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Analyses of topical policy issues

The role of market drivers in explaining the EU milk supply after the milk quota abolition

Roel Jongeneel [a,b], Ana Rosa Gonzalez-Martinez [a,*]

[a] Wageningen Economic Research, The Netherlands
[b] Wageningen University and Research, The Netherlands

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ABSTRACT

The abolition of the EU milk quota system since 2015 has allowed the dairy sector to fully react to market forces. This change should be properly reflected within the tools that support the design of EU/national policy interventions. This paper focuses on updating the milk supply responses at EU member state level in a context where still limited data is available. Using a Mixed Estimator a set of equations for the yield per cow and the size of the dairy herd, has been estimated, leaving the milk supply derived as an identity. An important outcome of this study is that milk supply at country level is inelastic, with the (short-run) yield and herd milk price elasticities being 0.2 and 0.1 respectively. The study concludes that two thirds of the impact of a milk price change is resulting from dairy cow yield changes, while a third is resulting from changes in the number of dairy cows.

1. Introduction

Within the EU, the milk quota system that was in force since 1984 was driving milk supply for more than three decades. In this market setting, production was constrained and farmers were obliged to adjust the size of the herd in order to avoid exceeding their quota. This 'quota' context was well represented within the AGMEMOD model (Chantreuil and Hanrahan, 2012), which is a well-established 'modelling tool' to produce market outlooks for agriculture commodities at European level (Salamon et al., 2019; Jongeneel et al., 2017). With the abolition of the milk quota in 2015 this instrument is no longer an important determinant of the EU's milk supply. Therefore, there is a good reason to reconsider and update milk supply as it is currently modelled in EU agricultural sector models such as AGMEMOD (Agricultural Member State Modelling) and CAPRI (Common Agricultural Policy Regionalised Impact analysis) with a close eye to its responsiveness to market signals.[1] From a broader perspective, understanding the dynamics of the EU market is key since the EU together with New Zealand and the United States are the main dairy exporters at global level.[2] Moreover, the topic of this piece of

* Corresponding author.
E-mail address: ana.gonzalezmartinez@wur.nl (A.R. Gonzalez-Martinez).

1 See, also: https://agmemod.eu/.

2 See, Rezitis and Rokopanos (2019) for an analysis of the impacts of trade liberalisation on the spatial price co-movements between the dairy markets of the EU, Oceania, and the United States.

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research is of high relevance from a policy perspective since trade flows of dairy products could be affected in a significant manner by changes in trade agreements.[3] For example, within the European continent, large volumes of cheese and other dairy products were traditionally traded within between the EU-27 and the United Kingdom. An important uncertainty in this regard is what could be the potential destination of those flows if no trade agreement is achieved.[4] Would these flows be redirected to Asia or is EU supply likely to adjust?

When considering the responsiveness of the milk supply, it is important to be aware of the main characteristics of dairy farming. Commercial dairy farming is a highly specialised business requiring large investments relative to for example extensive animal production (beef, sheep) and crop production activities. This leads to significant sunk costs and lock-in effects causing the milk supply to be not very responsive to short-run and temporary price fluctuations. This fact is translated into low econometrically-estimated elasticities.

In general terms, this paper provides considerations and details about the updating of the milk supply representation for EU Member States by using prior information as required by the Theil–Goldberger Mixed Estimator (Theil and Goldberger, 1961; Theil, 1963). A key feature of this approach is that it constitutes an exercise to bring together agronomic expert knowledge and economics in a systematic and transparent manner.

The value added of the present contribution is three-fold: Firstly, the fact that the elasticities that are presented in this contribution rely on sample and non-sample data represents an improvement of the suitability of the obtained parameters for scenario simulation of agricultural policy measures. Secondly, within the research community, these 'up-to-date' elasticities could provide new inputs for 'feeding' large scale models whose equations are calibrated using elasticities from the existing literature. As far as the authors are concerned, at the moment of carrying out this piece of research such a larger and consistent set of elasticities that fits the reality of the current EU dairy market were not available. Thirdly, the use of the Theil–Goldberger Mixed Estimator (TGME), and its related STATA estimation routine, constitutes a novelty in the sense that they are applied for the first time outside its traditional 'time series' context, being used to generate estimates for a panel of data.

