Economic Effects of Drought on Agriculture: Conceptual Methods and Stakeholders' Perceptions

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Abstract

Drought events are among the costliest natural disasters and are increasing in frequency and intensity. Various methods to assess their economic effects exist, yet clarity on their advantages and practical application is lacking. This study compares four conceptual market-based methods to assess drought's direct and distributive economic effects on agriculture. These methods are applied for the 2018 drought event in Flanders, Belgium, using production data from a regional soil water balance model and historical price data. Additionally, we contribute to the existing literature by including agricultural stakeholders' perceptions of two main topics through semi-structured interviews: 1) assessing drought's effects and 2) the perceived advantages and disadvantages of the conceptual methods. We find that some social groups could benefit from a drought event due to a so-called natural hedge, confirming previous findings in literature. While consumers are always negatively affected, interviewees state this effect is minimal. The producer surplus calculation yielded the most support from respondents but requires improvement for practical use. Investment in climate adaptation measures could reduce farmers' vulnerability to drought, which may cause short-term benefits from sector-wide price increases. These results offer valuable insights for designing efficient drought-management policies and suggest avenues for further research in this area.

Keywords: Agricultural stakeholders, Distributive effects, Economic surplus, Interviews, Microeconomics

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1. Introduction

Human-induced climate change increases extreme weather events' intensity and frequency urging researchers to investigate their (economic) consequences for different sectors (IPCC, 2022). Droughts are estimated to be among the costliest natural disasters, particularly impacting the agricultural sector (FAO, 2021; Fleming-Muñoz et al., 2023). Drought effects on agriculture can be identified as direct (e.g., crop loss), indirect (e.g., losses in other related sectors) and intangible (e.g. biodiversity loss) (Logar & van den Bergh, 2013). Vulnerability to drought can be reduced through investment in adaptation measures, yet their implementation is lagging, possibly due to limited and mixed knowledge of their economic advantages (Rossi et al., 2023).

In the past decade, a variety of methods to assess the economic effects of drought has been applied in different sectors (Gerber & Mirzabaev, 2017; Venton et al., 2019). However, it is not always clear what the benefits of the different methods are and how they can be applied in practice (Logar & van den Bergh, 2013). Market valuation methods (i.e. methods determining value based on selling prices of similar items) are generally recommended to assess direct drought costs, computable general equilibrium (CGE) (i.e. economic model showing how an economy might react to policy/technology/external changes) for indirect costs, and choice experiments (CE) (i.e. a survey approach intended to elicit respondents' preferences on hypothetical scenarios) for intangible costs (Logar & van den Bergh, 2013). Although it is often assumed that drought only causes negative effects, which could elicit the creation of compensation measures and government interventions, some studies have shown that certain stakeholder groups can benefit from a drought event (Espinosa-Tasón et al., 2022; Musolino et al., 2017; Musolino et al., 2018). This positive effect can be reached when a crop's price increase outweighs the quantity reduction due to drought. Should compensation measures be available to those who stand to gain from drought events, there would be inefficiencies in public spending. The economic surplus theory, a specific application of welfare economics, can be applied to measure welfare changes of both consumers and producers in the economy (Espinosa-Tasón et al., 2022). This makes the assessment of distributive effects possible, which relates to the allocation of positive and negative effects between market actors.

While previous studies on the subject have considerable merit and provide added value to their respective goals, it remains unclear what the advantages of the different methods are in practice, and whether stakeholders perceive them as useful. This paper compares four conceptual market-based methods to calculate the direct and distributive effects of drought in the agricultural sector and applies them to the case of the Flanders region in Belgium.

The benefits of the selected methods are the low data requirements, ease of application and precision of the results (Logar & van den Bergh, 2013). First, a damage-oriented calculation is carried out where short-term interactions are investigated (VMM, 2021). Second, a fixed price calculation is performed, as is often the case to assess drought losses in official reports (van Bakel et al., 2009). While these methods focus on the direct costs of drought, they do not consider possible positive effects or assess the distributive effects. The third method, the producer surplus calculation, is based on the economic surplus theory to investigate changes in producer surplus, clearly discerning both the positive and negative effects of drought on farmers (Musolino et al., 2017; Musolino et al., 2018). Lastly, the economic surplus calculation builds further on this method by including changes in consumer surplus.

The impacts of climate change in Belgium are becoming evident through recurring drought episodes, an increase in average temperature and intense precipitation events (De Ridder et al., 2020). Since Belgium is already sensitive to water scarcity, ranking 23rd out of 164 countries on water stress, it is crucial to increase resilience to drought in the country (Hofste et al., 2019). To ensure efficiency in policymakers' and farmers' actions taken, more information is needed on the economic effects of drought periods. Production data from a regional soil water balance model and historical price data are used to apply the four selected market valuation techniques to our case study. Emphasis lies on the potato crop for a specific drought year in the Flemish region. This paper contributes to existing literature by 1) comparing four conceptual market-based approaches to assess the economic effects of drought events in agriculture, and 2) including agricultural stakeholders' assessment of the applicability of the discussed methods, and their preferences.

2. Data and methods

2.1. Data

Our case study focuses on the Flemish region in Belgium. The agricultural area comprises 624,634 hectares, roughly 46% of the Flemish region (Statistiek Vlaanderen, 2021). Recent drought events highlighted the region's vulnerability to drought and water scarcity (De Ridder et al., 2020). Crops with superficial roots such as potatoes are particularly vulnerable to such events. In the European Union, Belgium ranked 5th in total potato production in 2020, emphasizing the importance of studying this crop in our case (Eurostat, 2023). Data on crop quantity and crop prices are used to calculate the economic effects of drought shock. Price data used in this study are provided by Eurostat (2022) and represent the average annual price of maincrop potatoes[4]. The calculations are made for the year 2018, during which a drought event occurred from June 2nd to August 6th (Departement Landbouw en Visserij, 2023). This event was recognized as an agricultural disaster, reaching extraordinary temperatures (Waterbeleid, 2018) and a precipitation deficit of 300-350 mm was measured (Willems, 2022). While less intensive than the historic drought events of 1921 and 1976, the drought event of 2018 provides an interesting case to perform the calculations (van der Schrier et al., 2021).

