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EU Dairy after the Quota Abolition: Inelastic Asymmetric Price Responsiveness and Adverse Milk Supply during Crisis Time

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Abstract: The abolition of the milk quota system in April 2015 has implied a transition towards a new "system" in which non-policy and non-EU elements have become important drivers of the EU dairy market. In terms of its contribution, after reviewing some of the existing literature, this article presents a theoretical framework to understand "irregular" supply behaviour, while it empirically identifies an "inverse" supply curve for the EU dairy sector. In doing so, milk prices have been decomposed by following the procedure proposed by James P. Houck. This exercise confirms the non-reversibility, and therefore an asymmetric response, in the behaviour of milk supply for most EU Member States. Moreover, this article also presents the results of a "stress" test of the dairy sector in order to analyse the responses of dairy production in a context of the asymmetrical behaviour of dairy farmers and assess the competitiveness of the dairy sector at Member State level. The outcomes emphasise the high competitiveness of the Irish dairy sector and suggest a deterioration of the competitiveness in the case of the United Kingdom and France. From the policy-making perspective, the identification of this type of farmer's reactions is key for an appropriate design of policy interventions and crisis management strategies.

Keywords: price asymmetry; agricultural commodities; price decomposition; dairy production; EU28

JEL Classification: D01; D40; Q10; Q11

1. Introduction

The EU's abolition of the milk quota system in April 2015 implied an important structural change with respect to the policy regime applicable to the dairy sector [1–4]. The milk quota system, introduced in 1984, provided national production quotas at Member State levels and individual quotas fixed for each producer or purchaser, with a levy payable (the "super-levy") for those exceeding their quota. For more than 30 years, the quota regime managed the EU milk supply and effectively contributed to curbing the oversupply that was characterizing the EU dairy sector in the 1970s and early 1980s. With the abandonment of the milk quota, an important constraint on the sector's development has been taken away, allowing market forces to become the primary driver of milk supply [5]. In order to smooth this transition, the European Commission (EC) introduced a so-called "soft landing policy", i.e., since 2009, the milk quotas were gradually expanded by 1 percent per annum. For most Member States, this led to a gradual phasing out of the milk quota [6]. At the moment of the milk quota abandonment, April 2015, only 12 out of the 28 Member States (MS) still had binding quotas (quotas that were effectively constraining milk supply). More specifically, these countries were Austria, Belgium, Cyprus, Denmark, Estonia, Germany, Ireland, Italy, Luxembourg, the Netherlands, Poland and Spain.

From a conceptual point of view, the abolition of the quota can be considered as a "trigger event" that may have induced a change in European farmers' strategies, forcing them to move from a path dependent stage into further phases of the farm management

decision-making cycle [7]. In the context of farm resilience [8], changes in the Common Agricultural Policy (CAP) require farms to rely on their adaptive capability. However, it can be argued that the abolition of the quota system implied the transition towards a new "system" in which non-policy elements become important drivers of the market. This transition created the need for farmers to reform their existing management strategies in order to explore the opportunities that open up beyond the borders of the EU. Therefore, this change in the CAP also required farms to use their transformative capability rather than relying solely on their adaptive capability.

The main contribution of this paper is to empirically confirm the existence of an "inverse" supply curve for the dairy sector. This is highly relevant when designing policy interventions to support dairy farmers since a well-deigned policy intervention relies on a good understanding of the behaviour of those operating in the market. More specifically, this piece of research reports on an "adverse" supply behaviour of farmers during a market crisis in which unusually low market prices were registered. This pattern is characterised by a relative increase in production in those periods in which low/declining milk prices are driving the market. To understand this short-run behaviour, two different mechanisms should be kept in mind: (i) low prices will result in an improvement of the affordability of milk that could lead to an increase in consumers' demand; and (ii) the producer's need for increasing the number of units sold in order to cover fixed production costs. From a policy-making perspective, the identification of this "counter-intuitive" pattern is crucial for the implementation of well-designed policies for crisis management, as well as in the context of the future CAP post-2020, which is more market-oriented than the existing body of regulation. Additional motivation for this piece of research is coming from the importance of having a better understanding of price responses of agricultural products under "crisis" conditions. An illustration of this need has come with the COVID-19 outbreak and the Russia-Ukrainian war, which had provoked important trade disruptions and has threatened the agri-food chain at various levels, e.g., shortages of labour force, temporarily closure of the food service and HoReCa channel, changes in consumers' preferences, etc.

After this introduction, the remainder of this paper is organised as follows. Section 2 focuses on reviewing the existing literature about farm behaviour and milk pricing, while it also presents a theoretical framework to understand "irregular" supply behaviour. Section 3 provides evidence on the observed asymmetric behaviour of farms and further explores the topic by decomposing prices. Finally, Section 4 summarises and concludes.

2. Materials and Methods

2.1. Milk Production and Management Practices

During the production cycle, a dairy farmer faces three important types of management decisions that are relevant to understand milk supply. Firstly, regarding his/her strategic planning, a farmer has to decide how large a dairy herd he/she should manage. Related to this decision, there are further associated investment decisions with respect to herd replacement and other assets determining the production capacity (e.g., stable, milking parlour, land-base). Note that this also relates to more general farm growth and exit strategies and this has a link to the farm household life cycle [9]. Secondly, and at a tactical level, a farmer has to choose the factors of production in order to achieve his/her desired output level. This includes the choice for a specific farming system, as well as specific dairy cow buying/selling and insemination decisions. Thirdly, at an operational level, a farmer has to make daily decisions about cow nutrition and pasture management by taking into account varying weather and market conditions that will influence the milk yield.

