfect substitutability between the two v&f while other demands (stock variation and governmental demands) are fixed.

We formally present below the NQES as applied to the final demand side in one region. The same type of equations apply at the import demand side, by replacing utility by commodity demand. This NQES is given by:

$$E(P,U) = A(P^d) + B(P^d).U \tag{7}$$

With $A(P^d) = \sum_i \alpha_i . P_i^d$ and $B(P^d) = \sum_i \beta_i . P_i^d + 0.5.\frac{\sum_i \sum_j \gamma_{ij}.P_i^d P_j^d}{\sum_i \delta_i . P_i^d}$

Where U stand for the utility, P^d the vector of prices at the demand level $\alpha, \beta, \gamma, \delta$ the deep parameters to be calibrated. From the Shephard lemma, we obtain the hicksian demand functions:

$$D_i = \alpha_i + U.\left(\beta_i + \frac{\sum_j \gamma_{ij}.P_j^d}{\sum_l \delta_l . P_l^d} - 0.5.\delta_i.\frac{\sum_l \sum_j \gamma_{lj}.P_l^d P_j^d}{\left(\sum_l \delta_l . P_l^d\right)^2}\right) \tag{8}$$

The marshallian demand functions are simply obtained by substituting the utility level with equation (7) and the macroeconomic identity between household expenditure and income (R):

$$E(P^d, U) = R \tag{9}$$

We constrain these demands to be non negative by allowing demand prices to be different from market prices. The complementarity conditions are given by:

$$D_i \geq 0 \ \perp P_i - P_i^d \geq 0 \tag{10}$$

This specification allows demand to be zero, at the initial point or after the simulation, if the market/producer price is higher than the price that household are ready to pay. This is the case in our initial situation, where the gly-free v&f product does not exist because its cost of production is higher than the virtual price of all households.

3.2.c. Calibration

By being more flexible than the traditional functions, the calibration of the parameters of the NQES allows to capture more external information, on price/substitution/income elasticities (we follow the calibration procedure detailed in Ryan and Wales, 1999). At the trade side, Fontagné et al. (2022) report a unique CES Armington econometric elasticity of 7 for conv v&f, but assuming that all households from developed/developing countries exhibit the same preferences. This assumption is generally not supported by country specific studies, leading to biased simulated results (Olekseyuk et Schürenberg-Frosch, 2016). Moreover European and USA v&f products are very likely more similar (mostly non tropical v&f products) than with v&f from RoW. Accordingly we double this substitution elasticity between the European/USA pair. The relevance of this elasticity will be later revealed when analyzing our regional simulated price effects.

As regards the currently non produced/consumed and traded gly-free v&f, we simplify the analysis by assuming perfect substitution across sources but impose unitary transport costs. We assume that these transport costs are the same for conv and gly-free v&f while segregation/identity costs are supported by foreign producers (see above).

As regards the calibration of the NQES parameters for the final demands, we first impose some natural separability assumption. At the upper level (with the NQES), we retain four products: the gly-free v&f, the conv v&f, an aggregate of other food products, an aggregate of other goods and services. For the two aggregates, we specify simple Cobb Douglas aggregators without prejudice, as our simulation experiments does not lead to huge price effects on other goods and income effects. For the upper level NQES parameters, a significant literature already assess the willingness to pay by consumers for reduced exposure to pesticide. Florax et al. (2005) show that this willingness depends on the risk levels of pesticide but that the income elasticity of reduced pesticide risk exposure is generally not significantly different from zero. We thus adopt the same income elasticity for the conv v&f and gly-free consumption, using the results of the meta-analysis by Femenia (2019), indicating a 0.6 income elasticity for v&f and 0.5 for the aggregate of other food products. As regards the virtual price that lead households to start consuming gly-free v&f, we assume that it is 6.5 per cent higher than (respectively equal to) the price of the conv v&f for European (respectively non European) households. We base this assumption on Marette et al. (2021) who find that European citizens are more concerned on the human/environmental effects of new crop technologies than non European ones. We justify the 6.5 figure as being half of the increase of price that leads European farmers to start producing gly-free v&f (see above). A sensitivity analysis of our results on this guess figure will be performed. Finally, we have six free cross price effects in our four good system (six free γ parameters). We first impose no cross price effects between our two v&f products and the aggregate of other goods and the same cross price effect of our two v&f products on the consumption of the food aggregate. This cross price effect is calibrated such as to reproduce the -0.6 own price elasticity of conv v&f demand reported by Femenia. Similarly the cross price effect of the food aggregate on the consumption of the other good aggregate is determined such that the own price elasticity of the food aggregate consumption equals -0.5. The last parameter to be determined governs the substitution between the conv and gly-free v&f. We calibrate it assuming that if the demand price of gly v&f reaches the demand price of conv v&f, then all European household will no longer consumer conv v&f.