The methods used to assess the economic effects of drought are market price methods, allowing the estimation of economic values of market goods (Logar & van den Bergh, 2013). These methods relate to partial equilibrium analysis and only require crop quantity and price data. Due to data availability issues, a crop model is added to simulate historical crop production. We use the Soil Water Balance Model (SWBM) as developed by the Soil Service of Belgium (SSB), which calculates the crop yield response to water (VMM, 2021). This model is a simplified version of the Aquacrop model (FAO, 2023). Based on climate input data such as precipitation and potential evapotranspiration (PET) retrieved from Waterinfo (2023), groundwater levels, soil type, crop area and several crop-specific variables, the crop production quantity is determined. The model distinguishes possible irrigated and non-irrigated crop surface areas. The output consists of crop yield data, crop yield loss due to drought stress and lastly, irrigation volume applied. The model is run for eight crop groups during the period 1986-2022. This model has certain restrictions that should be considered. Assumptions had to be made regarding the irrigated area in Flanders, the evolution of crop surface area over the years is not included, the function to determine groundwater levels is based on 2018 averages of measurements, and most importantly, a linear relationship between crop transpiration and crop loss is assumed, which leads to underestimation of drought impact in the case of extreme drought. However, the model has been applied in other studies and serves as a good alternative for the lack of production data (VMM, 2021).

2.2. Methods

This paper uses a mixed-methods approach. Firstly, four market price methods are applied to conceptually calculate the economic effects of a drought shock. These calculations provide useful quantitative insights into the direct and distributive effects of drought in the agricultural sector but remain theoretical. Therefore, the results and methods are assessed by 11 agricultural stakeholders from four different stakeholder groups: farmers, government experts, sector federation representatives and potato processors. By assessing stakeholders' perceptions of the applied methods, we can identify how they can be improved and applied in practice.

2.2.1. Calculation methods

A step-by-step analysis is applied, starting from the direct economic costs of drought in the agricultural sector and ending with a welfare effect. For each method, we assume that crop losses occur following drought, and prices respond to the decreased supply (Stratelligence, 2021). This process is depicted in Table 1Figure 1. The market equilibrium shifts from the "regular" point **E1** to **E2**, due to a reduction in crop quantity supplied during a drought year. Note that the supply curve is vertical since crop supply

[4] Price values are converted to the 2017 price level using the consumer price index (Statbel, 2023).

cannot be altered in the short term (van der Vat et al., 2016). Variable costs are assumed to be zero since all costs are already made during the growing season. These sunk costs do not influence the quantity supplied; the reduction is solely caused by the drought event. The price elasticity of demand is crucial in the estimation of the economic effects of drought (Reinhard et al., 2015). Prices of crops with more price-inelastic demand, as is often the case with potatoes (Huq et al., 2004), will fluctuate stronger following quantity changes than prices of goods that are more price-elastic.

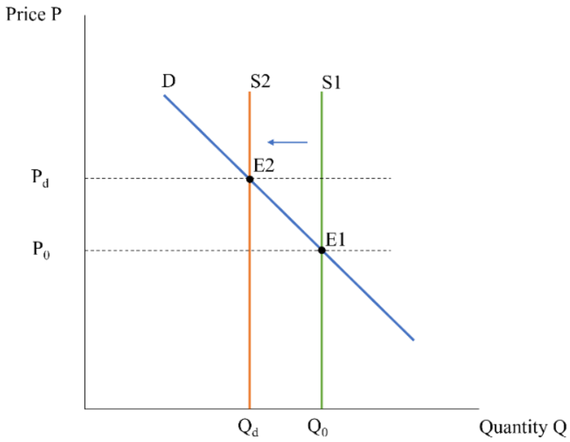

Figure 1: Short-term drought shock's impact on market equilibrium

In the following sections, we explain two methods to calculate the direct costs of drought and two methods that consider possible positive effects. The latter two are based on the economic surplus theory which is part of the field of welfare economics (Boulding, 1945). Several assumptions are made to use these methods (Espinosa-Tasón et al., 2022; Musolino et al., 2017). This study assumes drought as the sole cause of crop losses and attributes price changes exclusively to changes in crop quantity supplied, fully passed on to consumers. The case is considered a closed microeconomic system without import, export, or external influences. Production is assumed to be sold entirely, without stockpiling. However, these assumptions limit the methodology, as actual prices and crop quantity are affected by various factors, including farmers' adaptations to climate change and past crop prices. Individual responses are not included in current calculations. Figure 2 provides an overview of the different market-based approaches used.