The reader should be aware that from an econometric/statistical point of view, a well-specified model and a sufficient number of observations in order to get reliable estimates would be needed. In this regard, the context of this study impose a severe problem as sectors are only recently 'at their supply curves', i.e. only after the quota restriction was lifted. Other requirements to be satisfied by the estimated results would be consistency with economic theory; plausibility, ensurance of a controlled dynamics; predictive power, and the potential to tracking the recent history. It is this latter set of requirements that are implicitly addressed by the added prior/non-sample information by means of TGME.

The structure of this paper is as follows. Section 2 provides an overview of the literature on milk supply modelling. Section 3 presents and provides some analysis of the dataset. Section 4 elaborates on our proposal for updating the EU milk supply representation, including the econometric technique. Sections 5 and 6 present and discuss the estimated elasticities. Finally, some conclusions are presented in Section 7, while an Annex contains some supplementary tables.

2. Literature review and framework

2.1. The abolition of the milk quota

Before describing the present analysis and the framework underlying our model, it is important to refer to some previous attempts of modelling milk supply at EU level. This will provide some background to assess how much the EU milk supply response changed due to the abolition of quota regime, and alternatively, it will provide insights on how much the quota system distorted the market in the past. In this regard, a relevant contribution is Jongeneel and Tonini (2009) which looks at quota rents and milk supply elasticity estimates as they are represented in several partial equilibrium models, including: (i) the AGricultural MEmber states MODelling (AGMEMOD) model; (ii) the Common Agricultural Policy SIMulation (CAPSIM) model; and (iii) the European Dairy Industry Model (EDIM). These are the key dairy partial equilibrium models that were used back in time for analysing the EU dairy policy reform.[5] Looking at the supply elasticities, Jongeneel and Tonini (2009) identify an intermediate position for the EDIM model, with AGMEMOD presenting the largest supply responses. With supply elasticities being in the range of 0.16–0.67 for the former, while ranging between 0.50 and 0.83 in the latter case. Jongeneel and Tonini (2009) also explore differences in the coefficients of variation that are related to the estimates of the quota rent and elasticities used by the selected models. An interesting finding of this assessment is the evidence found in favour of the milk supply being more sensitive to quota rent estimates than to supply elasticities.

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3 See, Hallett (2019) for further discussion on trade deals and an assessment of the costs of disengaging from a trade association using Brexit as an example.

4 As per 2021, Northern Ireland still maintains access to the EU market via the Protocol on Ireland and Northern Ireland. However, an important issue is the additional costs for processors related to the separation between the milk that is produced in Northern Ireland and in the Republic of Ireland which were traditionally mixed into a single 'pool'. Processed products that use 'mixed origin' milk will not be eligible for EU trade agreements. To give an indication of the magnitude of this issue, it should be mentioned that more than around a third of the milk that is produced in Northern Ireland is exported to Ireland for processing due to limited processing capacity in the region of origin.

5 Another relevant partial equilibrium model that provides a representation of the world and EU dairy sector is the Food and Agricultural Policy Research Institute (FAPRI) model. See, Young II and Westhoff (2000) for a description of the modelling approach.

Bouamra-Mechemache et al. (2008) study the potential effects of alternative dairy policies in the context of a WTO agreement, including dairy policy adjustments. In particular, it focuses on the impact of gradual and considerable increases in EU milk quota (known as a 'soft landing') and elaborates on the potential consequences of different changes in the allocation of milk quotas among the EU Member States. For this purpose, the authors rely on a spatial model with international trade, which provides explicit representation of the main key players within the EU and at world level. The outcomes of this policy assessment indicate that the market impacts related to the abolition of the EU quota are similar to the ones that could follow in the case of imposing 2% gradual quota increase from 2009 onwards. The price elasticities used in this model, are in line with the ones reported by other studies such as Colman et al. (2005) and Boots et al. (1997). For instance, Colman et al. (2005) focus on the UK case and identify a milk supply elasticity in the range of 0.2–0.3 for a panel of specialised farms, being these results in the same range of other milk supply elasticities estimated for EU in the pre-quota period. This is in line with the estimates provided by Boots et al. (1997) who suggested a supply price elasticity of 0.26 in a no-quota regime.

The comparison of the elasticities underlying different models will be further extended in Section 6, when discussing the present results in the context of the existing literature (see, Table 4).