4. Scenario analysis

We are now ready to assess some market and welfare impacts of adding mirror clauses to the Green Deal, by comparing the results of the two following scenarios. The first scenario, hereafter named the Green Deal, introduces two instruments: a ban of glyphosate use by European v&f producers and an input tax on other chemical input used in this sector. The second scenario, hereafter named the mirror clause, introduces the same two instruments plus a ban on intermediate and final demand of conv v&f on the European market. This is equivalent to impose an import ban of conv v&f. Foreign producers can only serve the European market with gly-free v&f, incurring additional identity/preservation costs (see above).

4.1. Impacts of the Green Deal scenario

Table 1 reports some market impacts. By definition, the European conv v&f production disappears with this scenario, as well as European exports to foreign markets. Still the European demand is not null. The intermediate demands of conv v&f by European processing firms fully switch to imports and the final demand by European households drops by 76 per cent. This is only partly replaced by gly-free v&f whose simulated consumption amounts to 67.9 per cent of the initial household demand. This is explained by the higher prices of both foreign conv v&f (by around 7 per cent, when shipped to the European market) and European gly-free v&f (by 13 per cent). The European gly-free v&f production amounts to 60 per cent of initial production, mostly explained due a decrease of v&f acreage (-34.7 per cent). The European v&f yield decreases by only 5.3 per cent, because the increase of the output price partially compensate the joint effects of the input tax and the complete switch towards the gly-free technology.

As already obtained in previous studies, this scenario benefits to foreign productions (by around 3 per cent) for two reasons: an increase of European imports (close to 100 per cent) and a stop of European exports on foreign markets. On the other hand, the final demands in foreign countries slightly decrease (by less than 1 per cent). The price effects are not sufficient to justify gly-free production in the US.

Table 2 reports some "welfare" impacts, starting with total chemical uses (in volume) by the v&f sector and by all farming sectors. The chemical use by the European v&f decreases as defined in our scenario, thanks to a huge input tax of 300 per cent. This may at first sight appear very huge but chemical expenditure represents only 3.5 per cent of v&f output in the GTAP database. Moreover, the price of gly-free v&f increases, partially tempering the effects of the tax. In other countries, the chemical uses by their conv v&f sector increase in proportion of their production, due to the more limited price effects. It appears that the global use of chemicals by the v&f sector increases by 1.5 per cent. This result is explained by the lower European use of chemicals per unit of v&f output, compared to other countries, in the GTAP database. This result confirms the fears expressed by NGO of the environmental leakages. We even find that this issue also manifest at the global farm level. Indeed the reduction of European v&f production leads to a small increase of other crops, such as cereals, and hence use of chemicals in these sectors. The cross sector effects are of the opposite signs in other countries (for instance, a reduction of US production of cereals). Globally, the volumes of chemicals increases by 0.5 per cent with this scenario. This result is consistent with some previous studies that removing glyphosate may end up with more chemicals used in farm sectors (Ye et al., 2021).

Next columns of Table 2 report the impacts on farm incomes (the returns to primary factors of production, namely labor, capital and land). As expected, we find that the European farmers suffer from this scenario, by close to 25 billion dollars. This is supported in our medium term horizon by a decrease of the land return (by 8 per cent) and mostly the capital return (up to 51 per cent). As Gohin (2022), effects will be more dramatic in the long run, as physical capital will not be maintained. At the opposite, farmers in other regions gain. In percentage, these figures are not marginal.