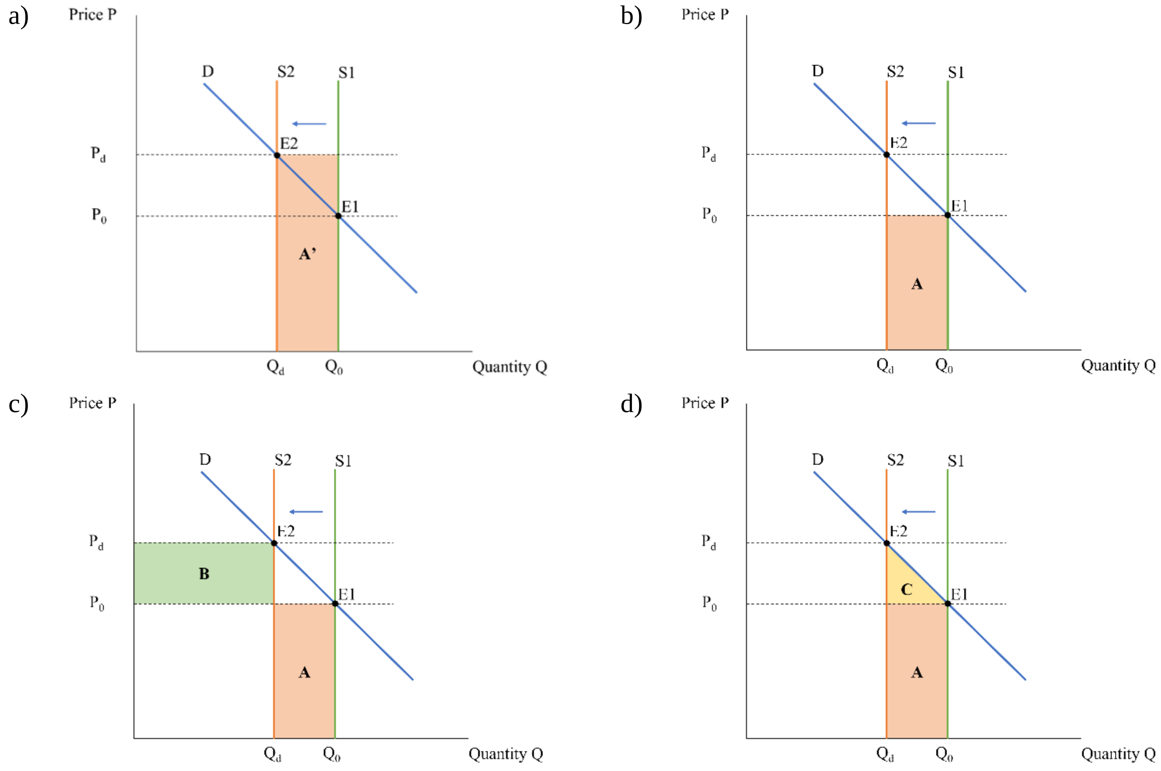

Figure 2: Calculation methods illustrated with a) damage-oriented calculation, b) fixed price calculation, c) producer surplus calculation and d) economic surplus calculation.

2.2.1.1. Method 1: Damage-oriented calculation

This first method focuses on calculating the direct economic costs of drought, by multiplying crop loss quantity with the current market price (VMM, 2021). This method has various limitations since price effects are not considered but it can be used to determine short-term direct costs. It has been used to quantify the effects of irrigation bans during drought years. As depicted in Figure 2 a), the economic costs *A'* are calculated by multiplying the quantity loss *(Q_0-Q_d)* and the price during a drought event P_d. Since a farmer in a regular year would attain crop quantity Q_0, the lost crop quantity cannot be sold at price P_d.

2.2.1.2. Method 2: Fixed price calculation

The second approach varies from the first in that the price increase of P_0 to P_d is ignored, since the drought price P_d can only be reached after a reduction in crop quantity supplied. This follows the law of demand: the lower the quantity supplied is, the higher the price will be (Marshall & Marshall, 1879). Therefore, crops that are lost should not be valued at a price caused by this same reduction. The costs of drought entail the loss of income *A* due to a drought event in this method (van Bakel et al., 2009). No price effects are included in this case as shown in Figure 2 b).

2.2.1.3. Method 3: Producer surplus calculation

The previous methods equated income loss to the economic costs of drought. However, other methods suggest that drought may have positive effects on farmers (Reinhard et al., 2015). Ding et al. (2011) note that farmers can transfer drought-induced losses to consumers. This is included in the calculations by Stratelligence (2021). Two effects can be distinguished that farmers experience during a drought event: a quantity and a price effect (Musolino et al., 2018). The quantity effect entails the income loss (*A*) following the reduction in crop yield (Q_0-Q_d). It is calculated as ($P_0 * (Q_0-Q_d)$). The price effect (B) calculated as ($Q_d * (P_d-P_0)$), represents the additional income gained due to the possible higher price (P_d) at which the residual crop production can be sold. The change in producer surplus is the difference between both effects (*B*-*A*), as shown in Figure 2 c). Should the price effect outweigh the quantity effect, the farmer experiences positive effects due to a drought event. The price elasticity of demand is crucial in these calculations. If demand is more price-inelastic, prices will fluctuate stronger following quantity reduction, and the more positive the change in producer surplus will be.

2.2.1.4. Method 4: Economic surplus calculation

The last method applied allows the quantification of positive and negative effects of drought events in terms of social welfare changes for producers and consumers (Espinosa-Tasón et al., 2022; Musolino et al., 2017; Musolino et al., 2018). Three different effects can be distinguished: the quantity effect, the price effect, and the deadweight loss. The price effect, defined as *B* in Figure 2 d), could lead to an increase in crop income for farmers. However, assuming that price increases are passed on to consumers, this is a zero-sum transfer and should not be considered (Ding et al., 2011). Elements that do affect the calculated social welfare are the quantity effect (*A*) and the deadweight loss (*C*) as shown in Figure 2 d). Deadweight loss indicates reduced crop consumption by consumers and can be calculated as $(((P_d-P_0)*(Q_0-Q_d))/2)$. Adding the effects on consumers and producers will result in a total welfare effect of $(-A-C)$, therefore a total welfare reduction is expected following a drought event affecting the agricultural sector.

Several Dutch reports apply the Agricultural Price Tool to determine potential economic effects following crop quantity loss, considering price effects (Polman et al., 2019; Reinhard et al., 2015; van der Vat et al., 2016). As mentioned, the price elasticity of demand is fundamental in estimating the economic effects experienced by producers and consumers. It expresses the relationship between the percentual change in product quantity demanded and in price (Vukadinović et al., 2017). This can be expressed through the following formula:

$$\epsilon^d = \frac{\partial Q_0^d}{\partial P_0} \ x \ \frac{\partial P_0}{\partial Q_0^d} \qquad (1)$$

ϵ^d represents the elasticity of demand, Q^d_0 represents the crop quantity demanded and P_0 is the crop price. This formula is crucial in calibrating the demand function, which is necessary to estimate the price changes of a crop following a drought event (van der Vat et al., 2016). The calibration is based on crop quantity supplied in a year Q^d_0, the non-drought crop price P_0, the price elasticity of demand ϵ^d, and the crop reduction quantity ΔQ. The demand function can be expressed as:

$$Q_0^d = a + bP_0 \qquad (2)$$

Where *b* stands for the slope and *a* represents the intercept of the demand function. The slope is calculated as depicted in formula (3) while the formula to calculate the intercept is represented in formula (4).

$$b = \epsilon^d \ x \ \frac{Q_0^d}{P_0} \qquad (3)$$

$$a = Q_0^d - bP_0 \qquad (4)$$

The report by van der Vat et al. (2016) uses estimations of price elasticity and changes in crop quantity produced following a drought event to estimate the new crop price. The new demand quantity is determined as $Q^d_n = Q_0 + \Delta Q$. Based on this, the new price P_n is estimated as:

$$P_n = \frac{Q_n^d - a}{b} \qquad (5)$$

This paper employs a case study with known historical prices, prompting slight adjustments in the calculations which are now performed over a range of different elasticities. We determine at which level of price elasticity the calculated price relates closely to the historic price. We apply the estimated price in the calculation of the consumer surplus and then estimate the total welfare effect of a drought period. This explains the difference in the price effect of the producer surplus and economic surplus method. We emphasize that these conceptual methods do not offer precise calculations of the total effects of the 2018 drought in Flanders.