2.2. Conceptual framework

As described in the existing literature (Hanrahan et al., 2018), milk production depends on various factors. A dairy cow's milk production is related to calve birth, and timely dairy cow pregnancy has an impact on the annual milk yield of a dairy cow. During the lactation cycle, milk production is influenced by the feeding regime, the cow's age, its health status, its genetic potential, as well as weather conditions. Feeding rations and genetics also influence milk composition and the supply of fat and non-fat solids (protein, lactose). More specifically, the responsiveness of milk production is influenced by the farming system and its evolution (structural change). Milk production from pasture-based dairy herds is known to be susceptible to variation due to seasonality of pasture production, grazing conditions and nutritional interventions. In contrast, milk production from intensive dairy production systems relies on relatively high compound feed intakes and highly controlled production conditions (e.g. computerised feed/production-optimisation, climate control, milking robots, etc.). The latter system is less vulnerable to weather shocks, but is likely to be more sensitive to feed price shocks as the milk margin is relatively dependent on purchased inputs. Together with the farm housing, the dairy herd is a key asset of a dairy farm. Specifically, the dairy-herd capital asset produces three outputs: (i) the main output, which is raw milk; and joined outputs: (ii) calves and (iii) meat. Whereas milk is directly marketable, calves are born once a year and are partly used for herd replacement and partly for fattening for slaughtering. The meat value at slaughter provides a dairy cow with a salvage value at the end of its production life cycle.

Broadly speaking in the modelling of milk supply, two main approaches can be distinguished. One strand is the farm management and agronomic literature in which milk supply is modelled by focusing on dairy cow herd management and herd yield optimisation (e.g. Demeter et al., 2011). According to economic theory, farmers maximise the expected utility of the present value of net returns subject to a production technology constraint. The latter includes the constraints following from the dynamics of the herd population. Under the condition that the farmer is risk neutral, utility maximisation is equivalent to the expected present value of profits. Nevertheless, another stream of the literature focuses on the economics of milk supply, either at sector or at farm level (Chavas and Klemme, 1986). This contribution connects to the latter branch of literature since its focus is on the economic modelling of the milk supply. However, this study also relies on the existing agronomic literature since it provides a good picture of the drivers of farmer behaviour and permits to derive the relevant prior information.[6]

Drawing attention to the literature that mainly focuses on (short-run) forecasting of milk supply (see Akter and Rahman, 2010), the vast majority of contributions follow a time series analysis approach (ARIMA and VAR models). Although these models take into account seasonality they do not strive for a close representation of the structural characteristics of dairying. More specifically, Munshi and Parikh (1994) focus on the Indian market and estimate milk supply as a function of the number of animals, the quantities of different types of feeds that are provided to mature animals, the 'health status' of the animal and its quality. The number of cooperative societies is also included to measure technological progress within the sector. Munshi and Parikh (op cit) find that both technological progress and the increasing use of feed are explanatory determinants of the growth of milk production (growth in the milk yield) in India over the period 1961–1986. The former is reported to be a much more important contributor of this increase.

Schmit and Kaiser (2006) present a supply and demand model of the US domestic dairy sector. Looking at the supply side the model distinguishes between retail, wholesale and farm markets. At farm level, milk supply is mainly specified as a function of all-milk price, feed prices and slaughter-cow prices. This function also includes other variables such as a time trend to reflect technological change, seasonal dummy variables, intercept shifters to account for particular policy interventions, as well as lagged farm supply to incorporate rigidities in the adjustment of the production process. Focusing on the yield milk, Murphy et al. (2014) provide a comparison of three techniques to forecast this variable using Irish data from a 3-year period, i.e. a nonlinear auto-regressive model with exogenous input, a static artificial neural network and

[6] See Samsom et al. (2017) for a summary of different typologies of farm strategies based on elements such as goals and attitudes towards farming.

a multiple linear regression model. This study concludes that the nonlinear auto-regressive model with exogenous input was the one with the highest accuracy when predicting milk daily production.

An important contribution for our analysis is Elterich and Masud (1980) which analyses milk supply in the case of Delaware by means of a distributed lag price model that is applied to the herd size and the yield per head. Their model is based on an identity, i.e. the aggregate milk production, and two estimated equations, i.e. the number of milk cows and the milk production per cow. In this model, the herd size is positively related to lagged price of beef cattle and distributed lagged price of milk, while it is negatively related to lagged prices of milk cows and farm labour. The milk production per cow is defined as a function of technology, seasonality of milk production, lagged prices of the dairy ration, alfalfa hay and milk. More specifically, it can be expected that a variation in prices affects milk production in two ways (Levins, 1982). In the short run, adjustments in total production take place through changes in altering feeding practices and occasional culling of dairy cows, while in the long run changes in the herd size are needed. Levins (op cit) also highlights that the estimation of a supply model that includes past prices is expected to show a stronger impact associated to recent prices, whose impact becomes weaker through time as the herd size plays its role.

