Halving the European farm uses of pesticides: looking for alternatives

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Draft submitted to the 17èmes journées de recherché en sciences sociales INRAE, SFER, CIRAD

September 2023

Abstract

With the Green Deal roadmap, the European Union aims to half the uses and risks of pesticide by the end of this decade. The European Commission claims that the proposal for pesticides will not disrupt European agri-food production and price. She argues that previous assessments of the roadmap provide an upper limit to the effects of the proposal, mostly by ignoring alternative production techniques that rely on integrated pest management principles. Our paper first explains that the general equilibrium approach applied by the USDA does correctly capture these alternatives, measured implicitly in econometric studies on the price inelasticity of pesticide use. Second, we show that the USDA study significantly underestimates the negative effects of the proposal in terms of agri-food production, due to the input taxes that are rebated as output subsidies. Finally we show that the other arguments raised by the European Commission are not equally supported by scientific evidence.

1. Introduction

For several years, many European countries have been searching for ways to reduce agricultural uses of synthetic pesticides by implementing policies such as banning the most hazardous active substances, promoting organic farming and other alternative pest control methods. However overall, the results obtained so far are mixed and the decrease in the use of other active substances is limited (Guyomard et al., 2020).

The Green Deal (GD) roadmap announced by the European Commission (EC) in 2020, gave new impetus to an old target: a 50% reduction in the total use of synthetic pesticides and their risks by 2030. From a practical point of view, this goal is reflected in proposed legislation published in 2022 on the sustainable use of plant protection products (called the SUR proposal[1]). This proposal was accompanied by a first assessment of its likely impacts on several economic, environmental and social indicators.[2] This assessment drew conclusions concerning the potential decrease in agricultural production as well as increases in the price of agricultural products and food.

The assessment was mostly qualitative, partially informed by quantitative studies of the comprehensive GD roadmap and was completed before the Ukraine crisis. However, as the Council of Europe was concerned with this first assessment, it requested additional quantitative analyses to assess the impacts of the SUR proposal on production and prices considering the new context of agricultural world markets[3]. Accordingly, the EC delivered an updated assessment in July 2023[4] that nuanced the previous impact assessment: "*Our response confirms that a significant reduction in pesticide use and risk can be achieved, and indeed has been already achieved, without disrupting food security, food production, availability or prices*"[5].

This new assessment surprised many stakeholders as it provided no new data on the likely impacts of the SUR proposal[6] and was mostly based on the quantitative studies of the GD already mentioned in the first impact assessment. The EC justifies its new conclusion by arguing that the previous estimates of yield and production declines should be considered as an upper limit. These estimates do not correctly factor in the following six dimensions:

1/ "non-farm uses": farm uses only account for part of total use of pesticides and other uses may be reduced with no impacts on agricultural and food markets;

2/ "inefficiency": the current applications of Integrated Pest Management (IPM) practices are sub-optimal, as suggested by their uneven rate of adoption by similar farmers. Reducing these economic inefficiencies can lead to reduced pesticide uses with no effects on crop yields;

3/ "flexibility": a badly managed reduction in pesticide use may reduce yields so Member states are given flexibility within their national plans to limit such negative effects;

4/ "dynamic": we currently observe a decrease in pesticide use with no reduction in crop yields and the SUR reduction targets are defined for 2030. So there is time for a managed transition with gradual changes;

5/ "organic": the Farm to Fork target on organic farming will deliver part of the SUR pesticide reduction target;

6/ "alternative technologies": as formulated in IPM principles, a broad variety of alternative agronomic and technological strategies relying on ecosystem services make it possible to

[1] https://food.ec.europa.eu/system/files/2022-06/pesticides_sud_eval_2022_reg_2022-305_en.pdf
[2] https://food.ec.europa.eu/system/files/2022-06/pesticides_sud_eval_2022_ia_report.pdf
[3] https://eur-lex.europa.eu/eli/dec/2022/2572
[4] https://food.ec.europa.eu/system/files/2023-07/pesticides_sup_comm-response_2022-2572_en.pdf
[5] https://ec.europa.eu/commission/presscorner/detail/en/speech_23_4003
[6] https://www.euractiv.com/section/agriculture-food/news/ministers-concerns-over-eu-pesticide-cut-plans-persist-after-commissions-extra-study/

reduce pesticide use and risk while preserving crop yields. A reduction of pesticide use will improve ecosystem services and hence increase crop yields.

The main purpose of this paper is to quantitatively examine the last argument, which recurs throughout the report. We also analyze arguments 2 to 5 in the discussion section of this paper. We do not discuss argument 1 due to lack of data and expertise. Our main contributions are the following. We first explain that the last argument raised by the EC is indeed theoretically captured in the macroeconomic analysis performed by Beckman et al. (2020) with the GTAP-AEZ Computable General Equilibrium (CGE) model (hereafter referred to as the USDA study).[7] We then argue that its measure is rather consistent with currently available econometric evidence. Finally we quantitatively demonstrate that the USDA estimates of the production reductions due to the GD provide a low estimate of the production reductions of the SUR proposal. The main reason is that this USDA assessment assumes the implementation of taxes on inputs (to achieve the reduction in the input reductions) and rebates the tax receipt to farmers in terms of output subsidy. This rebate incentivizes farmers to produce more, hence reducing the production effects of the input taxes.

