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# Halving the European farm uses of pesticides: Looking for alternative technologies

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## Abstract

With the Green Deal roadmap, the European Union aims to half the uses and risks of pesticides by the end of this decade. The European Commission (EC) claims that the proposal for pesticides will not disrupt European agri-food production and price. The EC 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 United States Department of Agriculture (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 rebated as output subsidies. Finally, we show that the underestimation is robust to the other arguments raised by the EC.

**Keywords:** Green Deal, Pesticides, Production.

**JEL codes:** Q11, 18.

## 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 per cent 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 Sustainable Use Regulation (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.

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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 the 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 suboptimal, 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; and
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 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 these arguments with the exception of argument 1 due to lack of data and expertise. Our main contributions are the following. We first explain that the macroeconomic analysis performed by Beckman et al. (2020) with the Global Trade Analysis Project-AgroEcological Zones (GTAP-AEZ) Computable General Equilibrium (CGE) model (hereafter referred to as the United States Department of Agriculture (USDA) study) theoretically captures these arguments.[7] We then argue that the calibration of the parameters of this model 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 our results comparing them to prior works. This fourth section also provides several sensitivity

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analyses motivated by the 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 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 (as discussed later). Our modeling 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, and 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 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 outputs 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]

The CES function was first proposed by Arrow et al. (1961) in a macroeconomic analysis of income redistribution. Many 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 specified in the first CGE models that detailed agricultural markets and activities. A number of studies reconciled the macroeconomic CES production function with individual agronomic production functions of the von Liebig type.[10] Houthakker (1955), Levhari (1968), and Sato (1969) 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

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(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 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 heterogeneous farmers adopting 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 heterogeneity between farms and the existence and activation of these alternatives according to economic incentives, which is the purpose of the following section.

## 3. Calibration

Like the USDA study, we start with the GTAP 10 database, which gathers economic flows for the year 2014 (Aguiar et al. 2019). Before their GD simulations are performed, two types of changes to the GTAP-AEZ model (Lee 2005) are introduced. The first type concerns the data. The study modifies the GTAP 10 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 the 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.[11] 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.[12] Due to lack of data on antimicrobials, we omit the data changes on animal sectors made by the USDA study. The impacts of the 2020 baseline built by the USDA study are later discussed with a sensitivity analysis of our results.

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

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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).

| Input uses\Price increases | 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 |

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.

As regards the substitution elasticity at the upper level, we are aware of only one recent econometric study by Ivanic et al. (2023). Their estimated elasticities evaluated with the static, steady state specification amount to 0.07 for sugar crops, 0.10 for coarse grains, 0.16 for fruits and vegetables, 0.19 for wheat, and 0.37 for oilseeds. The simple average of these elasticities for the main crops produced in the EU is 0.18, slightly higher than the imposed 0.13 value by the USDA. In order to obtain these elasticities, Ivanic et al. (2023) impose restrictive assumptions such as the same elasticity across all countries. Their econometric procedure relies on variations of unitary tax levels to deal with price endogeneity issues, but assuming no impacts of these taxes on prices.

In this context of limited direct econometric evidence, we also indirectly comment on this upper level 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 reports Hicksian elasticities simulated with our replication of the GTAP-AEZ model used by the USDA study, i.e. changes in European input uses by the aggregate of all

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**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).

| Input and production\Price increases | 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 |

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.

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 (2017) 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 that 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).

The first column in Table 2 again shows the changes that take place following a 1 per cent increase in the price of pesticides, obtained with our replication of the GTAP-AEZ model. 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 is 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

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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 31.4 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 a 100 per cent increase in the price of pesticides and find a Marshallian arc elasticity of −0.251.[13] Further, they obtain a 7.5 per cent (on average) reduction in reduction in crop yields, as well as 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 an 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 appears to be broadly consistent with the available econometric literature that mainly focuses on the price sensitivity of farm pesticide uses.[14] 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 fertilizer uses by European 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 fertilizer by European cropping). We also add another endogenous ad valorem subsidy on crop output. The level of this policy instrument guarantees that 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.[15]

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**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 |

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.[16] 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: (1) wheat and (2) fruit & vegetables (hereafter f&v).

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

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**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 |

reduction in our case, a 48.5 per cent 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.[17] 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 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 per cent reduction in wheat yield per hectare. The application of pesticide and fertilizer per hectare decreases by 26.1 and 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.