2.2.2. Semi-structured interviews

To evaluate how drought's economic effects are experienced in practice, 11 semi-structured exploratory interviews are conducted with agricultural stakeholders. Specifically, four farmers, two government experts, two potato processors and three sector federation representatives are interviewed. These stakeholders are important allies in the field to mitigate climate change (Micu et al., 2022). Do note that our sample was not limited to farmers, and we do not group our respondents based on their answers as often done (Hyland et al., 2016; Mitter et al., 2019). We interviewed a small sample of various agricultural stakeholders, posing limits to the transferability of our results. However, the results could provide valuable insights into the economic effects of drought, and related issues. Limited guidelines are available for determining non-probabilistic sample sizes, with recommendations ranging from 5 to 60 in-depth interviews (Morse, 2000). Baker and Edwards (2012) state the number of interviews needed "depends" and relates to the point of reaching data saturation. According to Guest et al. (2006), data saturation can become noticeable at 6 in-depth interviews, and evident at 12 in-depth interviews. Our choice of 11 respondents is also influenced by the actors available to be interviewed. Interviewee selection occurred through the public contact information. Farmers of different produce and company sizes were sought out. To guarantee anonymity, company names and crop cultivations are not included. All interviews were recorded and transcribed in Dutch. The interviews were conducted between May 22nd and July 25th, 2023, both in person and online depending on the respondents' availability. The interviews lasted one to two hours.

Benefits of semi-structured interviews include the flexibility of discussion topics, and the possibility to probe responses in depth while ensuring that particular points are covered (Wilson, 2014). Limitations consist of its time-consuming character and limited representativity of the responses (Knott et al., 2022). Data analysis was performed with the qualitative data software package NVivo. The anonymised transcripts were read and coded by the first author, first through open coding, then selective coding and finally through axial coding (Williams & Moser, 2019). The qualitative content analysis included familiarisation with the data, after which a combination of deductive and inductive construction of the codes, aided by exploratory mind maps and word clouds, led to a classification of codes and sub-codes (Drisko & Maschi, 2015). These were re-coded until all respondent's answers could be described in four main themes. Statements that were relevant for multiple topics, could be assigned multiple times.

3. Results

3.1. Results of calculation methods

In Figure 3, a downward-sloping demand curve is calculated based on historic potato prices and the estimated crop quantity by the SWBM (Eurostat, 2022; VMM, 2021). During the 2018 drought, potato yield was reduced by 1,045,760 tonnes while prices per ton increased from €64.7 to €197.45.

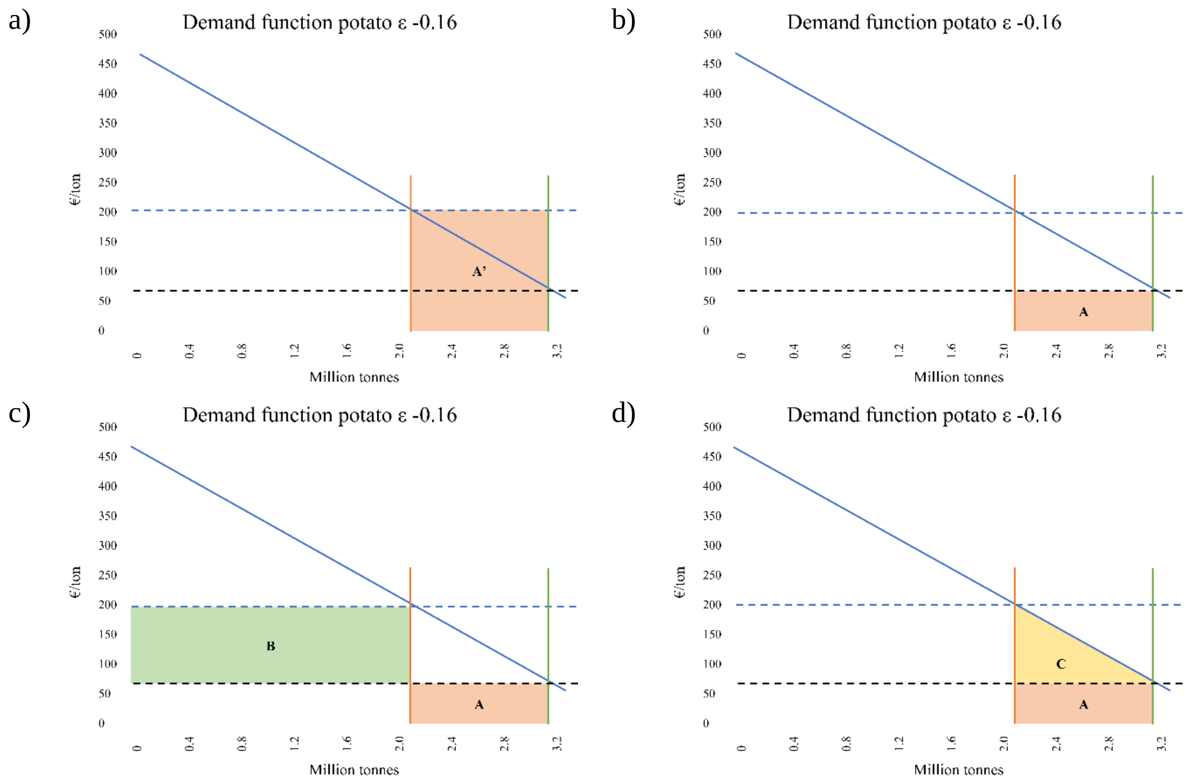

Figure 3: Results of calculations illustrated with a) damage-oriented calculation, b) fixed price calculation, c) producer surplus calculation and d) economic surplus calculation

3.1.1. Damage-oriented calculation

The direct economic cost of drought is calculated here by multiplying the reduction in crop quantity produced with the price during the drought year. This is interpreted as the foregone crop profit due to drought, resulting in a cost *A'* as shown in Figure 3 a). The economic effect amounted to a cost of €206 million.

3.1.2. Fixed price calculation

Figure 3 b) depicts the direct economic costs due to drought, calculated by multiplying the crop price of the previous year with the crop quantity reduction *A*. Since the price increase is ignored, the direct costs are considerably lower than in the previous method at €67 million.

3.1.3. Producer surplus calculation

The possibility of positive price effect *B* is included in this calculation, as depicted in Figure 3 c). The total economic effect is calculated as the difference between the price and quantity effect, resulting in a positive impact on potato farmers. The price effect caused an increase of €278 million while the quantity effect caused a reduction of €67 million, thus increasing producer surplus by €210 million. This positive effect arises due to the price-inelasticity of the crop, causing severe price fluctuations following crop quantity changes.