The rest of the paper is organized as follows. The first section qualitatively explains the theoretical properties of the crop supply specification in the GTAP-AEZ model. The second section assesses the calibration assumed by the USDA study. The third section reports the quantitative results of our simulation of the effects of the SUR proposal and compares them to the effects of the comprehensive GD roadmap. The fourth section discusses the other arguments put forward by the EC in its revised assessment. The final section concludes on potential fruitful future research.

Before proceeding, we wish to emphasize that our quantitative figures (reported in sections 2 and 3) are not directly comparable with those obtained by the USDA. While quite detailed, the USDA report does not provide all the assumptions made by the GTAP-AEZ model to simulate the effects of the GD. Our modelling assumptions are fully explained in section 2.[8]

2. Theory

The GTAP-AEZ model used by USDA builds on the GTAP CGE model and database (Lee, 2005). It is a static multi-region CGE model in which consumers are assumed to maximize their utility subject to budgetary constraints, and producers to maximize their profits subject to technological constraints. This model uses the following simplistic assumptions: there is perfect competition in all commodity and factor markets, flexible prices guarantee market equilibrium, investments are savings driven. The GTAP-AEZ model differs most from the benchmark GTAP CGE model because it incorporates Agro-Ecological Zones (AEZ) for land use modeling.

In most CGE models, including in GTAP-based CGE models, the modeling units at the supply side are not individual farms that produce many goods but activities or lines of business (such as wheat). These activities use variable inputs (e.g. chemicals and energy) and primary factors of production (e.g. land and labor) to produce one marketable good. The relationship between inputs and output is generally specified with (nested) homogenous constant elasticity of substitution (CES) functions. CES functions are crucial in determining input, yield and production responses to economic incentives (Keeney and Hertel, 2009). Accordingly, we only explain the properties of these CES production functions in this section.[9]

[7] We do not discuss the quantitative results obtained with the CAPRI Partial Equilibrium (PE) model (in particular by Barreiro-Hurle et al., 2021). The EC rightly emphasizes that the crucial effects of pesticide uses on crop yields were not endogenously captured by the version of the CAPRI model used to assess the GD roadmap.

[8] Our computer codes are available upon request. Running them requires a license for the GTAP10 database and a license for GAMS software.

[9] The CAPRI PE model also models farm activities but with a limited number of inputs and above all, assumes fixed relationships between inputs and output.

The CES function was first proposed by Arrow et al. (1961) to explain the observed heterogeneous distribution of aggregate value added between labor suppliers and capital owners and the contribution of wage levels to this distribution. This function rapidly became the standard in macroeconomic growth studies and is still the focus of much theoretical and empirical research today (see Leon Ledesma and Satchi, 2019, for the short term vs long term dimensions). Some authors looked for the theoretical micro-foundations of the aggregate CES function. Jones (2005) in particular demonstrated that it does not represent a single technology implemented by a representative firm but the many possibilities across different production techniques that individual firms may implement. These different production techniques may result from different ideas discovered over time, according to Pareto distributions.

The CES aggregated production function was naturally specified in the first CGE models that detailed agricultural markets and activities.[10] Again, a number of studies reconciled the macroeconomic CES production function with individual agronomic production functions of the von Liebig type.[11] Houthakker (1955), Levhari (1968) and Sato (1970) showed that it is possible to justify CES functions at the macroeconomic level (a region) and non-totally continuous production functions (such as von Liebig functions) at the microeconomic level (a plot or farm). To do so, at least one factor used in production has to be heterogeneous, i.e. differ in quality between plots/farms aggregated at the macroeconomic level. Only plots/farms that generate positive profits are included in the aggregation, the others are excluded and are available for other activities. This idea was explored empirically by Hertel et al. (1996). These authors showed that at the macro level, substitution between fertilizer and land can be very high, even if it is low (possibly even zero) at the level of individual plots with different application rates. Their field of application is corn production in Indiana. The justification is the heterogeneity of the land and of the managerial capacities of farmers.

Berck and Helfand (1990) provided a third justification for the CES aggregated production function by considering stochastic aspects. They allowed input productivity responses to be stochastic (below the plateau) to account for the effect of climate conditions or pests. Using experimental corn production data in California, they then showed that, if these stochastic elements are ignored at the level of individual production functions, then the existence of a macroeconomic production function of the usual form (CES/quadratic/exponential) is not possible. On the other hand, a macroeconomic production function exists when stochastic elements are recognized.