Last columns of Table 2 report the impacts on food bills. Again we find increases of the v&f expenditures, with larger effects in Europe due to larger price effects. More surprisingly, we find a decrease of the European food expenditure that is explained by both a 0.4 per cent decrease of European household income and small price decreases of other food products (for instance, by 0.4 per cent for beef). In other countries, these effects are opposite, leading to higher food bills. We also find that the wages of European unskilled workers noticeably decrease (by 0.7 per cent), linked to the reduction of European overall activity. This is the opposite in the Row (by 0.1 per cent).

Overall these results are qualitatively consistent with available results of studies evaluating the Green Deal, and quantify fears expressed by NGO and European farmers on the global environmental and farm income effects.

4.2.Impacts of the mirror clause scenario

Relative to our Green Deal scenario, the mirror clause scenario bans the European intermediate and final consumption of conv v&f. It also adjusts the European input tax, such as to reach the 35 per cent reduction of chemical use in the v&f sector.

The market impacts of this scenario are reported in Table 3 and compared to those of Table 1. This mirror clause scenario simultaneously decreases the demand of the conv v&f and increases the demand of gly-free v&f. As expected, this leads to a higher price of gly-free v&f. The European price is 29.3 per cent higher than the initial conv v&f price (compared to 12.6 per cent in the previous scenario). This has nevertheless a very modest additional impact on the European gly-free production: it represents 61.1 per cent of initial production (compared to 59.2 per cent in the previous scenario). This is explained by the higher input tax required to avoid the rebound effect on input use.

The higher European gly-free price also translates to a higher gly-free price in the USA, such that USA farmers start producing gly-free v&f. This production 59.5 per cent of their initial v&f production. This new production is partly to the detriment of their production of conv v&f (a decrease by 46.6 per cent). This cross supply effect is much larger than the loss of USA exports of conv v&f to the European markets. Hence the USA price of conv v&f increases by 8.6 per cent (compared to 1.4 per cent in the previous scenario). This price increase penalize USA consumption (by 3.1 per cent) and USA exports to the RoW (-74.6).

The effects are much simpler on the RoW markets. By assuming by default their inability to identify and segregate their potential gly-free v&f, the RoW producers of conv v&f face two shocks: a stop of their exports to the European markets on one hand, a significant reduction of competition from the USA production. Overall we find that the RoW price of conv v&f slightly increases (by 0.6 per cent), the RoW production slightly increases (by 1.5 per cent) with the additional output sold on the US markets (an increase of 89 per cent).

Some welfare impacts of this scenario are reported in Table 4 and compared to those of Table 2. By definition, we obtain similar figures on European farm use of chemicals. On the other hand, we find a significant increase of chemical use by the USA v&f sector (by 19.6 per cent), which is justified by an increase of USA global production of v&f and an increased share of gly-free production (that requires more chemicals to produce the same amount of v&f). By contrast, the chemical use increases less in the RoW, similar to the output effect discussed above. Overall, the world use of chemicals by the farm sector increases slightly less (0.4 per cent compared to 0.5 per cent in the previous scenarios), with also smaller amount of glyphosate. The addition of mirror clauses to the Green Deal thus moves the global economy towards NGO concerns but not enough to compensate for the Green Deal impacts.

We find that the impacts of the mirror clause scenario on European farm income indicators remain negative, with modest gains with respect to the Green Deal scenario (by 1 billion dollars). This is linked to the higher input tax to avoid the rebound effect on chemical use. It appears that the US farmers are the main beneficiary of this scenario (their gains increase by 13.7 billion dollars), thanks to their possibility to export gly-free v&f to the Europe without paying additional taxes to reduce their overall chemical uses. Logically, the producers from RoW lose from the addition of mirror clauses in our setting (by 11.5 billion dollars). Overall foreign producers gain (by 2.2 billion dollars) than European ones. Thus the addition of mirror clauses to the Green Deal thus support European farm incomes without hurting other producers globally.

As expected the addition of mirror clauses increases the food bills paid by American and European households. The latter now suffer from higher food prices, in particular because the processed foods, that includes gly-free v&f, are more expensive. On the other hand, RoW consumers enjoy a small decrease of their food expenditures, compared to the Green Deal scenario, due to market effects reported above.