3.1.4. Economic surplus calculation

In this last method, changes in both consumer and producer surplus are considered. To calculate these changes, the demand function is estimated based on historic price and production data and estimates of the price elasticity of demand. The demand function that closest approaches actual price data relates to a price elasticity of demand of -0.16. The estimated price of €200.21 approaches the actual price data of €197.45. Since a positive price effect for a farmer directly results in a negative price effect for the consumers, price effect *B* is a zero-sum transfer and should be ignored. The effects that do affect welfare are the quantity effect *A* and the deadweight loss *C*, as presented in Figure 3 d). Both reduce the economic surplus. The quantity effect reduces welfare by €67 million while the deadweight loss causes a reduction of €70 million. The 2018 drought event in the agricultural sector led to an estimated effect of -€138 million.

3.1.5. Crops compared

As a robustness check, the calculations are performed for different crops. We show the results of the onion crop in this section. The results of six other crops are included in the appendix. The results of the four calculation methods are depicted in Table 1 for the price-inelastic potato crop during the 2018 drought. While the first methods only depict negative effects, the producer surplus method clearly shows that positive effects can also occur. Considering this price effect, farmers could benefit from a drought event since the remaining crop quantity can be sold at a higher price. However, since this price increase is directly transferred to the consumers, the overall welfare effect remains negative.

Table 1: Economic effects of potato crop, 2018 drought

Potato crop	Affected group	Damage-oriented	Fixed price	Producer surplus	Economic surplus
Quantity effect	Producer	-€206,481,249	-€67,660,675	-€67,660,675	-€67,660,675
Price effect	Producer	/	/	€278,410,276	€284,207,663
	Consumer	/	/	/	-€284,207,663
Deadweight loss	Consumer	/	/	/	-€70,855,630
Total	Producer	-€206,481,249	-€67,660,675	€210,749,601	€216,546,988
	Consumer	/	/	/	-€355,063,293
	Welfare	/	/	/	-€138,516,305

Key to these effects is the price elasticity of demand. Since the potato crop is price-inelastic (-0.16), a small quantity decrease can cause a large price increase. Due to this price increase, the impact of a drought event can be beneficial for farmers. The onion crop was estimated to have a crop price elasticity of -1.43. Here, crop quantity decreased by 160,155 tonnes while the price increased by €14.17 per ton according to historical data. Through the calculated demand function, the estimated price increase is €15.26 per ton. The estimated price is only used for calculations in the economic surplus method, explaining the slight difference in price effect. The results are shown in Table 2.

Table 2: Economic effects of onion crop, 2018 drought

Onion crop	Affected group	Damage-oriented	Fixed price	Producer surplus	Economic surplus
Quantity effect	Producer	-€24,418,734	-€22,149,412	-€22,149,412	-€22,149,412
	Consumer	/	/	/	/
Price effect	Producer	/	/	€12,128,597	€13,060,840
	Consumer	/	/	/	-€13,060,840
Deadweight loss	Producer	/	/	/	/
	Consumer	/	/	/	-€1.221,874
Total	Producer	-€24,418,734	-€22,149,412	-€10,020,815	-€9,088,572
	Consumer	/	/	/	-€14,282,714
	Welfare	/	/	/	-€23,371,286

The total economic effects of the 2018 drought event on the onion crop are always negative. The positive price effect considered in the producer surplus calculation was much smaller than the quantity effect, resulting in a total negative effect. This highlights the importance of considering the price elasticity of demand for a certain crop. Positive effects due to a drought event may arise for agricultural producers with price-inelastic crops, yet the overall welfare effect will always be negative.

3.2. Stakeholders' perception

Since actors in the agricultural sector face several important challenges, discussions during interviews often extended over different themes such as manure and nitrogen standards and the broader issue of climate change and water availability. In the following sections, four main themes of the results are discussed: (1) the general background of the agricultural landscape, (2) the broad effects of drought and other extreme weather events, (3) the perception of the economic effects of drought and (4) stakeholders' outlooks and perceptions of different adaptation measures. Some respondents had opposing views on certain topics. To cope with this, takeaways are highlighted if shared by the majority of respondents, and singular opposing or additional views are mentioned. In Table 3, several key takeaways from the interviews are presented for each of the four main themes.

Table 3: Highlighted results of the perception interviews

Case background	Effects of drought and other disasters
♦ Extreme events and awareness increased over the years ♦ Government develops advice, subsidies, and legislation yet implementation is straining farmers ♦ Farmers feel overly targeted, require support for innovation ♦ Challenging to keep up with legislation and standards ♦ Water access and extraction controversies ♦ Nitrogen and water challenges are connected yet often not recognised	♦ Drought deemed less damaging and more manageable than flooding or heat waves ♦ Negative effects of drought involve reduced crop yield, quality, and rising water demand ♦ Negative chain effects include impact on nitrogen levels in measurements, well-being, and fodder import ♦ Some respondents mentioned possible positive effects following drought such as reduced crop protection, transport, labour, and a possible transition in mindset ♦ Crops grown under contract are more affected in the short term due to lagging price effect
Economic effects	**Adaptation and expectations**
♦ The damage-oriented calculation is too simplistic for a systemic drought shock ♦ The fixed price calculation improves on the damage-oriented calculation, yet insufficiently ♦ The producer surplus calculation gained the most support, but other cost elements (e.g., irrigation) should be included ♦ The economic surplus calculation is deemed interesting, yet measures a broader perspective and provides less applicable results for producers ♦ Differences in price mechanisms and costs should be considered	♦ Irrigation reduces negative effects of drought, yet is expensive, labour-intensive and increases water demand ♦ Concerns about future access to water ♦ Crop breeding and drought-tolerant crops are necessary, yet provide a limited solution ♦ Adaptation measures' effectiveness is context-dependent, soil health is crucial, and individual measures are insufficient ♦ Policymakers should provide more evidence and guidance, alleviate the strain of expectations on farmers and avoid lock-in ♦ Price-incentive to adapt has diminishing marginal returns