Accordingly, the aggregated CES production functions specified in the USDA study are justified for crop activities. By allowing substitutions between chemical and other inputs in the different crop activities, these functions recognize that farmers may apply different production techniques adapted to their local physical and market environments. Some techniques may rely on limited amounts of chemicals and significant amounts of other factors, such as labor and/or capital and/or ecosystem services embedded with the land factor, to produce a given amount of product. Farmers switch from one crop management practice to another one depending on price incentives. On the other hand, this aggregate approach does not explicitly recognize the potentially different quality of the crop products delivered because they are sold on domestic/foreign markets at the same price, which is usually an average of the market prices of the different quality crops. The implicit assumption is that the differences in price across these qualities (for instance, between organic, branded and conventional crops) do not change

[10] The macroeconomic energy and climate change literatures also rely on aggregate CES production functions, adding energy inputs to labor and capital. When considering more than two inputs, some specification choices with nested CES functions are required because a simple CES function constrains substitution possibilities to be identical across input pairs.

[11] Concretely, these agronomic functions assume that the production of a crop increases linearly (or non-linearly in more elaborate versions) with an increase in the volume of the limiting input. This effect becomes zero when this input is no longer limiting and another factor becomes limiting (for example nitrogen, phosphorus, water).

with the simulated scenario. Clearly, no distinction is made between organic technologies and markets in the USDA study, likely due to lack of the data needed to model them. We discuss this point later.

Overall, the CES-based macroeconomic specification used by the USDA for crop supply theoretically does not rule out the existence of a broad variety of alternative agronomic and technological strategies using ecosystem services, as claimed in the revised assessment of the SUR proposal. The question then becomes to know if the USDA correctly measures the existence and activation of these alternatives according to economic incentives, which is the purpose of the following section.

3. Calibration

The USDA study starts with the GTAP 10database which gathers economic flows for the year 2014. Before their GD simulations are performed, two types of changes to the GTAP-AEZ model are introduced. The first type concerns the data. The study modifies the GTAP10 database by disaggregating mineral fertilizers, pesticides (indeed an aggregate of all pesticides) and antimicrobials from the aggregate chemical sector. The USDA study also splits the 'animal sector' between hogs and poultry; and the 'other meat products sector' between pork and poultry meat. Finally a simulation updates the data to 2020. These changes are not fully documented in the report (e.g. the sources of pesticides or antimicrobials data are missing). Because the main subject of our paper is impact assessment of the SUR proposal, we focus on the fertilizers and pesticides used for cropping. To this end, we first rely on the Eurostat Economic Accounts for Agriculture.[12] These accounts provide the total expenditures of European farmers for fertilizers and soil improvers (19.1 billion euros in 2014), as well as for plant protection products (12.3 billion euros in 2014). We introduce these figures in the splitcom software developed by Horridge (2008) to disaggregate a GTAP sector. When following this procedure, we also assume that the only chemical products used for cropping are fertilizers and pesticides.[13]

The second type of changes concerns the calibration of substitution elasticities. The standard GTAP-AEZ calibration assumes no substitution between variable inputs and the value added aggregate. The latter is a CES aggregate of primary factors of production, with an elasticity of substitution of 0.26. To properly model the substitution between fertilizers and pesticides with other inputs (land, labor and capital), the USDA uses a substitution elasticity of 0.13 between all variable inputs and the value added aggregate at the upper level of their crop production functions. This positive substitution elasticity assumes alternative crop technologies exist with different levels of pesticide use per unit of product for each crop. The USDA justifies this value as being half the value of the substitution elasticity between primary factors of production in the value added aggregate. This is indeed a default practice used by the GTAP community. The USDA study also justifies this calibration based on a macroeconomic study focused on substitution between fertilizers and land (Barteling et al., 2016).

To our knowledge, econometric evidence for these two crucial substitution elasticities is limited. Dudu and Smeets Kristkova (2017) provide the most recent results for the lower level elasticity in the value added component. These authors investigate the impact of European agricultural subsidies on productivity, using NUTS-2 regional data. They estimate a CES production function for the period 2007-2013. Their estimated substitution elasticity between labor, capital and land amounts to 0.28 and is statistically significant. This estimated value provides credibility to the first crucial substitution elasticity used by the USDA.

[12] https://ec.europa.eu/eurostat/databrowser/view/AACT_EAA01__custom_7191380/default/table

[13] We do not claim our procedure is error free as it imposes the same expenditure to all the crops, and no such expenditures to pastures. Note that the revised assessment of the SUR proposal by the EC makes it clear that these crucial data are unfortunately not available. Neither do we claim that we exactly replicate the USDA. We only rely on the reference procedure that deals with missing data in the GTAP community.