As advanced earlier, the dynamics in dairy production are complex and involve several time lags. The herd dynamics rely on a bio-economic process involving different age cohorts of dairy cattle (e.g. female calves, heifers, dairy cows with first, second and higher lactations), farmer decision-making with respect to herd replacement and net imports of heifers and/or dairy cows.[7,8] Focusing on the dynamics of the milk production, the seminal contribution by Chavas and Klemme (1986) considers the dairy herd as a another capital good and assumes that changes in this 'capital stock' are influenced by market prices. These authors propose a dairy production model for the United States that relies on three equations and one identity. Firstly, the number of replacement heifers is defined as a function of the number of dairy cows, the slaughter cow to dairy ration price ratio and the milk to dairy ration price ratio. The second equation shows how the herd size is related to the number of replacement heifers, their age and the prices of slaughter and milk relative to the value of the dairy ration. Thirdly, the yield is modelled as a function of milk to dairy ration price ratio and a time trend that accounts for technological progress in the dairy sector. Finally, total milk production is derived as the yield times the herd size.[9] With regard to the econometric technique, the yield equation is estimated by means of ordinary least squares (OLS) while the number of heifers and cow equations are estimated by non-linear least squares.

In addition, Chavas et al. (1990) focuses on milk supply in several US regions and find that the impact of milk prices and feed prices on milk production varies across regions. In particular, Chavas et al. (op cit) propose to model the number of dairy cows as a function of the milk to slaughter price ratio, the milk to feed price ratio and a risk variable. This risk variable is computed as the three-year moving average variance of the milk to feed price ratio. This paper presents the results of a pooled time series-cross section model estimated by means of seemingly unrelated regression (SUR).

In a nutshell, the explanatory factors that are expected to determine the herd size (as measured by h_t representing the number of dairy cows at time t) are the relevant (expected) market prices, including milk prices, *mp*, feed costs, *fc*,[10] prices of meat or slaughter price, *bp*, and other factors such as technological progress, *t*. With regard to the yield per cow, *yc*, the most important factors that are expected to explain its development are milk prices, *mp*, feed costs, *fc*, as well a variable characterising genetic progress and innovations in dairy animal husbandry practices and technology (e.g. increased use of ICT and milk robot), *trend*.[11] Therefore, total milk supply, *ms*, is calculated as the milk yield multiplied by the size of the herd. By assuming a double-log linear specification, the conceptual relationships above can be translated into the following model applicable at Member State level:

$$h_{i,t} = \alpha_{i,1} + \beta_{i,1} * mp_{i,t} - \beta_{i,2} * fc_{i,t} - \beta_{i,3} * bp_{i,t} + \beta_{i,4} * trend_{i,t} + \varepsilon_{i,t} \tag{1}$$

$$yc_{i,t} = \alpha_{i,2} + \gamma_{i,1} * mp_{i,t} - \gamma_{i,2} * fc_{i,t} + \gamma_{i,3} * trend_{i,t} + \tau_{i,t} \tag{2}$$

$$ms_{i,t} = yc_{i,t} * h_{i,t} \tag{3}$$

where all the symbols have the meaning indicated above, with the exception of α_1 and α_2 that are the intercept of the regressions; ε and τ which are vectors of the error white noise process. The estimated parameters are represented by β and γ, while i refers to each of the EU Member States. All the variables included in (1) and (2) are log terms, permitting the interpretation of all coefficients β in terms of elasticities.

7 Since the focus of this contribution is on aggregate milk supply at Member State level rather than at farm level, the possibility to expand the (national) dairy herd by buying decisions (import live dairy animals from third countries) is considered to be limited.

8 See, also, Chavas and Klemme (1986) for a model of the US milk production that consists of a dynamic model of the aggregate dairy herd's size and structure, as well as an analysis of milk cow productivity. In general terms, short-run elasticities of milk supply are reported to be small, while they are larger in the long-run.

9 See, also, Murphy et al. (2014) for an application of neural networks to forecast milk yields.

10 Feed prices have been introduced as an index that takes into account the price of different cereals and compound meals, as well as its actual use for feed purposes.

11 Demeter et al. (2011) simulate the dynamics of the actual herd in the Netherlands by means of a herd optimisation model and found that the energy requirements for maintenance and feed intake capacity of the herd did not influence its optimal composition, while they have an impact on the feed intake and the economic results obtained. This analysis reports economic benefits associated to class variety in the herd, although they are declining through time.