Therefore, milk production at farm level is the outcome of economic elements and is also influenced by a non-tangible factor, i.e., the strategy followed by the farmer in the decision-making process. It is via this strategy or longer-term vision that a farmer "coordinates" all his action at the noted three decision-making levels. Focusing on the Dutch context during the post-quota period, ref. [10] suggest that farmers' production strategies are the outcomes of economic factors, farms' structural factors, as well as other

elements such as social and environmental conditions. The understanding of the drivers of the mentioned decision-making process has been gaining increasing attention through time. A seminal contribution in this field is [11], who analyse the role played by attitudes and objectives within the overall process by estimating a structural equation model (SEM). This piece of research distinguishes between business and environmentally oriented behaviour, emphasising the importance of psychological factors within the process. Moreover, previous work by [12] provides a wider typology that in addition to business and environmentally-oriented behaviour includes categories such as emergent and stressed behaviour. For a complete 'picture', we also refer to [13–15] which provide examples of different estimation methods for forecasting and empirically modelling milk supply.

On a different matter, ref. [16] presents an example of how stochastic budgeting can be used for assisting the whole-farm decision-making process in a quota regime by focusing on a Norwegian dairy farm. The adoption of such an approach is based on the fact that the farming business entails substantial risks that should be assessed properly when designing the strategy to pursue in the coming years. Moreover, ref. [17] propose the use of decision-making profiles and the analysis of managerial capacities of farmers to explain the management strategies and performance of dairy farms. Specifically, management is assessed in terms of pasture management, nutritional and reproductive strategies, and aspects of animal health. The analysis of performance includes milk yield per cow per day, milk yield per hectare per year, margin per cow per day, margin per ha per year, rate of and return on working capital, as well as an indicator of efficiency.

Another important aspect in farm behaviour is the credit risk aversion and the liquidity management approach that is followed. As defined by [18], liquidity management helps farmers to cope with fluctuations in cash flows related to unexpected changes in commodity prices, yields, and the cost of production inputs. When credit enters in the system, farmers lose part of their financial capacity in favour to the lenders, which might change their behaviour in view of the general developments of agriculture and the conditions of the financial markets. This additional uncertainty is the "premium" that farmers have to pay for using credit as a source of liquidity. More specifically, liquidity constraints seem to play an important role for the timing of key decisions that farmers need to take in the course of their productive activities. As [19] explored by means of a survey conducted in Mozambique, those farmers that are liquidity-constrained sell their harvest 50 percent more rapidly than those that are not liquidity-constrained. These authors also conclude that liquidity-constrained farmers are more responsive to their expectations about future price developments and to price risk than those who are not subject to this type of constrain. Moreover, ref. [20] tested the life cycle-permanent income hypothesis for farmers in the US and found that they behaved according to this hypothesis, in contrast to people working as "wage-earners". This suggests that family farmers in industrialised economies borrow from and lend to their farms to smooth their consumption, thereby temporarily affecting the financial situation and managerial behaviour of farmers.

2.2. Milk Pricing: Formation, Volatility and Asymmetry

With regard to milk price formation, ref. [21] explore the existence of a cycle in milk prices, as well as their implications for the US dairy supply change. In doing so, they apply the state space method (SSM) to explain milk prices as a function of seasonal dummies, cyclical components, feed prices, exports values, and quantities among others. Their results indicate that there is indeed a transmission of feed costs to milk prices, which might appear with some delay in time. In particular, their analysis reveals that an increase in the cost of 100 lbs of ration is associated with a USD 0.83/cwt increase in milk prices during the same quarter.

A key aspect to discuss is the relationship among productivity, regulation, and price volatility in the dairy sector. Focusing on the southeast of Germany, ref. [22] investigate the development of productivity during the phasing-out of the EU milk quota. This paper found empirical evidence in favour of the hypothesis that a reallocation of resources

towards more productive farms increased during the phasing-out of the quota system in the EU. Moreover, the reallocation of resources towards more productive farms seems to be favoured by peaks in milk prices too. Nevertheless, policy developments that support improvements of productivity within farms could potentially contribute to the overall efficiency of the sector since a large share of the productivity gains observed at sectoral level can be attributed to productivity growth within farms. The effects of price volatility on the exit and entry behaviour of farms have been also studied by [23], who observed two different effects. On the one hand, higher price volatility has a positive effect on the probability of new farms entering the market. On the other hand, increasing price volatility leads to an increase in the probability of exiting the market for small farms, while it reduces the exit probability for large farms. Moreover, ref. [24] focus on different segments of the supply chain of dairy products and report that retail prices are less volatile than milk producer prices. An additional finding of this piece of research is that while producer and wholesale prices are subject to seasonality, consumer prices do not reflect any seasonality. Therefore, the potential seasonality that might exist seems to be counterbalanced by other stages of the supply chain, including processors, retailers, and wholesalers. Furthermore, ref. [25] rely on the Farm Accountancy Data Network (FADN) database to analyse the economic situation of EU dairy farmers. This study identifies important differences in terms of production scale and manufacturing intensity across EU farmers. Overall, the analysis points out that the medium- and large-sized intensive farms are key when it comes to understand the developments of milk supply within the EU. This segment of farms shows high productivity levels although their profitability seems to be constrained. For further details on the EU dairy milk supply chain the reader is referred to [26].