4.3. Discussion

Our central results just discussed are conditional to the different assumptions made. We discuss below two critical assumptions.

a. On the explicit modelling of gly-free v&f technology and market

We previously argue that it is crucial to allow new technologies and markets to appear, depending on economic conditions. We now simulate our two scenarios, assuming that the gly-free v&f technology and market do not exit. Hereafter we refer to a standard CGE model. We thus only introduce the European input tax in the Green Deal scenario. For the mirror clause scenario, we add a similar input tax in the US (targeting a 35 per cent reduction of chemical use in the conv v&f) and a prohibitive European tariff on conv v&f coming from the RoW ; we thus follow Beckman et al., 2022 with only one difference : we impose a prohibitive scenario and not a speculative 50 per cent tariff.

The impacts of the Green Deal scenario are reported in Tables A.1 and A.2 in the appendix and compare to Tables 1 and 2. The impacts are qualitatively the same, the main difference concerns the European production of conv v&f : it now decreases by 31 per cent while it disappears in our central results. The second noticeable difference concerns the environmental leakage effects. The global farm chemical use increases less (0.2 per cent, compared to 0.5 per cent in the central results) because the foreign production increases less.

The impacts of the mirror clause scenario simulated with our standard CGE model are reported in Tables A3 and A4. Let's first analyze this scenario in isolation. Without surprise, we find that the imposition of the input tax leads to a huge decrease of chemical use in the US and hence a significant decrease of US v&f production. US exports to the European market still increases considerably (by 432 per cent) because RoW producers are no longer able to export to the European market. On the other hand, we find that the US export to the RoW nearly disappears. The reduction of European v&f consumption is now considerable (by 37 per cent), mostly explained by the higher European price of conv v&f (70 per cent). The welfare impacts are also quite significant. In particular we find a reduction of global chemical use (by 0.1 per cent) mostly thanks to the US input tax. The income of the American producers now decreases (by 20.4 billion dollars), also due to the input tax. Finally it is interesting to note that the food bill of the US households slightly decrease (by 0.1 per cent) due to an income effect and a higher consumption of cheaper other food products. By contrast, the food bill of the European household increases considerably (by 29 billion dollars or by 1.5 per cent) in part due the higher prices of processed foods.

It thus appears with our standard CGE model that the addition of the mirror clause considerably improves the global environmental impacts of the Green Deal, by limiting the leakages to foreign countries. On the other hand, this addition penalizes much more foreign producers (by 17.9 billion dollars) than it supports the income European producers (by 3.1 billion dollars). According to these figures, which are consistent with those of Beckman et al. 2022, the addition of mirror clauses is more likely to be contested by foreign producers. We obtain the opposite result with our innovative CGE model detailing new production standards and markets. The simple reason is that we believe that a mirror clause can be effectively imposed on a production technology, not on a taxation scheme that leads to an overall reduction of chemical uses.

b. On the calibration of the gly-free v&f technology

Our empirical results are obviously conditional on the many calibrating assumptions described above. We gather many figures for the European v&f sector and simply extrapolate them to foreign countries. We furthermore simplify the analysis by assuming prohibitive segregation/identity costs in the RoW. It might be the case that for some (developing) countries, their production costs of gly-free v&f, relative to conv v&f, as well as their segregation/identity costs, will be lower than those assumed above. Thus these countries may be able to produce and export gly-free v&f to the European market. On the other hand, these countries may offer more differentiated (tropical) products, meaning that their substitutability with European products may not be perfect. Measuring the net effect of these two dimensions is left for future research.

As regards the assumptions made on the US v&f sector, two dimensions not factored in the previous analysis may question our calibration choice. First, there is growing evidence of increasing resistance of weed to glyphosate (Vanb Deynze et al., 2022), meaning that their production costs of conv v&f may increase in the future, irrespective of the Green Deal. Second, there is an overall greater optimism in the US, compared to the EU, on the promises offered by modern agriculture, particular the new breeding technologies (Paarlberg, 2022). We intend to capture these two dimensions with a sensitivity analysis of our calibration of the gly-free technology in the US. In this sensitivity analysis, we assume that the gly-free yield is only

5 per cent lower than its conventional counterpart (it was 10 per cent in our central analysis). This alternative assumption means that the price needed to push farmers to grown gly-free v&f is initially only 9 per cent higher than the price of conv v&f.