3. Data

During the milk quota system the modelling of milk supply and dairy herd could be relatively simple, as the milk output was determined by the milk quota constraint. To this a productivity equation explaining the milk yield per dairy cow was added. Given the quota and the milk yield evolution also the dairy herd evolution was determined (Bartova et al., 2009; Chantreuil and Hanrahan, 2012).

With the milk quota policy being abandoned in April 2015, a new situation has arisen.[12] Farmers are no longer directly constrained with respect to their milk supply.[13] As a consequence it seems a logical step to use a revised approach to model milk supply, i.e. using the dairy herd and milk yield equations as a starting point, letting the milk supply follow the formulation shown in (3). This new conceptual framework in which milk supply is equal to the dairy herd times the milk yield per cow is in line with the design of the AGLINK-COSIMO model,[14] which is extensively used for market outlooks by international organisations such as FAO, OECD and European Commission.

A drawback of the recent change in the dairy policy regime is that the number of annual observations for estimating the supply response was limited at the moment of collecting the data (in a strict sense only two years of post-quota data were available, whereas 2016 was also a special year characterised by a large drop in farm gate milk prices all over the EU, while for 2017 the data were still provisional). This might be less of a problem for estimating the yield equations, since the milk yield per cow is expected to be not so much affected by the milk quota regime. For estimating the milk yield equation therefore also information from the 'with-quota' period can be used. Turning to the dairy herd equations, the data limitations are more serious. However, for those Member States where the milk quota was no longer effectively constraining the milk supply (as a result of a successful 'soft landing' policy), the data period can be extended backwards.[15] Moreover, even for those (few) Member States that did have the milk quota still constraining their milk supply till 2015, it could be argued that dairy farmers already anticipated the expected quota abolition and responded by changing their supply behaviour (especially their herds). Despite this fact, the length of the time period is too short to allow for the estimation of herd stock equations at individual Member State level. Rather than doing this, an unbalanced panel of various EU Member States is used, combining information on countries which are expected to be rather 'similar'.[16]

Before moving onto the econometric results, important aspects to discuss are the evolution of the EU dairy herd and its implications with regard to structural change over the last decade. In terms of the number of dairy cows, a less homogeneous pattern is identified, with only a few countries reporting positive rates of growth over the period 2007–2017.

Fig. 1 reports on the annual average number of cows per specialised dairy farm in 2007, 2014 and 2017. The EU dairy sector is characterised by a clear long term trend of herd size increase at farm level, with Hungary, Malta, Lithuania, and Romania being exceptions. For several Member States, however, a decline in the average number of dairy cows is observed in the post-quota period (e.g. Hungary, Poland, Slovenia), which is in contrast with an strong increase in number of dairy cows at Member State level in the years prior to the abolition of the milk quota. In the Netherlands this pattern corresponds to the implementation of several pieces of environmental regulation, e.g. the so called 'Phosphate quota'.[17] In other countries like Slovenia this decline could be the outcome of specialised dairy farms looking for a more 'suitable' size with regard to profitability in a more integrated European market.

Looking at the evolution of the number of farms over the period 2007–2016 (Fig. 2), a decline in the absolute number of specialised dairy holdings is observed for most of the countries with the exception of Ireland. This trend seems to be quite relevant in the case of the Eastern European economies, with the strongest declines reported by Estonia and Slovakia (both around 70% lower). Nevertheless, the total dairy cow stock of these two countries is relatively small compared with other EU Member States (Fig. 3).

In general terms, a concentration process of the specialised-dairy sector has been identified when analysing together the number of specialised holdings (Fig. 2) and the evolution of milk supply (Fig. 3). This process of concentration seems

[12] See, Kersting et al. (2016) for further discussion on the impact of the milk quota in the case of Western-Germany. An important finding of this paper is that the abolition of the quota scheme could lead to substantial price declines.

[13] See, also Philippides and Waschik (2019) for an application of the MAGNET (Modular Agricultural GeNeral Equilibrium Tool) model to simulate the effects of the abolition of the milk quota for EU farmers. According to this study an increase in extra-EU export orientation in the coming years can be expected.

[14] Full details on the AGLINK-COSIMO model are available at: http://www.agri-outlook.org/about/.