In terms of the cost differentiation of farms, ref. [5] find that elements such as milk output, milk yield, herd size, labour input, and fodder production are related to marginal cost differentiation. However, in the case of crop and animal output, grassland, stock of other animals, and depreciation, only minor differentiation across farms was identified. Moreover, ref. [27] explore the potential role of different risk management strategies to cope with prices (and income) volatility in the Netherlands. Higher income volatility is reported in the case of smaller dairy farms compared to the larger ones. However, income volatility for dairy farmers is less pronounced than in other sectors such as arable, horticulture, pig, or poultry farming. The authors of [28] also focus on milk price volatility, paying special attention to the cost of feed across several countries. This paper studies the contribution of different elements to the total production cost in a sample of 46 countries. Focusing on 2010, the cost of milk production in 2010 was in the range from 16.91 USD/100 kg Energy Corrected Milk (ECM) to 97.27 USD/100 kg ECM. The upper-bound figure corresponds to Switzerland, while the lower bound is the case of Armenia. The cost differences are mainly explained by the diversity in feeding systems and farming practices. Overall, purchased feed costs and labour seems to be the most important cost components, although land and machinery also played roles. The econometric analysis concludes that costs are highly correlated with milk yield and milk price but not to herd size.

For a better understanding of milk price responses, it is key to analyse the presence of possible asymmetries in the market. In this context, ref. [29] concentrate on the evolution of the Spanish dairy market over the period from July 1994 to December 2000. The authors of [29] found that the scarcity of quotas has offered some protection to milk farms, bringing milk prices above the level that probably should have corresponded to a market situation with no quota system in place. This study indicates the presence of menu costs in the Spanish dairy market and, therefore, the existence of small and asymmetric responses from retail prices to farm-price shocks. Moreover, ref. [30] study the mechanism of price transmission between producer and consumer prices for milk prices in the case of Austria. By using vector error correction models, their analysis also confirms that asymmetries play an important role in the pass-through of prices for milk products in the market under consideration. Their co-integration framework suggests that the adjustment to the equilibrium level only occurs when deviations from the mentioned level are large enough.

The presence of an asymmetric behaviour [31,32] that causes farmers to increase supply in response to a context of low and declining prices is also confirmed by our contribution (Section 3). From a broader perspective, ref. [33] focus on the European food market and also identified several cases of price asymmetry along the supply chain. The authors find that in both the long- and short-run, retail prices respond more strongly to processor price increases than decreases, while the same is observed for processor prices due to farm price changes.

Finally, we also refer to [34] who developed a two-period cycle model in order to represent farm households' behaviours in which production and restrictions on debt are considered. As the model shows, in those cases in which the household is debt constrained, it is possible that the farmer reacts by increasing the output in response price declines that are exogenously induced to the market. This type of "adverse" market reaction is further discussed and explored in Section 2.3.

2.3. A Framework to Understand "Irregular" Supply Behaviour

The adverse price response behaviour might seem to be at odds with basic microeconomic producer theory [34,35], but this needs not to be so when a more general approach than short-run profit maximization is followed [36]. As has been argued before, the literature suggests that farmers indeed follow certain strategies in which they "connect" decisions at the operational level (how to respond to a short run price shock) with other levels (tactical, strategic). This quite naturally follows from an intertemporal profit or utility maximizing framework [37]. However, it should be highlighted that that under extreme conditions (e.g., a large drop in prices) the conventional separability assumption between the farm production and the farm household part may no longer hold. According to this separability assumption the family farm household production and consumption decisions can be analysed independently. Under extreme conditions this may no longer be the case since the farm household wants to extract a minimum amount of money from the firm for consumption purposes, while there are also obligations with respect to the payment of debt services and the bills of purchased inputs. A framework to understand and analyse this is a farm household production model [38]. In this framework, the farm household is assumed to maximize a utility function $U(.)$ subject to three constraints: (i) a production technology $F(.)$ constraint; (ii) a budget constraint BC; and (iii) a time constraint. In order to address the challenges posed at the operational level by extreme farming conditions (say a very low price-period due to a dairy market crisis), a fourth constraint is added to this model: a liquidity constraint $LC(.)$ [38]. This has to be taken into account because a farmer also under such conditions has to satisfy a minimum number of financial obligations as indicated above. This liquidity constraint, or "additional short term budget constraint", can become binding under extreme conditions and is then likely to then codetermine short-run production decisions.

To further illustrate this, and building on [39], the farm household is assumed to maximize $U(.)$, which satisfies the standard properties and is a function of a composite consumption good c and leisure time l (consumption of own produced good is assumed to be zero).

$$U = U(\,c,\,l) \tag{1a}$$

subject to:

$$F(q; x,\,L) = 0 \tag{1b}$$

$$p_c \cdot c \ \leq p_q \cdot q - v - x + S \tag{1c}$$

$$l + L \ \leq E \tag{1d}$$

$$\alpha \cdot (p_c \cdot c_{min} + v \cdot x) \leq \alpha \cdot (p_q \cdot q) + S \tag{1e}$$

p is the price of food with the quantity produced being q, v represents the price of variable input x, and L represents labour time worked at the farm. The symbol α indicates the fraction of the costs for farm inputs and basic consumption that have to be incurred/covered

independent of the actual profitability of the farm. S stands for off-farm transfers or policy support, e.g., the EU direct payments of the CAP.

By substituting the time constraint and writing the Lagrangian yields, we obtain Equation (2):

$$L = U(c,\ E - L) + \lambda\ BC(.) + \varphi\ F(.) + \mu\ LC(.) \tag{2}$$

The first order conditions associated with this optimization problem are shown in Equations (3a)–(3c):

$$\varphi \cdot \partial F(.)/\partial q = \lambda\ p^* \tag{3a}$$

$$\varphi \cdot \partial F(.)/\partial x = -\lambda\ v^* \tag{3b}$$

$$\varphi \cdot \partial F(.)/\partial L = -\lambda\ w^* \tag{3c}$$

where $p^* = (1 + a\ \mu/\lambda) \cdot p$, $v^* = (1 + a\ \mu/\lambda) \cdot v$, and $w^* = (1 + a\ \mu/\lambda) \cdot w$, with w being the (exogenous) price of labour.