We found no similar econometric study concerning substitution elasticity at the upper level. Nevertheless, we can comment on this substitution elasticity by computing the price elasticity of the pesticide demand by the aggregate of cropping activities and comparing it to the extensive literature on the price sensitivity of farm pesticide uses. Bocker and Finger (2017) conducted a meta-analysis based on studies that estimated pesticide demand elasticities in Europe and North America. Their meta-analysis revealed that the own-price elasticities of demand for pesticides are, with a median of −0.28, significantly smaller than zero, but also significantly larger than −1, i.e. inelastic. Such price inelasticity implies that the alternative crop production techniques that rely on small amounts of pesticides (organic technologies, for instance) are more costly than the production practices previously used by farmers. Otherwise, following an increase in the price of pesticides, farmers would widely adopt these alternative techniques and greatly reduce their use of pesticides. It is thus relevant to analyze the substitution elasticity used by the USDA study with this price elasticity of pesticide demand.

Table 1 below reports Hicksian elasticities, i.e. changes in European input uses by the aggregate of all crop sectors following increases in the price of pesticides while assuming that European crop production is fixed. Here, we only report at the aggregate crop level and not per crop as the results per crop did not differ significantly. The first column in Table 1 lists the changes that took place following a 1 per cent increase in the price of pesticides. As expected, the demand for pesticides for all EU crops decreased by 0.125 per cent (hence a price elasticity of –0.125), which is close to the substitution elasticity imposed at the upper level. The first column also shows that EU farmers will rely more (roughly 0.003 per cent more) on other inputs to produce the same amount of crops. Column two (respectively three) lists changes in the use of inputs uses following a 10 per cent (respectively 100 per cent) increase in the price of pesticides because the SUR proposal and GD target significant reduction in the use of pesticides by farms. The results show that the levels of elasticities are rather preserved (i.e. if we divide the figures in column three by 100, the results are close to those in column one). The most noticeable exception is the change in the use of pesticides, with an arc price elasticity of -0.083. The CES specification thus implies that it will be harder to find substitutes for pesticides when their initial uses are already “low” at the aggregate level.

<Table 1 here>

These Hicksian elasticities do not account for increases in crop production costs, i.e. the market price of a crop will increase if the prices of other inputs do not change. Most econometric studies reviewed by Bocker and Finger (2007) report Marshallian elasticities in which crop output levels can vary while crop prices remain fixed. Table 2 reports our Marshallian elasticities, i.e. changes in the use of European inputs by all crop sectors following increases in the price of pesticides while assuming that crop prices remain constant. In this case, the land rental prices adjust to guarantee prices and marginal costs are equal. Changes in crop production are no longer null but are determined by the amount of land available for cropping (Keeney and Hertel, 2009).

<Table 2 here>

The first column in Table 2 again shows the changes that take place following a 1 per cent increase in the price of pesticides. At the bottom of the column, we also report changes in total crop production. We obtain a 0.367 per cent reduction in pesticide use. The Marshallian price elasticity is larger (in absolute value) than the previous Hicksian one because the increase in the price of pesticide results in a 0.3 per cent decrease in land returns (not shown in Table 2) Hence, 0.047 per cent less land is allocated to cropping to the advantage of other activities (pasture, forestry). We also obtain a roughly 0.13 per cent reduction in the labor and capital allocated to cropping. One may wonder why more labor or capital are not allocated to cropping. The explanation is that, when we compute these elasticities, we assume labor and capital prices remain constant, so there are no economic incentives to attract more labor and capital to the crop sectors. Rather we obtain an “extensification” process in which the cheapest input (land) is used more intensively and the most expensive one (pesticides) is used less intensively. In fact, we obtain a 0.121 per cent reduction in crop yield (the difference between production and land impacts) and smaller quantities of pesticides used per unit of production (0.199 per cent less, again given by the difference between production and pesticide use impacts).

The second (respectively third) column of Table 2 again reports the same changes following a 10 per cent (respectively 100 per cent) increase in the price of pesticides. Similar to the previous findings on Hicksian elasticities, Marshallian elasticities appear to be rather stable. In particular, the use of pesticides for cropping in Europe decreases by 31.454 per cent following doubling of the price of pesticide, hence an arc elasticity of -0.31, which is pretty close to the median elasticity reported by Bocker and Finger (2017).

Since this meta-analysis, new econometric efforts have been made to identify these price elasticities. To our knowledge, the study by Bareille and Gohin (2020) is one of the studies focused on the French economy. These authors obtain more elastic pesticide demand (-0.82) using regional data, but acknowledge that their estimate is highly influenced by the non-robust allocation of pesticides to the fruit and vegetable sectors. Carpentier et al. (2023) were able to collect more detailed data on French conventional crop farms, where chemical inputs are allocated to individual crops, thus getting round the allocation problem. These authors also simulate 100 per cent increase in the price of pesticides and find a Marshallian arc elasticity of -0.251.[14] Further, they obtain a 7.5 per cent (on average) reduction in reduction in crop yields, as well a 12.4 per cent reduction in the use of fertilizer, while considering fixed total acreage per farm. Our results in column three are comparable, with a 11.3 per cent reduction in crop yield, an 18.4 per cent reduction in fertilizer use per hectare, and a 24.9 per cent reduction in the use of pesticide per hectare.