3.2.1. Case background

The Flemish agricultural sector has seen an increase in extreme weather events, including drought, heatwaves, and floods. Respondents highlight that the economic impact of such natural disasters is highly crop- and market-specific. Crops grown under contracts only experience price changes in the subsequent year, influenced by external factors like input costs or global events such as conflicts. One potato processor highlights: "*They say it is an expensive year for potatoes, but how many truly benefit? Some profit greatly, while others can barely cover their contract. Water scarcity during drought can hinder irrigation, with possible bans on extraction for irrigation from watercourses. Without your personal water catchment, you are then faced with a fait accompli"*. This last point emphasizes the water availability issues that strain the sector, specifically due to extraction bans and an increasingly arduous process of obtaining groundwater extraction licenses. While the interviewed farmers realise that water is a scarce resource and should be used sustainably, they do feel targeted compared to other sectors. Government experts and sector federations recognize the need for response systems to address recent drought challenges. These systems intend to gather information, provide advice, boost awareness, offer subsidies, and implement legislation for adapting to extreme drought events. However, translating these ambitions into practice encounters hurdles. Agricultural stakeholders contend that compliance information with European, Belgian, and Flemish standards is fragmented, causing a significant administrative workload. Some respondents perceive an increase in restrictions yet support for innovation is lacking. The ever-changing legislative landscape adds complexity to staying compliant: "*The legislation is constantly changing. We struggle to adapt to new systems, only to find out they are altered again.*". A sector federation respondent confirms the need for more guidance: "*Is it clear where agriculture needs to go? People are vocal about it, but we don't have a clear path."* Farmers perceive the government to be protecting consumers. One additional, understated concern is the nitrogen crisis. In recent years, the Flemish government aimed to reduce nitrogen emissions through more strict emissions standards (Merckx et al., 2023). These limit farms' expansion possibilities and could lead to closures, adding risks and uncertainty for farmers. Drought impedes crops' ability to take up regular fertilizer amounts. Interviewed farmers claim that this factor is not considered in nitrogen analyses, potentially leading to sanctions. Interviewed respondents express a readiness for change and stress the importance of nature preservation. However, they raise concerns about the sector's room for innovation and sustainable production amid evolving challenges from extreme weather events and regulatory shifts.

3.2.2. Effects of drought and other disasters

Many respondents view flooding and heat waves as more damaging and less manageable than drought. Flooding impacts sowing and harvest dates, root rot, soil structure and causes storage problems. While drought events are generally perceived as easier to adapt to, one respondent noted that drought control is still in its infancy. The measures taken to mitigate drought's creeping effects are lagging in practice. Drought events can reduce crop yield and quality, in perennial crops even persisting over multiple years. Quality effects include reduced crop size, damaged structure, unsuitability for food, and storage issues. Irrigation could reduce these negative effects yet requires time and resources. Additionally, depending on the timing of the drought, certain crops may only experience temporary stunting. Other negative effects include the increased growth of weeds, rising demand for irrigation, herbicides, and preservatives. Furthermore, uncertainty regarding crop yield and quality can negatively affect farmers' well-being. Lastly, the reduced nitrogen uptake of a crop in drought stress could lead to further sanctions. Some possible positive effects of drought could entail a lesser need for crop protection against plant diseases, reducing labour and transport costs. However, the costs per kg product might not decrease. System transitions could also gain footing: "*One potential upside is people start to see the need for a new system after facing calamities. This needed mental transition can be a benefit*". However, another respondent remarked: "*With a year of abundant rainfall after several drought years, you might sense that the urgency of various political issues diminishes*". Drought has various chain- and societal effects. E.g., in fodder crops, reduced yields could result in increased imports. Additionally, price increases will be less visible for local drought events in Belgium since it is a small market player globally, depending on the crop. International drought events induce price increases due to reduced supply. Furthermore, potato prices on the open market are very volatile, while contract prices are fixed within the same year. Additionally, farmers unable to meet their contracts possibly have to buy their deficit at open market prices. Of course, price increases are influenced by speculation, and emotional and psychological context on the open market as well. A farmer can spread their risk by partly selling under contract, and partly on the open market. Farmers able to invest in adaptation measures could even benefit from natural hazards. However, if there is no access to water, the agricultural production process cannot persist.

3.2.3. Economic effects

Respondents generally view the first method applied in this paper, "damage-oriented calculation", as too simplistic and not applicable in practice. This is because this method possibly overestimates the income reduction and includes too few effects of a drought shock. One respondent did see the potential of this first method in calculating the economic effects of a non-systemic disaster event. The second method, "fixed price calculation", receives some support, especially for crops grown under contract. However, this method does not capture market complexity and ignores adaptation costs. The third method, "producer surplus calculation", is well-received by 90% of respondents. One farmer stated: "*That's correct, with lower crop yield, you can earn the same amount. Of course, if you can still irrigate and maintain high tonnage in that year, it's a golden year because you have your regular production, and the prices are high due to the difficulties in the rest of the sector.*". Several respondents were concerned with its applicability. Due to the lagging price effect, this method cannot be applied for crops under contract. Furthermore, total market impacts cannot be assessed, the results would be more useful for individual farmers. Other concerns were the exclusion of distributive effects and adaptation costs. The fourth method, the "economic surplus calculation", faced more scepticism. While multiple respondents were interested in this method, the results spanned beyond producer-only effects. This method should be investigated further to entail related factors that influence consumer behaviour, simultaneously highlighting the limited market power of farmers. The respondents shared various factors that could be investigated further in drought's economic assessment. Firstly, differences in price changes per crop and per trade method (under contract or open market) need to be highlighted. Open market traders of price inelastic products may experience short-term benefits, but one farmer notes that long-term outcomes are evenly balanced. Related costs, such as those of irrigation, crop protection, energy, labour, adaptation, transport, functional loss of biodiversity, inability to meet nitrogen emission standards, and import of fodder should be considered. Since results are context-specific, this is challenging, and additional insights are required. Another important aspect is climate adaptation. While this could reduce vulnerability to drought, concerns remain surrounding future water availability. Concerning applicability, various respondents mentioned the difference in impacts depends on the actors involved. Positive impacts for one actor could be negative for the other, therefore the diffuse knowledge on drought should be bundled and oriented towards a clear goal.