Under extreme conditions the liquidity constraint is likely to be binding and the farmer responds to the shadow price p^* rather than the (lower) market price p. Additionally, then the responses with respect to variable input use (v^*) and labour input (w^*) become different from normal market signals. Graphically (as seen in Figure 1), this can be illustrated by a temporary outward shift of the supply curve, where S' is the shadow price-equivalent supply curve (defined as a function of the observed market price), which is to the right of the conventional supply curve $S(p)$.
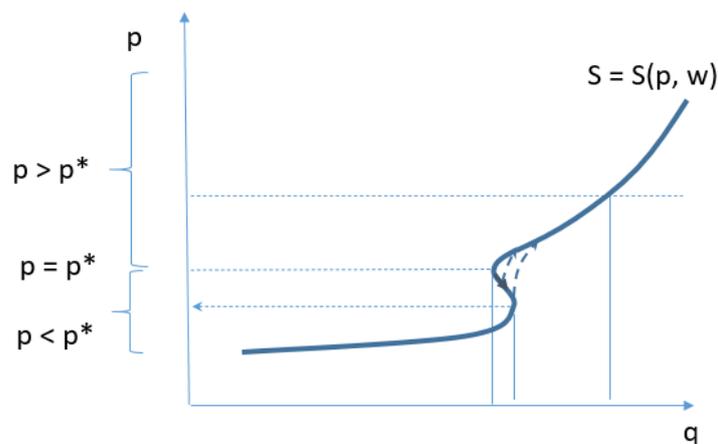

Figure 1. Supply curve under liquidity constraints. Source: Authors. Note: p^* is a benchmark price. When the price declines to a level below p^*, the liquidity constraint is binding and the supply will increase. When the price further declines, the supply will increase further to ensure a certain minimum cash flow. Beyond a certain point, the firm will sharply diminish its supply and/or close business. Moreover, when the price increases (given $p < p^*$), it will not follow the flat supply curve and decrease its supply with increasing prices, but it will rather follow a route according to the dotted lines and directly lead to increases in supply. This causes an asymmetric price response pattern.

The model presented above (see Equations (2) and (3)) is a very rich and generic model. When adding specific assumptions, various types of asymmetric price responses can be shown, deriving from different origins, such as: (i) the avoidance of a financial disaster; (ii) the presence of cash/non-cash inputs; (iii) the consideration soil regenerative aspects; (iv) the risk aversion in relation to busts and booms; and (v) the degree of capacity utilisation and development among others. To further elaborate on these elements, we begin with the avoidance of a financial disaster. In this case, the farm can be shown to increase its family labour efforts under financial stress conditions, with the aim to meet urgent external financial obligations and a minimum consumption level, e.g., [37]. In terms of the presence of cash/non-cash inputs, it is important to mention that the family labour adjustment is a specific illustration of the use of cash/non-cash inputs, where a farmer

can increase its output by reallocating its purchased versus non-purchased inputs (e.g., roughage produced from owned pasture) mix [40]. Regarding soil regeneration, one should keep in mind that under financial stress conditions the farmer can adjust the fallow land and crop rotation and trade-off future productivity effects against short-run soil productivity "investments" [37]. Focusing on the farmer's risk aversion, a relevant aspect is that a farmer's wealth may decline during a bust (due to declining land prices), with a lower wealth increasing a farmer's risk aversion, which in turn may lead to "adverse supply behaviour" [37]. Finally, moving to the capacity utilization and development aspects, it should be considered that a farmer's dynamic optimization behaviour may lead to adverse investment and production responses to temporal/instantaneous price signals, especially when these differ from (expected) longer term equilibrium patterns [41].

In the remaining sections of this paper, we will not try to capture the details that can lead to adverse supply behaviour because the available data would not allow for this, e.g., there is a lack of farmer wealth and risk-aversion data both at individual and sectoral levels. Instead, the focus will be on the empirical identification of an adverse supply behaviour in the EU dairy sector.

3. Results and Discussion

3.1. Milk Supply Responses within the EU

Coming back to the structural characteristics of the dairy sector across the EU, it is important to analyse the responses of milk supply over different periods in which the market was driven by unusual low milk prices, i.e., the periods 2007m11–2009m05 and 2013m11–2016m07. This kind of "stress test" provides us with further insights regarding the competitiveness of the dairy sector across the different MS (Table 1).

Table 1. Comparison price and quantity reactions of milk production.

	Period from 2007m11 to 2009m05			Period from 2013m11 to 2016m07		
	% Change in Price	% Change in Quantity	Ratio (% Change Quantity/% Change Price)	% Change in Price	% Change in Quantity	Ratio (% Change Quantity/% Change Price)
Austria	−39.73	24.03	−0.60	−35.28	11.42	−0.32
Belgium	−69.54	20.50	−0.29	−61.69	17.63	−0.29
Bulgaria	−27.71	3.93	−0.14	−34.70	13.65	−0.39
Croatia	NA	19.58	NA	−28.18	3.86	−0.14
Cyprus	15.95	7.75	0.49	−5.67	22.22	−3.92
Czech Republic	−49.53	9.89	−0.20	−41.82	24.49	−0.59
Denmark	−43.33	17.61	−0.41	−50.07	15.31	−0.31
Estonia	−46.02	15.38	−0.33	−55.41	10.11	−0.18
Finland	−17.40	15.42	−0.89	−30.01	10.79	−0.36
France	−31.73	10.74	−0.34	−27.00	1.16	−0.04
Germany	−58.68	17.60	−0.30	−57.80	14.09	−0.24
Greece	−20.44	15.82	−0.77	−18.02	4.64	−0.26
Hungary	−46.06	17.23	−0.37	−50.29	12.16	−0.24
Ireland	−68.88	83.07	−1.21	−58.84	95.58	−1.62
Italy	−20.60	16.12	−0.78	−26.68	4.10	−0.15
Latvia	−69.36	17.05	−0.25	−60.80	32.62	−0.54
Lithuania	−72.00	19.67	−0.27	−72.85	35.20	−0.48