Overall, the choice of calibration made by the USDA study to represent the current diversity of crop production techniques appear to be broadly consistent with the available econometric literature that mainly focuses on the price sensitivity of farm pesticide uses.[15] By contrast, the EC revised assessment does not provide any macroeconomic data on the economic properties - such as their cost structure and price sensitivity - of alternative cropping techniques.

4. Simulations

The SUR proposal is only one - but highly disputed - component of the comprehensive GD roadmap. In addition to halving the uses and risks of pesticides, the GD roadmap also targets a reduction in the use of mineral fertilizers, of antimicrobial uses by livestock sectors, the expansion of organic markets or the share of areas devoted to biodiversity. The scenario simulated by the USDA thus includes more objectives than only the reduction of pesticide use and associated risks. In addition, they tax inputs to reach the targeted reduction in their use, and rebate the tax receipts to farm activities as an output subsidy. This assumption is at odds with changes made to the Common Agricultural Policy (CAP) over the last 30 years. So one naturally wants to know which simulation assumptions drive most of their results. The purpose of this section is to undertake the necessary decomposition to get the answer.

We perform the decomposition using our GTAP-AEZ model as described in the previous section. We also make a third type of change, similar to that made by the USDA, to implement policy objectives. By default, all policy instruments are exogenous in the GTAP-related models. We thus introduce two endogenous ad valorem taxes applied to the pesticide and to the use of fertiliser uses by European

[14] These authors accurately simulate a 100 per cent pesticide tax, and then rebate the tax revenues to farmers in a land-based manner. The rebate takes the form of increased area payments while the total areas are fixed for each individual farm. Accordingly this rebate has limited effects on their production/input effects. See also our third section.

[15] We again stress that our figures are not obtained directly from the modeling framework developed by the USDA. When computing these elasticities, we made assumptions on the pesticide and fertilizer expenditures per crop that may differ from their undocumented assumptions.

cropping. These ad valorem levels guarantee that the two policy objectives are achieved (i.e. the 50 per cent/20 per cent reduction in the use of pesticide/mineral fertiliser by European cropping). We also add another endogenous ad valorem subsidy on crop output. The level of this policy instrument guarantees the new input tax receipts are returned to cropping in the form of output subsidies. This rebate takes place at the aggregate level, i.e. the ad valorem output subsidy is the same for all crops. Finally, concerning the objective of 10 per cent of land being dedicated to high diversity landscape features, we exogenously apply a 10 per cent decrease in available land across the 18 AEZ.[16]

We now use our modified GTAP-AEZ model to assess the production and price impacts on European crop markets in three different scenarios. The first scenario, which is closest to the GD scenario implemented by the USDA, implements the 50/20/10 per cent reduction in pesticide use/fertilizer use/available land and the output subsidy rebate. Hereafter, this is referred to as the GD scenario with coupled support. This scenario most resembles - but still differs from the one analyzed by the USDA, in particular due to the omission of the objective of reducing the use of antimicrobials. The second scenario is almost the same as the first, the only difference being the absence of tax rebates. This scenario is referred to as the GD scenario without support. Finally the last scenario only considers the 50 per cent reduction in the use of pesticides. We call it the flexible SUR proposal because we do not include differentiated rules for ecologically sensitive areas.[17] The production impacts of these three scenarios are reported in the three columns of Table 3. In Table 4, we also report price effects, which help explain our production impacts. For the same reason, in Table 5, we finally report changes to production techniques for two activities with contrasting results, (i) wheat and (ii) fruit & vegetables (hereafter f&v).

<Table 3 here>

<Table 4 here>

The production impacts of our first scenario are qualitatively identical to those obtained by the USDA, and even the effects on EU wheat production are very close (a 46.8 per cent reduction in our case, a 48.5 reduction in the USDA study). The reduction in production is indeed limited by the fact there is an increase in the market price (e.g., a 34.7 per cent increase in the price of wheat). The impacts are also limited due to the coupled support, which mainly explains why the European production of f&v increases (by 12.8 per cent). According to the GTAP 10 database, f&v cropping relies relatively less on chemicals than other crops. The cost of pesticides accounts for 1.3 per cent of the f&v revenues, whereas it accounts for 3.6 per cent for wheat. Hence f&v cropping is less impacted by the tax on chemical inputs while benefiting from the uniform output subsidy. In other words, net subsidies for this activity increase.[18] More importantly, our ranking of crops based on output effects is similar to the one obtained by the USDA, and above all, our simulated effect on the global European agricultural production amounts to 9.6 per cent, which rises to 15.5 per cent if we only consider crop activities. Once the objective of reducing the use of antimicrobials is excluded, this compares well with the 12 per cent reduction obtained by the USDA. In our scenario, the reduction in European animal production

[16] Due to the lack of details, we do not understand the implementation of this objective by the USDA. In the GTAP-AEZ model, the areas devoted to farm and non-farm activities are determined endogenously. These areas depend on their relative returns and on the total amount of land available (which is exogenous). Because the mobility of land between these different usages is limited in the GTAP-AEZ model, a reduction of the availability of land likely decreases the land dedicated to farm activities and non-farm activities (forestry) by roughly the same percentage. The reduction in other land use likely has minor effects on their agricultural/food market impacts.