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 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

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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 3–5. 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 1,502 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. However, 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 productions 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 1,495 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).

## 5. Discussion

By definition, the results of our first scenario are close to those simulated by the USDA study. To our knowledge, our second scenario has never been simulated in prior works. We can still discuss the results of our second scenario as many authors already assessed the sole impacts of the CAP payments (Balkhausen et al. 2008). One most recent assessment is offered by Boysen-Urban et al. (2016). These authors showed using the GTAP model that the removal of EU-coupled support would decrease the EU production by 6.2 per cent. We obtain a 5.8 per cent additional reduction of EU agricultural production when moving from our first to second scenarios. While not being directly comparable, this shows that the magnitude of our results aligns with available results. To go further in the analysis of the effects of the rebate, we consider a variant of our first and third scenarios. We now assume that the input taxes are rebated to crop activities as a uniform land subsidy per hectare. The production

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**Table 6.** Sensitivity of crop production effects (per cent with respect to the 2014 crop year).

| | Green Deal with coupled support | Flexible SUR proposal |
|---|---|---|
| Benchmark | −15.5 | −26.1 |
| Land subsidy* | −26.2 | −25.8 |
| Crop supply × 1.5** | −10.3 | −19.1 |
| Crop supply × 0.75*** | −19.3 | −30.3 |
| Quotas**** | −17.6 | −28.1 |
| Baseline***** | −11.5 | −21.8 |

*: input taxes are rebated to crop activities as uniform land subsidy per hectare; **: crop substitution elasticities are increased by half; ***: crop substitution elasticity are reduced by 25 per cent; ****: input reductions are imposed for each crop activity; and *****: simulation after a simulated 2020 baseline.

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impacts of this variant are reported in the second line of Table 6. As expected, we find that the production impacts of the third scenario are slightly less negative, from 26.2 to 25.8 per cent, because non-crop activities do not receive these land subsidies. This slight production effect is consistent with results obtained by Boysen-Urban et al. (2016).

As regards our last scenario on the SUR proposal, few macroeconomic studies have measured the impacts of pesticide regulations. Rendleman et al. (1995) assessed the impacts of pesticide taxes on the US economy. They found limited output reductions (less than 1 per cent) of taxes that led to a 20 per cent reduction of pesticides. Bareille and Gohin (2020) performed similar assessments on the French economy. They found higher production effects, up to 10 per cent for oilseeds, of taxes that led to a 37 per cent reduction of pesticides. In these two papers, the pesticide demand is more price elastic than in the USDA study: the own price elasticities amount to, respectively, −1.7, −0.8, and −0.3. This difference of elasticities likely explains a significant part of the differences between production results. As already demonstrated by Keeney and Hertel (2009) and Ivanic et al. (2023), the absolute figures obtained with the GTAP framework are sensitive to crop yield elasticities. We thus perform a sensitivity analysis of our results on the production elasticities. The third and fourth lines of Table 6 report the aggregate effects on crop production when we vary the crop substitution elasticities (at the upper and lower levels, see Scetion 3).

Let's focus on the case where we increase the substitution elasticities by half to go deeper in the analysis of the arguments 2 (on inefficiency), 5 (on organic), and 6 (on alternative technologies) raised by the EC. These three arguments indeed suggest that we should consider more price elastic demand of pesticides. More precisely, according to argument 2, the current applications of IPM practices are suboptimal, as suggested by their uneven adoption by similar farmers.[18] This argument suggests that the aggregate demand of pesticides is more price elastic, as suboptimal farmers may first reduce their inefficiencies following a small increase of pesticide price. According to argument 5, the development of organic farming will facilitate the conversion of conventional farmers to organic technologies, thus increasing the price response of the aggregate demand of pesticides.[19] According to argument 6, many alternative crop technologies exist. This argument suggests that it might not be too costly to find an alternative crop technology for many farms, hence a more price elastic demand of pesticides. When we increase by half the crop substitution elasticities, the pesticide demand effectively becomes less inelastic (the own price elasticity amounts to −0.48). The third line of Table 6 shows as expected that the production effects of our two scenarios are reduced, by 5.2 per cent for the first one (from 15.5 to 10.3 per cent) and by 7 per cent for the last one (from 26.1 to 19.1 per cent). Interestingly, this sensitivity analysis does not invalidate our main result: The production effects obtained by the USDA when simulating the GD do not provide our upper estimate of the SUR proposal. The difference between the two scenarios remains close to 10 per cent. We find a similar difference in the fourth line reported in Table 6 when we reduce the elasticity of pesticide demand.