Table 1. *Cont.*

	Period from 2007m11 to 2009m05			Period from 2013m11 to 2016m07		
	% Change in Price	**% Change in Quantity**	**Ratio (% Change Quantity/% Change Price)**	**% Change in Price**	**% Change in Quantity**	**Ratio (% Change Quantity/% Change Price)**
Luxembourg	−60.06	25.66	−0.43	−49.52	31.58	−0.64
Malta	NA	NA	NA	−8.04	NA	NA
Netherlands	−59.91	14.41	−0.24	−55.07	22.73	−0.41
Poland	−51.74	29.22	−0.56	−44.32	22.75	−0.51
Portugal	−32.45	24.34	−0.75	−29.89	14.13	−0.47
Romania	NA	20.46	NA	−35.68	27.24	−0.76
Slovenia	−24.41	12.76	−0.52	−40.60	19.43	−0.48
Slovakia	−59.62	4.93	−0.08	−40.96	10.21	−0.25
Spain	−47.59	12.22	−0.26	−30.26	12.87	−0.43
Sweden	−45.15	14.87	−0.33	−43.47	5.03	−0.12
United Kingdom	−48.48	17.04	−0.35	−49.91	8.78	−0.18

Source: Authors' elaboration based on Eurostat and AGMEMOD.

Drawing attention to the period from 2007m11 to 2009m05, Table 1 reports large price declines (around −70 per cent) in the case of Lithuania, Latvia, Ireland, and Belgium. During this period, prices also reacted considerably in countries such as Luxembourg, Slovakia, Germany, and the Netherlands in which milk prices declined at least by 60 per cent. Conversely, milk prices in Finland, Italy, and Greece were less sensitive to market conditions, declining by 20 per cent over the period under consideration. In terms of the volume of milk collected, a sharp increase in production was registered in Ireland (83%). This reaction is far away from the responses that were observed in the rest of the countries under analysis. For example, in the case of important dairy producers such as Germany, the Netherlands, and the United Kingdom, the increases were around 14–17 per cent. During this period, only a small increase (around 3%) was registered in the case of Bulgaria, which was accompanied by a price decline of 27 per cent.

With regard to the period from 2013m11 to 2016m07, important differences are observed across the countries. More specifically, the largest negative changes in prices were observed in Lithuania (−72%), Belgium (−61%), Latvia (60%), and Germany (−57%). Milk prices also declined notably in the case of other main EU players such as Ireland, the Netherlands, and the United Kingdom (−58%, −55%, and −49%, respectively). However, small economies such as Malta and Cyprus seemed to be less sensitive to the market situation, as indicated by the low-price response. Moving to the production responses that were observed during this period, the reactions in the case of the Irish economy need to be highlighted since the amount of milk collected increased by 96 per cent compared to the beginning of the period. More moderate increases were observed in Latvia and Luxembourg (33% and 32%, respectively). In contrast, the volume of milk collected over the period increased by less than 10 per cent in the case of Greece, France, Croatia, Italy, Sweden, and the United Kingdom.

When jointly analysing price and quantity responses over the period from 2007m11 to 2009m05, a strong responsiveness of the volume of milk that is produced is observed in Ireland, with milk production increasing by 1.2 per cent in response to a 1 per cent decline in milk prices. Slower responses are observed in countries such as Greece, Italy, Poland, and Finland, in which increases in the range of 0.56–0.88 per cent occurred in response to a 1 per cent decline in price. During this period, milk production seemed to be less sensitive to changes in prices in the case of Bulgaria, the Czech Republic, and Slovakia (−0.14, −0.19, and −0.08, respectively). A slightly different picture is observed during

the period from 2013m11 to 2016m07. Dairy farms in France and the United Kingdom exhibited weaker reactions during the most recent period. In contrast, the strongest increase in milk production associated with a 1 per cent decrease in prices is found in Cyprus and Ireland (3.9 and 1.6 per cent, respectively). Nevertheless, some statistical issues have been encountered when analysing the data for Cyprus. Therefore, the reader is advised to consider this figure with caution.

The positive responses of milk production to price declines suggest the existence of a downward sloping supply curve that emerges during "stressful" market conditions, i.e., periods of low market prices, which could explain market behaviour in the short run. The observed supply reaction can be decomposed in a movement along the supply curve (pure milk price response, which according to economic theory should be negative) and a rightward/upward shift of the supply curve (a net positive technology-shift cum herd adjustment). The technology shift may have been strengthened because "extreme" market conditions forced the farmers to improve productivity. Assuming a technology shift of 0.8 per cent per annum, this implies that the so-called "pure milk price response" to the observed price declines is still positive in most cases. The inverse price response maybe due to the need farmers felt for increasing sales in order to cover production costs, benefit of economies of scale, and ensure profitability in a context of shrinking margins. For the second period, it may also be partly related to the peak prices of 2013 and the positive but lagged response to this past price increase. Further discussion deserves the case of Ireland, in which these shifts of the supply curve seemed to have played a big role to shape the dynamics of the market. More specifically, there was a strong milk supply push policy along the supply chain, i.e. processors invested in capacity and contracted farmers, agreements such as the pricing scheme offered to dairy farmers by Glanbia to guarantee more stable prices were put in place, etc.