[17] See https://food.ec.europa.eu/system/files/2023-01/pesticides_sud_sur-non-paper_en.pdf

[18] We simulate a variant of this scenario in which output subsidies are defined per activity, that is, the input taxes paid by each activity are redistributed to that activity alone. In this variant, the European production of f&v decreases by 11.2 per cent while the reduction in European wheat production is less marked *(*by 31.8 per cent)

is mostly explained by the increase in the price of animal feed and the reduction in the extent of pasture.

Table 5 shows that the reduction in European wheat production is mostly explained by the 38.7 per cent reduction in wheat acreage, resulting in an 8.1 reduction in wheat yield per hectare. The application of pesticide (respectively fertilizer) per hectare decreases by 26.1 per cent (respectively 4.9 per cent). These results compare well with those of Carpentier et al. (2023). The reduction in yield is also modestly explained by the slight reduction (by 1.9 per cent per hectare) in labor (and capital) allocated to wheat. Conversely, 21.2 per cent more farm labor is devoted to f&v because it becomes relatively more profitable, thanks to the uniform output subsidy. Still we obtain a reduction in the use of pesticide by this activity, a total reduction of 29.4 per cent, or of 37.3 per cent per hectare. The increase in yield is due to the application of larger quantities of fertilizer and to the allocation of more labor/capital to this activity. All these changes are evidence that different technologies are being implemented by farms.

<Table 5 here>

In the first scenario, which tries to mimic the GD scenario simulated by the USDA, the levels of policy instruments are huge: the ad valorem input tax on fertilizers reaches 50.8 per cent, the output subsidy 78.9 per cent and the tax on pesticides 5357 per cent. These instruments are mitigated by the output price (rebound) effects. All crops considered, the first scenario leads to a 15.5 per cent decline in crop production and to a 10.5 per cent decrease in land allocated to crops (identical to the USDA estimate). So we obtain a 5.0 per cent overall decrease in crop yield. By assumption, the European farm use of mineral fertilizers decreases by 20 per cent (hence by 9.5 per cent per hectare of crops), and pesticide uses by 50 per cent (hence by 39.5 per cent per hectare of crops).

Let’s turn to our second scenario in which the input tax receipts are no longer returned to crop activities as an output subsidy. Indeed neither the GD roadmap nor the SUR proposal provide precise information and figures on potential additional public support that will be provided to help the European farm sector cope with new restrictions on inputs. The results of this second scenario are reported in the second column of Tables 3 to 5. It appears that without rebate, the production effects are either the same or greater, notably for the f&v sector. European f&v production now decreases by 11.0 per cent and the market price increases by 13.3 per cent. The production of the aggregate of all crops decreases by 26.6 per cent (compared to 15.5 per cent in our first scenario). The land devoted to crops decreases by 18.0 per cent, so the overall crop yield effect amounts to an 8.6 per cent reduction. The levels of input taxes required to reach the GD objectives are less drastic. The pesticide ad valorem tax amounts to 1502 per cent. It even appears that the use of fertilizers will need to be subsidized (by 50 per cent) to reach the 20 per cent reduction target. At first glance, this may appear curious. But the pesticide tax alone justifies a significant reduction in the use of fertilizers, as shown in Table 2. Carpentier et al. (2023) obtained similar results.

Our second scenario reveals the huge impacts of the tax rebate assumed by the USDA. Yet this scenario does not mimic the SUR proposal as it includes the targeted reductions in the use of mineral fertilizer and land availability for biodiversity purposes. In our last scenario, we remove these two objectives. The impacts on production are quite similar to those of our second scenario. The most notable difference concerns European livestock productions which decrease more marginally. Livestock production benefits from the removal of the land use restrictions, meaning more pasture is available. By contrast, cropping is penalized by the removal of the fertilizer subsidy we obtained in the second scenario. Our flexible SUR proposal scenario leads to a 28.0 reduction in the use of mineral fertilizer for European crops. Total land devoted to cropping decreases by 9.5 per cent. So we obtain an overall reduction in crop yield of 16.7 per cent. The pesticide ad valorem tax amounts to 1495 per cent. This is tremendous but consistent with our output price effects and the assumed price inelasticity of pesticide demand.