3.2.4. Adaptation and expectations

In this last section, we highlight the experiences and perspectives of our respondents concerning possible drought adaptations. Irrigation measures are most discussed. Irrigation can mitigate adverse effects on crop yield, allowing farmers to potentially benefit from market price increases during drought. However, investment costs can be high, especially including the costs of water, energy, and labour. Drip irrigation, while more water-efficient, is typically more expensive than travelling gun irrigation. Additionally, drip tape use in arable farming is wasteful and poses a risk if irrigation is unnecessary post-installation. Water availability in the long term is a significant concern, considering extraction bans and stringent groundwater extraction processes. The possibilities of reusing industrial water are limited and met with scepticism. Given this increasing strain on water availability, alternative adaptation measures that reduce irrigation requirements are needed. One such example is cultivating drought-resistant crop varieties. However, natural crop breeding is time-intensive and deemed to be no encompassing solution. The introduction of innovative cultivations is also considered a potential solution, yet uncertainties persist regarding market demand and their feasibility in Flanders. Technical and nature-based solutions, such as recharge- and buffering measures like infiltration pools, level-controlled drainage, recharge basins, and weirs also exist. However, their effectiveness is context-dependent and numerous uncertainties surround their impact. Nurturing soil health emerges as a well-supported adaptation measure since it restores the sponge function of the landscape. Nevertheless, it is emphasized that these measures, while reducing vulnerability to water-related disasters, cannot comprehensively address system-wide issues.

One respondent stated: "*As long as it remains individualistic, there is never going to be a net positive effect. We have also been too quick to focus on adaptation and must not forget mitigation. We need to move towards landscape-scale solutions*". While current adaptation investments have an important visual impact, such efforts alone cannot solve societal challenges. A more collaborative relationship with government bodies is deemed essential, although the ongoing nitrogen crisis communication has strained this relationship. Several respondents highlighted the need for government bodies to provide guidance and evidence. Another risk-reducing measure is the government-encouraged broad weather insurance. However, in Belgium, this system is still in its infancy and has already experienced subsequent disaster years (Vilt.be, 2023). Farmer uptake is lagging due to limited perceived benefits. Some actors see potential in these insurance schemes to buffer non-systemic shocks, stating that government intervention through disaster funds could hinder innovation. Naturally, innovation is paired with increased risk. Due to the various climate- and emission-related challenges, administrative obligations and increasing input prices, farmers do not always have room to innovate. Additionally, one interesting concept relates to adaptation investments and their incentives. First-adopters of adaptation measures may benefit in the short term from increased prices following a reduced market supply. However, if most producers invest in adaptation, the price incentive decreases drastically, and those who do not invest may be worse off. This phenomenon could be compared to the law of diminishing returns. One respondent confirms: "*I agree that there can be an incentive for the farmer to invest in irrigation or short-term adaptation to protect their yield and take advantage of high prices in a weak market. If everyone does this, the price increase will be lower, and you won't have an incentive anymore. If this benefit disappoints, the farmer may say, 'I've done everything I can, and I still get nothing in return, so forget it'*". Subsidies do exist that could support investing in adaptation measures, yet their implementation is lagging. In conclusion, addressing the challenges posed by drought shocks in the agricultural sector necessitates a collaborative and multifaceted approach. Balancing individual farmer initiatives with broader systemic solutions and effective government collaboration is essential.

4. Discussion

Our results follow the findings of Musolino et al. (2017), stating that social groups are affected differently by drought events. This highlights that producers of price-inelastic crops could gain short-term benefits due to price increases following drought. This price effect is context-specific, depending on the crop and farmers' practices, as shown in the appendix. We assumed a closed micro-economic system, yet in reality price changes are affected by various factors, including the market size of producers (Reinhard et al., 2015). This explains why local supply decreases can coincide with price decreases and vice versa. Regardless, some producers could gain positive short-term effects following drought, further emphasizing social justice issues resulting from climate change (Musolino et al., 2018).

Espinosa-Tasón et al. (2022) highlight that farmers who can irrigate benefit from price increases following drought. We posit that investments in climate adaptation measures could provide the same results. This incentivises investment in adaptation measures in the short term. However, should all producers invest in climate adaptation, the price increase will diminish, and the expected incentive vanishes. This relates to the law of diminishing returns, where an increase of one factor, ceteris paribus, will result in an optimum beyond which additional increases will decrease output (Montevirgen, 2023). In this scenario, non-adopters will be worse off since they only experience the quantity effect. Our respondents largely agree that this phenomenon could occur. Additionally, should widespread climate adaptation action be taken, the free rider problem (i.e., a type of market failure where actors can freely benefit from resources) could occur. How this phenomenon will manifest in practice, and possibly hinder adaptation, needs further investigation.

Our interviews showed that while awareness of extreme weather events increases, the implementation of response mechanisms is lagging and increasing pressure on the farmer. While government experts note improvement, other stakeholders struggle to keep up with the changing legislation and related issues, noting limited support for innovation. Woods et al. (2017) note that Danish farmers view policy as hindering adaptive action. Our results suggest a less strong sentiment but emphasize the need to enhance the policy-practice relationship. Another interesting result is that many of our respondents saw drought as more manageable and less damaging than flooding or heat waves. Some respondents even noted possible positive effects of drought such as a mindset transition concerning drought and reduced transport and labour costs. Regarding adaptation and mitigation, the respondents perceive irrigation as crucial, yet resource-intensive and concerns arise on future water availability. More governmental guidance is required on effective adaptation to avoid lock-in mechanisms and ease farmer strain. Furthermore, while individual measures are deemed insufficient, adaptation measures' effectiveness is context-specific. Additionally, Duinen et al. (2015) found that farmers' drought risk perspective, and by extension their willingness to implement adaptation, is motivated by subjective and objective risk variables. They call for policymakers to consider the heterogeneity present in risk perceptions, in policy formulation on adaptation measures. Regarding the perceptions of the actors on the four conceptual calculation methods, the first important aspect is the difference in trade mechanisms. Specifically, the fixed price calculation is deemed more appropriate in contract farming for short-term damages due to a lagging price effect. While these methods' practical applications differ depending on the actor, the producer surplus calculation yielded the most support in open-market farming. However, additional costs such as irrigation should be included. Possible price effect benefits could diminish if variable costs (irrigation, labour, …) increase as well. These costs can be difficult to quantify, such as the value of an additional m3 of water during drought. Mens et al. (2022) attempt to do so by calculating the shadow price of water. While Musolino et al. (2018) state that these increased costs do not offset possible gains, this could be context-specific and needs to be investigated further.