Note that the "inverse" supply response has been consistently observed for all Member States for both periods, a phenomenon that complicates the estimation of the "regular" supply response. Similar supply responses have been observed in the case of other commodities such as natural gas [42], beef meat [43], and pork meat [44] among others. In a market situation characterised by low prices that are maintained in the long run, only the most competitive farmers are likely to be able to increase production in order to satisfy a rising demand that follows an improve in "milk affordability". Coming back to the analysis of the European market, the results above reveal the competitiveness of the Irish dairy sector during both periods. However, the competitiveness seems to have deteriorated in the United Kingdom and France, as indicated by a slower quantity response during the second period.

3.2. Milk Price Decomposition

The identification of price asymmetries in supply/demand responses seems to be a recurrent topic in economics. Since the early 1970s, several approaches to decompose price time series have been developed. To begin with, we refer to the initial proposal by [45] to study the supply of agricultural commodities. Author of [45] modifies the proposal by [46], who accounted for the irreversibility of supply-to-price changes by segmenting the price variable into two variables, i.e., one for increasing prices and another one for decreasing prices. Wolffram's [45] suggestion is to replace the lacking serial values at the end and the beginning of the "segmented" variables by the last observation value of each preceding period. Moreover, ref. [47] studies the presence of non-irreversibility in t that translates into asymmetrical changes from a previous position $t-1$. An important highlight of this contribution is that differential effects are assessed in terms of changes from the previous position and not its level, this point not being acknowledged by the previous [45,46] and even later price decompositions [31,32].

Then, the topic was revisited in the 1990s in the context of energy demand. In particular, ref. [31] proposes a price decomposition mechanism relying on the principle that consumers distinguish between three types of price fluctuations: (i) price increases that lead to new

historically high prices; (ii) price increases that will eventually return to previously observed price levels; and (iii) price decreases. In other words, ref. [31] proposes to decompose any price time series into three components: (i) *Pmax*, which is defined as the cumulative increases in the logarithm of maximum historical price; (ii) *Pcut*, which is calculated as the cumulative decreases in the logarithm of price; and (iii) *Prec*, which is the cumulative sub-maximum increases in the logarithm of price. In other words, the procedure distinguishes between two types of price increases, i.e., those that result in a new maximum price, *Pmax*, and other increases that results in a price recovery, *Prec*. In this framework, if a price increase fails to result in a new maximum that exceeds all previous prices it is treated as a price recovery. Later, ref. [32] further explore this mechanism in the context of demand for energy and oil. Their main conclusion is that demand for both energy and oil react asymmetrically with the most elastic price response occurring to new price maxima. However, ref. [48] suggest that Gately and Huntington's [32] price asymmetry could instead be a proxy for capturing energy-saving technical change that is not explicitly considered in their analysis. In particular, ref. [48] also criticised the Gately and Huntington's [32] approach since its outcome is dependent from the initial price level that is considered.

After identifying some evidence in favour of the presence of an asymmetric farm behaviour (Section 3.1), we proceed to analyse milk prices in a more detailed manner. Figure 2 focuses on the evolution of milk prices at the EU level and shows how they have been fluctuating over the last fifteen years, while milk supply has been steadily growing and not entirely reflecting price changes.
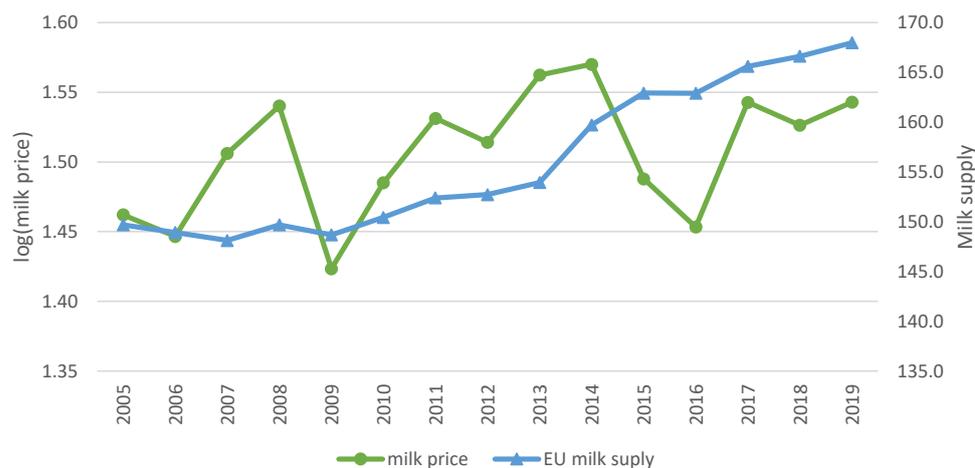

Figure 2. Milk price evolution. Source: Authors' elaboration based on DG AGRI's Milk Market Observatory.

After having discussed several price-decomposition approaches, we follow the Houck's proposal [47] in the case of the supply of milk and pinto beans. This approach is selected since its results are not dependent from the initial year of analysis, as explained earlier. More specifically, ref. [47] proposes a generic and flexible decomposition of any time series Y that are related to a time series X by assuming the following relationship for each $i = 1, 2, \ldots, n$ of the observation period. Following Houck's terminology [47]:

$$\Delta Y_i = \beta_o + \beta_1 \cdot \Delta X_i' + \beta_2 \cdot \Delta X_i'' \tag{4}$$

in which $\Delta Y_i = Y_i - Y_{i-1}$; $\Delta X_i' = X_i - X_{i-1}$ if $X_i > X_{i-1}$ and $=0$ otherwise; $\Delta X_i'' = X_i - X_{i-1}$ if $X_i < X_{i-1}$ and $=0$ otherwise; and X_o and Y_o are the initial values for X and Y, respectively. In the context of (4), some kind of non-reversibility is present in ΔY if $\beta_1 \neq \beta_2$.