Our simulation results show that the impacts on production simulated by the USDA underestimate the production impacts of the flexible SUR proposal by roughly 20 per cent in relative terms, from 12 per cent in the USDA study (with the antimicrobial reduction objective) to 15 per cent in our flexible SUR proposal scenario. When we focus on the crop aggregate, the underestimation is larger. Let's assume the reduction of antimicrobials used by livestock production has negligible impacts on this crop aggregate, then the USDA results underestimate the effects of the flexible SUR proposal by 40 per cent in relative terms, by 10 per cent in absolute terms (from 15.5 to 26.2 per cent).

Our simulated levels of underestimation depend on the many GTAP-AEZ modeling assumptions used by the USDA. As already demonstrated by Keeney and Hertel (2009), the absolute figures obtained with the GTAP framework are sensitive to yield and trade elasticities. We now test if our levels of underestimation are robust to these elasticities. Table 6 reports the aggregate effects on crop production when we vary the crop substitution elasticities and Armington elasticities. The results are as expected. For instance, when the crop supply becomes more elastic, the effects on production are less marked. Importantly, the production effects of the flexible SUR proposal are always smaller than the effects obtained with the GD scenario with coupled support, around 10 per cent in absolute terms.

<Table 6 here>

Overall, these simulation results demonstrate that the production impacts simulated by the USDA do not constitute an upper limit of the production impacts of the flexible SUR proposal. The reason lies in the input tax rebates in the form of output subsidies. We also find that the underestimation is robust to calibrated elasticities.

5. Discussion

We now qualitatively discuss arguments 2 to 5 raised by the EC.

According to argument 2, the current applications of IPM practices are sub-optimal, as suggested by their uneven adoption by similar farmers. One big challenge faced by all analysts is to find farms and farmers that are identical to be able to compare their outcomes as there are many reasons why farms and farmers differ. These reasons include their location, the cropping history of the plot/farm, structure/organization (such as the management of peak labor time with different degrees of access to equipment), anticipated level of crop growth conditions and pest pressure, market conditions, the farmer's short vs long term objectives, their risk attitudes, their initial wealth and physical/financial portfolios, to name but a few. Tailored econometric procedures need to be developed to control for these often-unobserved factors (Frisvold, 2019). To give an example, Carpentier and Reboux (2018) analyze French farmers' fungicide protection of winter soft wheat to understand the reasoning behind their decisions concerning fungicide treatment. They show that these farmers are less likely to overuse fungicides when a dynamic analysis is conducted to capture the gradual information received by farmers during the crop campaign. Claiming without new proof that farmers' decisions on pest management are sub-optimal does not do justice to the considerable micro-econometric literature trying to assess their economic (in)efficiency. Argument 2 is thus not sufficiently defended.

According to argument 3, the SUR proposal gives flexibility to Member states such that the variation in the use of pesticides on specific crops could be exploited, which would flatten the EU-wide yield shocks. The USDA study implements input taxes to reach the variable input reduction targets, arguing that this approach allows the model to search for the most economically efficient use of remaining chemicals. A large economic literature generally calls for taxes for tackling externalities due to their low transaction cost and their incentives to substitute away from taxed inputs, both in the short and long run with price/policy induced technical changes (e.g. Lichtenberg, 2004). Our simulation results reported in section 5 confirm that we do not obtain uniform reduction of pesticide use per crop (by 63/36 per cent for wheat/f&v). This thus invalidates argument 3.

According to argument 4, sufficient time is given to stakeholders for a smooth transition period, noting some already significant reductions (between 14 and 26 per cent, depending on the indicator) of pesticide uses and risks between 2020 and the 2015-2017 baseline values. During the same period, crop yields exhibit no clear downward trend.[19] Unfortunately, these recent trends remain unexplained, providing no indication of their potential future continuation. Are they explained by reduced pest pressure, reduction of (if any) farm inefficiencies and/or market price effects? More importantly, do they result from policy decisions as happened in Denmark with reshaped pesticide taxes (Nielsen et al., 2023)? If the past policy decisions have had no effect while the uses and risks of pesticides are in fact decreasing, do we really need new strong policy actions so that the 50% target is reached by 2030? These questions indeed involve the complex challenge of measuring the dynamic effects of policy interventions. In this respect, the USDA study gives due reference to the large literature that assesses the delayed effects of research and innovation policies. The USDA clearly states that agricultural productivity (that is, the set of alternative technologies) is fixed during the 8 to 10 year horizon of their analysis. In this respect, we can mention Dudu and Smeets Kristova (2017) who identify the productivity effects of CAP second pillar measures. Even if this European study did not include lag effects, it showed that significant public expenditure is necessary to boost farm productivity of primary factors. Neither the GD roadmap nor the SUR proposal give the amount of R&D support that can introduced in the GTAP-AEZ modeling framework to perform a more dynamic analysis. So, again, argument 4 is not sufficiently supported.