Before analyzing the results with this alternative calibration, we again emphasize that banning the glyphosate use is different from not using glyphosate for some years. As long as glyphosate is not banned, some farmers may rely on it in case of increasing weed pressure for instance. On the other hand, when glyphosate is banned, famers may need to change their production practices to prevent potential future weed pressure if other herbicides are consider less efficient. Dealing with this dynamic dimension is out of scope of the present analysis. In this sensitivity analysis, we assess the impacts at the steady state, implicitly assuming that this dynamic dimension is less severe in the US compared to the EU.

The market impacts of the Green Deal scenario with this alternative calibration are reported in the Table B.1. They are nearly equal to the market impacts of this scenario with our central calibration. Indeed it appears that US farmers just start producing gly-free v&f (by 0.2 per cent of their initial v&f production). Accordingly the welfare impacts of this scenario are roughly the same as those obtained with the central calibration.

The market impacts of the mirror clause scenario with this alternative calibration are reported in the Table B.3. Here we observe noticeable quantitative differences with the results reported in Table 1. In particular, the simulated price of the US gly free v&f is 20.5 per cent higher than the initial conv v&f price (it is 26.1 per cent in the central calibration). The US production of gly-free v&f is greater, amounting to 63.3 per cent of initial US production (compared to 59.5 per cent). In terms of welfare (Table B.4.), the addition of mirror clause becomes even more beneficial to US farmers (by 14.6 billion dollars), compared to the European one (by 0.5 billion dollars). The higher productivity of US farmers when growing gly-free v&f benefits EU households who food bills increase less (by 5.8 billion dollars, compared to 9.2 billion dollars in the central calibration).

Table 1. Market impacts of the Green Deal scenario

	Conv v&f (changes in %)					Gly free v&f (% of initial conv v&f)		
	Price	Supply	Exports to EU	Exports to Row	Final Demand	Price	Supply	Final Demand
USA	1.4	3.1	97.5	1.4	-0.8	9.4		
EU	-	-100	-	-100	-76.5	12.6a	-40.8b	-32.1c
RoW	0.9	2.8	102.2	-	-0.4			

a: the simulated price of the gly-free v&f is 12.6 per cent higher than the initial price of the conv v&f.
b: the simulated production of the gly free v&f is 40.8 per cent lower than the initial production of the conv v&f
c: the simulated final demand of the gly-free v&f is 32.1 per cent lower than the initial final demand of the conv v&f.

Table 2. Welfare impacts of the Green Deal scenario

	Chemical use in v&f (%)	Chemical use in farms (%)	v&f income (bi $ and %)	Farm income (bi $ and %)	v&f bill (bi $ and %)	Food bill (bi $ and %)
USA	3.1	0.5	2.1 (5.9)	2.7 (1.8)	0.2 (0.4)	0.4 (0+)
EU	-35.2	-7.1	-24.6 (-48.6)	-27.6 (-13.1)	1.6 (2.4)	-0.9 (-0.1)
RoW	2.6	0.9	28.7 (3.8)	33.1 (1.7)	4.8 (0.8)	10.0 (0.2)
Total	1.5	0.5				

Table 3. Market impacts of the mirror clause scenario

	Conv v&f (changes in %)					Gly free v&f (% of initial conv v&f)		
	Price	Supply	Exports to EU	Exports to Row	Final Demand	Price	Supply	Final Demand
USA	8.6	-46.6	-100	-74.6	-3.1	26.1	-40.5	
EU	-	-100		-100	-100	29.3	-39.9	-19.9
RoW	0.6	1.5	-100		-0.3			

Table 4. Welfare impacts of the mirror clause scenario

	Chemical use in v&f (%)	Chemical use in farms (%)	v&f income (bi $ and %)	Farm income (bi $ and %)	v&f bill (bi $ and %)	Food bill (bi $ and %)
USA	19.6	2.4	14.7	16.4	0.8	5.5
EU	-35.1	-7.1	-23.9	-26.6	2.5	9.2
RoW	1.5	0.6	17.2	21.6	3.2	8.4
Total	1.1	0.4				