By linking the equation above to the initial position and carrying out several algebraic transformations, ref. [47] suggests estimating the following expression:

$$Y_i = \beta_o \cdot t + \beta_1 \cdot R_i^* + \beta_2 \cdot D_i^* \tag{5}$$

where Y^* is $Y_i - Y_o$; R^* is the sum of all period-to-period increases in variable X from its initial value up to period n, $\Sigma \Delta X_i'$; D^* is the similar sum of all period-to-period decreases in X, $\Sigma \Delta X_i''$; and t is a trend variable. R^* is always positive, while D^* is always negative. In other words, R^* comprises the cumulative price-increase response, while D^* captures the cumulative price-decline response. As described by [47], $\beta_1 \neq \beta_2$ confirms non-reversibility (asymmetric price response). The author of [47] also indicates that a positive (negative) net relation exists between Y and X, when both β_1 and β_2 are positive (negative) in the expression proposed in (5). Therefore, $\beta_1 > 0$ and $0 > \beta_2 < \beta_1$ would imply an asymmetric supply response, while in the case of $\beta_2 < 0$, an inverse supply response would result as production will increase in those periods in which the dairy farmer faces declining prices.

Table 2 reports on the econometric results of estimating Equation (5) by means of Ordinary Least Squares (OLS). For a more direct comparison, two additional columns $(R^* \cdot P/Q; D^* \cdot P/Q)$ were included in order to standardise the coefficients R^* and D^*. Some additional statistics (R-squared and Root MSE) are reported in Appendix A.

Table 2. Modelling milk supply by means of decompose prices after Houck.

MS	T	(β_1) R*	R*·P/Q	(β_2) D*	D*·P/Q
EU	−821,148.300	45,337.280	0.093	−76,777.880	−0.157
Austria	0.007	0.001 **	0.122	−0.001 **	−0.110
Belgium	0.027 **	0.0004	0.030	−0.002 **	−0.211
Bulgaria	−34,656.130 ***	991.116 **	0.293	781.157	0.231
Croatia	5443.494	−466.048	−0.166	2738.792 ***	0.975
Czech Republic	−38,285.390 ***	2001.187 ***	0.197	−1640.161 ***	−0.161
Denmark	27,007.820 ***	1558.472 **	0.093	−1883.726 **	−0.113
Estonia	6828.033	−205.322	−0.075	−662.951 **	−0.243
Finland	−24,444.110 ***	976.614 ***	0.174	−2700.322 ***	−0.481
France	−48,439.440	−8328.050	−0.100	−26,492.890 **	−0.319
Germany	154,831.400 *	665.522	0.007	−12,543.980	−0.123
Greece	4789.926	−905.786 ***	−0.525	−263.422	−0.153
Hungary	−66,375.020 ***	2347.511 ***	0.361	−1403.257 ***	−0.216
Ireland	−29,197.970	7229.128 ***	0.311	−5379.740 *	−0.231
Italy	28,276.840	4305.363 *	0.132	−131.482	−0.004
Latvia	869.964	270.688	0.082	−439.082 ***	−0.133
Lithuania	13,680.230	−1565.929 ***	−0.246	−58.891	−0.009
Netherlands	80,547.800 ***	4704.578 ***	0.109	−7567.050 ***	−0.176
Poland	77,878.470 **	−194.288	−0.004	−2431.263 *	−0.053
Portugal	−23,327.640 ***	226.561	0.040	−1016.918 **	−0.178
Romania	−75,298.480 *	−2756.438	−0.177	−10,447.790	−0.670
Slovenia	−6101.555 ***	422.986 ***	0.201	−550.132 **	−0.261
Slovakia	−25,494.210 ***	508.802	0.157	−394.832	−0.122
Spain	−98,947.470 **	5116.289	0.225	−7506.397 ***	−0.330
Sweden	−68,699.820 ***	980.665 ***	0.122	−1250.942 **	−0.156
United Kingdom	−432,274.400 ***	23,687.210 ***	0.461	−20,162.130 **	−0.392

Source: Authors' elaboration based on AGMEMOD database. Note(s): ***, **, and * indicate that the corresponding regression coefficients are statistically significant at the 1%, 5%, and 10% levels. *P* and *Q* stand for the average price and quantity, respectively, calculated over the period 2014–2018. *R*·*P/Q* is a price elasticity for price increases, while *D*·*P/Q* is a price elasticity for price decreases. Cyprus and Malta were not included in the baseline of the version of the AGMEMOD model that was used to obtain the data and, therefore, they are not reported as separate countries. Within AGMEMOD, Luxembourg is jointly modelled with Belgium. The above estimates cover the period 2005–2019, being both years included. Within this approach, the impact of lagged price-responses is taken into account since *D** and *R** are cumulative. A higher number of decimal positions have been reported in this table to avoid a loss of information in those cases in which parameters are close to zero.