According to argument 5, the development of organic farming will contribute to the objective. However the development of this sector is not the purpose of the SUR proposal. Moreover, nothing in the current European and national policy decisions guarantees that this objective will be effectively achieved. The argument is consequently not relevant.[20]

6. Concluding comments

Farm uses of pesticides are heavily debated in Europe. This paper demonstrates that, given current scientific knowledge and announced policies, reducing these uses will have significant impacts on European agricultural production and on the food prices paid by consumers. This does not mean that no action should be taken to reduce these uses. Sound cost-benefit analysis are essential to define efficient policies. This paper only adds a piece to the debate on likely agri-food related impacts.

Further research efforts are needed to inform this debate including the urgent need to gather better data to enable more robust analysis, such as on the different active substances applied on different crops. From a purely economic modeling point of view, we believe that new research on the external validity of economic elasticities and a better distinction between short and long-term responses considering future stochastic productivities of all production factors will be fruitful.

[19] Recent figures tend to suggest reverse trends in pesticide expenditures, possibly partially explained by new levels of crop prices. See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_consumption_of_pesticides#Analysis_at_EU_and_country_level

[20] The USDA study explicitly acknowledges that the organic objective is not explicitly taken into account in their analyses. Organic farm technologies and markets are indeed merged with all other farm technologies and markets. Future research, following the first example of Kremmydas et al. (2023), should examine if the organic distinction will significantly change USDA production and price estimates.

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Table 1. Hicksian input uses by European crop activities following price increases of pesticides (per cent with respect to the 2014 crop year)

\Price increases Input uses	1	10	100
Pesticides	-0.125	-1.193	-8.280
Fertilizers	0.004	0.039	0.369
Services	0.004	0.036	0.346
Land	0.003	0.031	0.295
Unskilled Labor	0.003	0.030	0.286
Skilled Labor	0.003	0.031	0.293
Capital	0.003	0.031	0.294

Table 2. Marshallian input uses and production levels by European crop activities following price increases of pesticides (per cent with respect to the 2014 crop year)

\Price increases Input and production	1	10	100
Pesticides	-0.367	-3.605	-31.454
Fertilizers	-0.238	-2.403	-24.985
Services	-0.222	-2.240	-23.266
Land	-0.047	-0.488	-6.543
Unskilled Labor	-0.109	-1.102	-11.730
Skilled Labor	-0.132	-1.339	-14.066
Capital	-0.133	-1.342	-14.096
Production	-0.168	-1.698	-17.849

Table 3. Impacts on European productions (per cent with respect to the 2014 crop year)

	Green Deal with coupled support	Green Deal without support	Flexible SUR proposal
Paddy rice	-19.0	-24.7	-24.9
Wheat	-46.8	-47.1	-47.5
Coarse grains	-17.9	-17.0	-17.0
f&v	12.8	-11.0	-8.7
Oilseeds	-50.6	-49.2	-50.1
Sugar crop	-13.4	-12.8	-13.1
Other crops	-26.9	-36.3	-37.2
Cattle	-2.2	-1.5	-0.7
Other animals	-3.1	-2.9	-2.6
Milk	-2.1	-1.4	-0.3
All crops	-15.5	-26.6	-26.2
All agricultural goods	-9.6	-15.4	-14.9

Table 4. Impacts on European market prices (per cent with respect to the 2014 crop year)

	Green Deal with coupled support	Green Deal without support	Flexible SUR proposal
Paddy rice	23.3	31.2	31.4
Wheat	34.0	34.7	35.0
Coarse grains	48.7	45.1	45.6
f&v	-11.5	13.3	10.6
Oilseeds	40.5	39.2	40.3
Sugar crop	52.6	49.2	51.0
Other crops	21.8	31.8	32.8
Cattle	4.7	3.3	0.9
Other animals	3.3	3.1	2.8
Milk	6.1	3.4	-0.5
All crops	16.8	28.1	27.6
All agricultural goods	11.2	16.8	15.6

Table 5. Impacts on European technologies (per cent with respect to the 2014 crop year)

	Green Deal with coupled support	Green Deal without support	Flexible SUR proposal
Wheat activity			
Production	-46.8	-47.1	-47.5
Land	-38.7	-37.8	-32.2
Yield	-8.1	-9.3	-15.3
Pesticide	-64.8	-61.9	-62.1
Fertilizers	-43.6	-38.9	-45.4
Labor	-40.6	-45.7	-46.4
f&v activity			
Production	12.7	-11.0	-8.7
Land	7.9	-6.9	3.8
Yield	4.8	-4.1	-12.5
Pesticide	-29.4	-37.4	-36.0
Fertilizers	13.1	0.9	-7.5
Labor	21.2	-9.7	-8.3

Table 6. Sensitivity of crop production effects to elasticities

	Green Deal with coupled support	Flexible SUR proposal
Benchmark	-15.5	-26.1
Crop supply *1.5	-10.3	-19.1
Crop supply *0.75	-19.3	-30.3
Trade *2	-18.0	-28.1
Trade *0.5	-13.2	-23.6