Up to this point, we only consider the implementation of input taxes in order to reach the SUR policy objectives. The USDA study argues 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). Indeed, Rendleman et al. (1995) compare the market effects of reducing agricultural chemicals using a market-based (taxes) approach and a command-and-control approach. These authors found that the market-based approach is more efficient. Our simulation results reported in the previous section confirm that we do not obtain uniform reductions of pesticide use per crop (by respectively 63/36 per cent for wheat/f&v). According to the third argument raised by the EC, 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. In order to analyze this argument, we perform a new variant of our first and third scenarios where we impose a 50 per cent reduction of pesticide uses by each crop activity. Results of this new variant are reported in the fifth line of Table 6. Consistent with Rendleman et al. (1995), we obtain larger reduction of crop productions, by roughly 2 per cent in our two scenarios. Again, this sensitivity analysis does not invalidate our main results concerning the underestimation of production effects: The underestimations are similar with the market-based and command-and-control approaches.

Our last discussion focuses on the time dimension of the analysis. The model used by the USDA study is a static one, relevant to compute counterfactual scenarios at the steady state. In the results reported above, we assess the market impacts with respect to the 2014 reference year. By contrast, the USDA study first updates the GTAP 2014 database to the 2020 and then performs the assessment of the GD. Building relevant baseline is a difficult task with CGE models as many assumptions on parameters and policy variables are required (Dellink et al. 2020). One critical question is to know if these two reference years (the 2014 being observed, the 2020 being simulated) are relevant for assessing the SUR proposal. According to the fourth argument raised by the EC, 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.[20] 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 per cent 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 8–10 year horizon of their analysis starting from their simulated 2020 year.

In order to inform this time dimension, we proceed in two steps with our version of the GTAP-AEZ model. First, we try to replicate the baseline built by the USDA study by implementing their shocks on the factor endowments and productivities. Importantly, the USDA study does not indicate if it only introduces neutral technical changes or if it additional supposes biased technical changes toward the reduction of inputs like pesticides. Accordingly, we assume neutral productivity changes, which is the standard practice when building baseline with CGE models. Our simulated 2020 baseline leads to a slight increase of EU crop

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production (by 2.2 per cent compared to the 2014 observed year) and a modest decrease of EU pesticide demand (by 5.9 per cent, again compared to the 2014 observed year). This decrease is intermediate between the 14 per cent observation made by the EC and the absence of decrease projected by Guyomard et al. (2020). Second, we implement our first and third scenarios, starting from our 2020 baseline taking into account that part of the objectives are already achieved (for both the reduction of mineral fertilizers and pesticides). Results are reported in the sixth line of Table 6. To be comparable with the previous results in this table, we report the evolution of EU crop production with respect to the 2014 observed year.[21] As expected, we find that the reductions of EU crop production are lower, by roughly 4 per cent. Again, the production reduction of the GD scenario does not provide an upper limit of the production impact of the SUR proposal.

## 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. Estimates provided by the USDA study on the likely impacts of the GD do not provide an upper limit to the effects of the proposal. This does not mean that no action should be taken to reduce these uses. Sound cost-benefit analyses 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 for more robust analysis, such as on the different active substances applied on different crops and the explicit distinction of different technologies. 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. 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.

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## Supplementary material

Supplementary data are available at *Q Open* online.

## Data availability

The code of the model is written in GAMS and is available in the Online Appendix. A GTAP license is necessary to get the data used by the model (https://www.gtap.agecon.purdue.edu/databases/default.asp).

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## End Notes

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/
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 provided in the Online Appendix. Running them requires a license for the GTAP 10 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 outputs.
10 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 (e.g. nitrogen, phosphorus, water).
11 https://ec.europa.eu/eurostat/databrowser/view/AACT_EAA01__custom_7191380/default/table
12 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.
13 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 Section 3.
14 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.
15 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.
16 See https://food.ec.europa.eu/system/files/2023-01/pesticides_sud_sur-non-paper_en.pdf.
17 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)
18 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- versus 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.

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19 Note that nothing in the current European and national policy decisions guarantees that this objective will be effectively achieved.

20 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.

21 The absolute impacts are 2 per cent lower with respect to the simulated 2020 crop production. For instance, the first scenario leads to a 13.5 per cent reduction of the EU crop production with respect to the 2020 level.

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