As shown above, in the vast majority of cases, the coefficients reported are statistically significant and have the expected sign suggested by our testable hypothesis, i.e., R^* coefficients are positively signed, while D^* coefficients are negatively signed. For the EU as an aggregate, the estimated (absolute) value for β_2 is larger than the (absolute) value of β_1. The econometric results confirm the findings of Section 3.1 and, therefore, support the hypothesis of non-reversibility in the behaviour of milk supply for most Member States. More specifically, for most of them, a positive coefficient β_1 and a negative coefficient β_2 were identified, suggesting an adverse supply response in the case of declining farm-gate milk prices. Section 3.1 reports how low ratios "change in quantity-to-changes in price" in the case of Estonia while the analysis above seems to indicate a net negative relation between the milk supply and its price since both coefficients are negatively signed, although one of them is not statistically significant. There are other cases for which both parameters (β_1 and β_2) are negative and, therefore, a net negative relation is identified for Greece, Lithuania, Poland, and Romania. For the latter three countries, Section 3.1 reports ratios "change in quantity-to-changes in price" around -0.4, indicating strong, though inelastic, responses of production to decreases in milk prices. In the case of Bulgaria, both parameters are positive, indicating a normal price response (everywhere has a positively sloped supply curve), but with some price asymmetry as $\beta_2 < \beta_1$ (when the milk price declines, production will go down, but less than the increase in case of a price increase). Nevertheless, the regression fails to support the mentioned hypothesis in the case of Croatia for which supply remained more or less stable with quantity increases below 5 per cent in response to milk price declines in the order of magnitude of 20–30 per cent, as reported in Table 2.

However, the analysis above presents some problems in terms of the OLS results, i.e., the coefficient correctly signed and significance of the parameters. These differences could be explained by the different time horizons that are analysed in Sections 3.1 and 3.2 ("stressful" periods versus "entire" period). In the case of Ireland, for which a very strong response was reported, the hypothesis of non-reversibility is confirmed in Table 2.

4. Conclusions

The EU dairy sector has experienced an important transition over the last decade due to the abolition of the milk quota in April 2015, as well as the "soft landing policy" already becoming effective in 2009. This change in the policy regime has permitted the entrance on the scene of new market forces that are now the actual drivers of milk supply in the EU. When exploring the evolution of the sector towards this new market setting, we have identified the existence of an inverse supply response that under certain adverse conditions, i.e., low milk prices, causes farms to tend to increase production in order to cover their fixed costs and ensure normal profits that permit them to continue operating in the market. This finding is not a rarity relating to exceptional cases but applies to the majority of the EU Member States. A special mention is deserved for the case of Ireland, whose dairy sector seems to be the most resilient and competitive in Europe. In this particular case, a strong positive response of milk production in those periods of strong declines in milk prices has been observed. More specifically, the Irish sector has come out of a strong disequilibrium situation since the milk quota constrained production at a level that was far away from its "normal" market equilibrium, leading its abolition to an adjustment process towards its "normal" level that is still ongoing. Nevertheless, the Irish sector, which mainly relies on grazing, has received significant financial and policy support in the recent years, this being another reason that explains this positive result.

With regard to "incidental" factors, extreme weather events or market speculation are expected to become more frequent than ever (e.g., due to climate change). In this new context, in which "incidental" factors will become more and more part of the general landscape for dairy production, regulation will be a key element to shape the dynamics of the sector in the coming years. On the one hand, crisis prevention and crisis management instruments will become of increasing importance to cope with "extraordinary" market developments [49]. This has been clearly demonstrated in the case of unusually low farm

gate milk prices that characterised the EU market during the period 2013–2016. In a similar but hypothetical context, the implementation of measures such as public intervention and private storage, as well as aid packages directly targeting farmers, would be of high value, e.g., the 2016 EU voluntary scheme to provide financial aid to those farmers who voluntarily restricted their production. On the other hand, there is an incipient body of environmental regulation, e.g., the EU Nitrate and the Bird and Habitat Directives, which will impose additional constraints affecting the size of the dairy herd and its production, especially in environmental hotspot areas. Nevertheless, there are some lessons to be learnt from public intervention during the mentioned crisis. For instance, it could be the case that in the short term, a crisis in the sector could be exacerbated due to a poorly designed program as farmers start to supply more in case of a short-term low-price shock, which eventually could lead to a spiral of further price declines. Therefore, measures, especially crisis measures implemented at the EU level, should be carefully designed in order to avoid the introduction of distortions in the market, e.g., prolonging the crisis, unequal treatment of farmers across different Member States, etc. Finally, the "new" CAP aims to be more market-oriented than its "predecessor" and, therefore, it should also take into account the existence of "counter-intuitive" market reactions such as asymmetric price-responses, as well as the absence of the usual market "self-correction" mechanism as in the mentioned case of the 2013–2016 crisis. Focusing on the country proposals for risk management within the CAP for the period 2023–27, income stabilisation tools [50] that provide compensation for changes in margins seem to be a promising instrument. In this regard, the common fund for income variations that will be launched in France is a good reference. In particular, this tool aims at protecting the income of sugar beet producers in the Grand-East region against the effects of changes in the market conditions or the impacts of climatic, health, or environmental events [51].

Appendix A

Table A1. Additional indicators.

MS	R-Squared (%)	Root MSE
EU	88.26	4,000,000.00
Austria	98.97	0.04
Belgium	98.38	0.09
Bulgaria	97.19	39,731.00
Croatia	86.96	33,735.00
Czech Republic	94.56	40,801.00

Table A1. *Cont.*

MS	R-Squared (%)	Root MSE
Denmark	99.08	63,548.00
Estonia	93.94	22,661.00
Finland	92.98	20,078.00
France	52.13	540,000.00
Germany	95.96	640,000.00
Greece	79.69	22,684.00
Hungary	89.75	41,217.00
Ireland	97.56	220,000.00
Italy	94.29	190,000.00
Latvia	98.01	18,878.00
Lithuania	92.92	46,960.00
Netherlands	98.96	230,000.00
Poland	97.20	190,000.00
Portugal	88.88	40,229.00
Romania	91.54	250,000.00
Slovenia	81.89	10,651.00
Slovakia	94.83	34,443.00
Spain	78.88	190,000.00
Sweden	97.58	52,697.00
United Kingdom	65.06	450,000.00

Source: Authors' elaboration based on AGMEMOD database.

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