Some limitations are present. Firstly, several assumptions were made to calculate the economic effects of drought. Calculation results are limited to direct and distributive effects in the agricultural sector, excluding chain effects. Crop price and quantity effects are assumed to be solely caused by drought and fully passed on to consumers. Crop prices of subsequent years are compared instead of 5-year price averages. The produced quantity is assumed to be sold and the market is limited to a closed microeconomic system without import, export, or other external factors. Abstraction is made of the concept of crop stocks, therefore only short-term drought shocks can be discussed (Polman et al., 2019). The crop market under investigation here is limited to the Flemish region. In reality, expected price effects will differ depending on the market share in a certain crop (Kobus, 2014; Reinhard et al., 2015). Assuming a local drought, Belgian crop supply fluctuations are insignificant on the world market. No price effect would occur, resulting solely in a negative quantity effect for Flemish farmers. The approach used could be improved further.

Our paper leads to proposals for further research. Firstly, the investigated mechanism where farmers benefit from short-term price increases called a "natural hedge" in literature, indicates a negative price-yield correlation (Finger, 2012). To better delineate the effects of drought, crop prices in drought years could be compared to 5-year crop price averages, or a Tobit regression could be conducted to investigate the natural hedge effect. Secondly, we emphasize the importance of climate adaptation to reduce vulnerability to extreme weather events. The focus is on nature-based solutions, which could induce co-benefits (Miralles-Wilhelm, 2021), not on technical measures such as crop insurance (Di Falco et al., 2014). More information is needed on adaptation measures' effectiveness and farmers' behaviour to invest in them, noting the possible decreasing price incentives should more farmers invest. Thirdly, the long-term effect of drought is not yet clear. It is assumed that farmers adapt their management to reduce vulnerability (Reinhard et al., 2015), yet the effect of this adaptation is unpredictable since the food-price formation system is complex (von Braun & Tadesse, 2012). Particularly interesting is the impact of price volatility (i.e., the dispersion of a price series from the mean), since extreme weather events are one of its root causes. Through changes in farmer adaptation and consumer preferences, price volatility and inelasticity could be reduced in the long run. This needs to be investigated further to tackle uncertainties in the food-price markets. Fourth, possible production cost increases following drought could offset the possible positive price effect. Fifth, the impact of drought events on farmers' well-being is understated in literature. Lastly, our interview results emphasized that drought management should be framed in the broader agricultural system. Specifically, the interaction of drought and nitrogen emissions requires further research. While challenging, fragmentation of agricultural policy should be avoided. Added insights into the economic effects of drought and how they are perceived can aid policymakers in deciding on their drought policy measures, especially noting the increasing frequency of extreme weather events.

5. Conclusion

We describe four conceptual market-based approaches, based on partial equilibrium analysis, to calculate the direct and distributive effects of drought on the Flemish agricultural sector during the 2018 drought. We contribute to the existing literature by including agricultural stakeholders' perceptions of drought's economic effects. The results show that the economic effects vary greatly per calculation method. Specifically, we find that some social groups could benefit from drought, as shown in the work of Musolino et al. (2017). Following producer surplus calculations, potato farmers in 2018 experienced an estimated increase in crop income of €210 million through a positive price effect, possibly due to a strong natural hedge. However, the effects on total welfare are always negative because of the zero-sum transfer of the price effect. Consumers are always negatively affected. Since some farmers can benefit from a drought event, the traditional response of taking public relief measures could be inefficient. Because adaptation measures may safeguard crop yield during extreme weather events, price increases in the market following a drought event could pose a short-term incentive to invest in them. However, should the entire sector invest in adaptation, this incentive disappears.

While we cannot generalise our findings for all farmers and crops in Flanders, we can draw several exploratory conclusions from our interviews. Firstly, the current legislative context is expanding, yet challenging to adhere to. The effects of drought take many forms, but this extreme weather event is considered more manageable than flooding or heat waves. Irrigation reduces drought's negative effects yet concerns arise for future water security. Other adaptation measures' effectiveness is context-specific, and increased governmental guidance and support for innovation is needed. Farmers feel overly targeted in water restrictions compared to other users and related issues like nitrogen emissions. They disagree that consumers are largely negatively affected by drought. As for the conceptual methods, while each could have its merit depending on the usage, the producer surplus calculation yields the most support to estimate the economic effects of drought. However, this method is incomplete as well, and more information on related costs such as irrigation should be included.

The results highlight that price elasticity is key in determining the size of distributive effects following a drought event. Farmers of price-inelastic crops like potatoes could experience a crop income increase, even though their crop production decreases. However, in the case of price-elastic crops, the negative quantity effect outweighs the positive price effect. Important to note is that crop prices are not only affected by demand. While price elasticities and the natural hedge effect are key in further investigation of the economic effects of drought, other factors such as increased costs of input and adaptation costs could also influence the economic effect experienced by farmers. Additionally, only the short-term effects of drought are considered here. In conclusion, our study urges policymakers to design a more efficient relief system and promote the implementation of climate adaptation measures adapted to the local context.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT 3.5 to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Appendix

In the appendix, the economic surplus method is applied for six crop types. Table 4 clearly shows that the price effect for farmers is not always positive, as would be expected following the law of demand. Calculations are made based on the historical price data actualised at the 2017 level. No demand functions were estimated. The quantity effect is calculated through (*P0 * (Q0-Qd))*. The price effect is calculated as (*Qd * (Pd-P0))*. Finally, deadweight loss is calculated as (((*Pd-P0*)*(*Q0-Qd*))*/2*). Three out of six investigated crops below experienced a reduction in both crop price and crop quantity.

Table 4: Comparison of crop effects

Crop type	Affected group	Quantity effect	Price effect	Deadweight "loss"
Apple	Producer	-€145,063,691	€129,857,424	/
	Consumer	/	-€129,857,424	-€27,316,431
Sugar beet[a]	Producer	-€6,468,534	-€3,661,180	/
	Consumer	/	€3,661,180	€295,264
Pear[a]	Producer	-€181,314,997	-€54,291,320	/
	Consumer	/	€54,291,320	€11,420,564
Carrot	Producer	-€52,322,581	€88,648,515	/
	Consumer	/	-€88,648,515	-€8,293,292
Beans[a]	Producer	-€1.026,503	-€5,749,208	/
	Consumer	/	€5,749,208	€18,054
Leek	Producer	-€1,921,260	€72,780,897	/
	Consumer	/	-€72,780,897	-€907,598

Superscript [a] indicates a crop where both a crop quantity and price reduction occurred. Deadweight "loss" is therefore not always negative.