Table A.1. Market impacts of the Green Deal scenario: with the standard CGE model

	Conv v&f (changes in %)					Gly free v&f (% of initial conv v&f)		
	Price	Supply	Exports to EU	Exports to Row	Final Demand	Price	Supply	Final Demand
USA	0.8	2.0	61.7	0.5	-0.5			
EU	7.4	-31.4	-	-73.2	-3.1			
RoW	0.6	1.7	66.6	-	-0.3			

Table A.2. Welfare impacts of the Green Deal scenario: with the standard CGE model

	Chemical use in v&f (%)	Chemical use in farms (%)	v&f income (bi $ and %)	Farm income (bi $ and %)	v&f bill (bi $ and %)	Food bill (bi $ and %)
USA	2.0	0.3	1.4	1.7	0.1	0.2
EU	-33.3	-6.7	-22.8	-25.5	0.9	-0.9
RoW	1.7	0.6	19.3	21.9	3.0	6.5
Total	0.7	0.2				

Table A.3. Market impacts of the mirror clause scenario: with the standard CGE model

	Conv v&f (changes in %)					Gly free v&f (% of initial conv v&f)		
	Price	Supply	Exports to EU	Exports to Row	Final Demand	Price	Supply	Final Demand
USA	11.1	-32.9	432.9	-95.2	-4.3			
EU	69.7	-28.7		-100	-37.0			
RoW	0.7	2.2	-100		-0.4			

Table A.4. Welfare impacts of the mirror clause scenario: with the standard CGE model

	Chemical use in v&f (%)	Chemical use in farms (%)	v&f income (bi $ and %)	Farm income (bi $ and %)	v&f bill (bi $ and %)	Food bill (bi $ and %)
USA	-34.2	-4.0	-18.7	-20.4	0.8	-0.1
EU	-32.8	-7.2	-20.2	-22.4	-0.2	29.1
RoW	2.2	0.7	24.4	26.1	4.3	9.7
Total	-0.2	-0.1				

Table B.1. Market impacts of the Green Deal scenario: alternative calibration

	Conv v&f (changes in %)					Gly free v&f (% of initial conv v&f)		
	Price	Supply	Exports to EU	Exports to Row	Final Demand	Price	Supply	Final Demand
USA	1.4	3.0	97.0	1.1	-0.8	9.4	-99.8	
EU	-	-100	-	-100	-76.6	12.6	-40.8	-32.1
RoW	0.9	2.6	101.9	-	-0.4			

Table B.2. Welfare impacts of the Green Deal scenario: alternative calibration

	Chemical use in v&f (%)	Chemical use in farms (%)	v&f income (bi $ and %)	Farm income (bi $ and %)	v&f bill (bi $ and %)	Food bill (bi $ and %)
USA	3.1	0.5	2.2	2.7	0.2	0.4
EU	-35.3	-7.1	-24.7	-27.6	1.6	-1.0
RoW	2.6	0.9	28.6	33.1	4.8	10.0
Total	1.5	0.5				

Table B.3. Market impacts of the mirror clause scenario: alternative calibration

	Conv v&f (changes in %)					Gly free v&f (% of initial conv v&f)		
	Price	Supply	Exports to EU	Exports to Row	Final Demand	Price	Supply	Final Demand
USA	8.4	-46.1	-100	-73.8	-3.1	20.5	-36.7	
EU	-	-100		-100	-100	23.7	-40.5	-16.6
RoW	0.6	1.5	-100		-0.3			

Table B.4. Welfare impacts of the mirror clause scenario: alternative calibration

	Chemical use in v&f (%)	Chemical use in farms (%)	v&f income (bi $ and %)	Farm income (bi $ and %)	v&f bill (bi $ and %)	Food bill (bi $ and %)
USA	20.7	2.5	15.6	17.3	0.9	5.6
EU	-35.4	-7.1	-24.3	-27.1	2.2	5.8
RoW	1.5	0.6	16.8	21.1	3.1	8.0
Total	1.1	0.4				

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