[15] The abolition of the milk quota in 2015 was preceded by several measures in order to ensure a 'soft landing'. More specifically, the final date to abolish quotas was initially decided in 2003 and reconfirmed in 2008. This was providing EU producers with more flexibility to progressively respond to growing demand, especially at world market level. The mentioned 'soft landing' was achieved by means of several transitional measures, including a gradual annual 1% increase of the existing quotas, in addition to prices set to (nearly) zero for farmers seeking for additional quota. Further details on the quota regime and the transitionary measures are provided in Bouamra-Mechemache et al. (2009), while an assessment of the EU quota reform using the AGMEMOD model is provided by Chantreuil et al. (2008).

[16] The empirical work of this piece of research is based on annual data at Member States level. For the yield and herd equation estimation, the data used is taken from AGMEMOD model database which combines information from several statistical sources including FAO, Eurostat, National Statistical Sources. The time coverage of the AGMEMOD database depends on the country and the specific variable, although for most of the cases data goes back to 1973 and it is annually updated for including the most recent observations available at the moment.

[17] In a more general economic context, Halkos et al. (2019) provide some discussion on the relationship between economic cycles and environmental regulation.

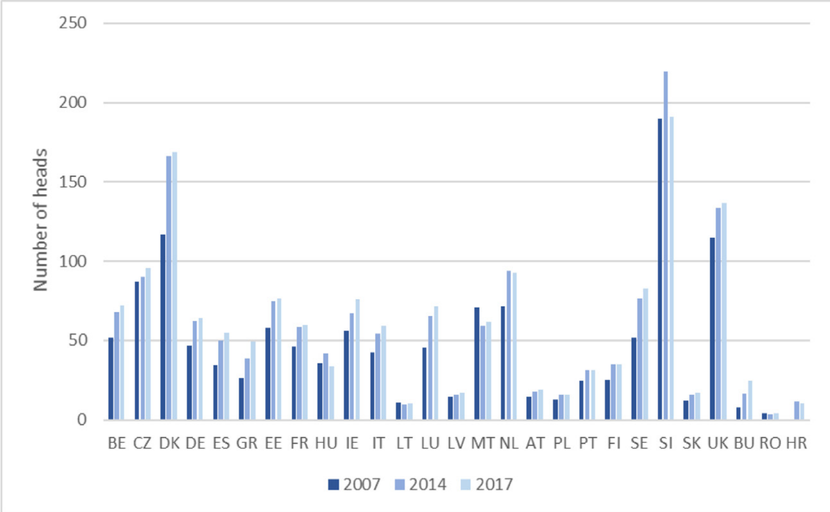

Fig. 1. Average number of cows per specialised dairy holding (2007–2017) Note(s): For Greece, the information reported corresponds to 2004, 2006 and 2013. This is so since the mentioned source only reports values for 2004, 2006, 2012 and 2013 in the case of this country.
Source: Authors' elaboration based on annual FADN data. This indicator can be obtained from the DG-AGRI FADN website.

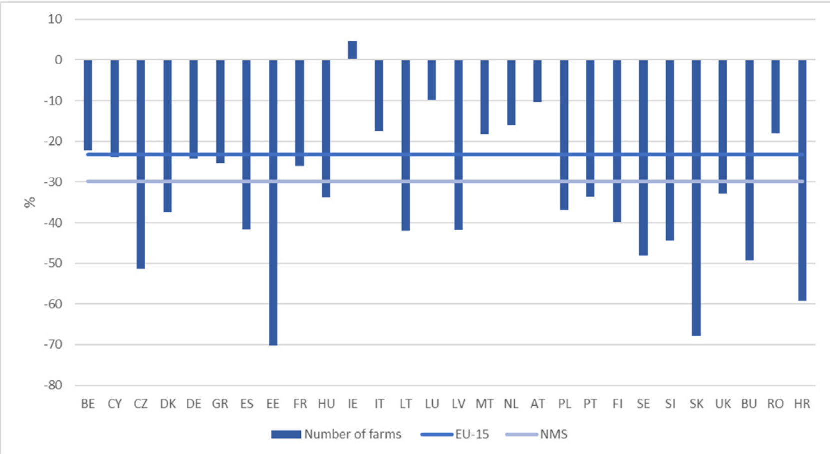

Fig. 2. Change in the number of farms with dairy cows over the period 2007–2016.
Source: Authors' elaboration based on annual Eurostat data, Theme 'Agriculture, forestry and fisheries'.

to be particularly relevant in the cases of those countries that show stable production (defined as rate of growth in the interval [-0.5, 0.5]) and declining number of specialised dairy holdings. These two elements have a reflection in terms of the structural characteristics of the sector, which show a higher number of dairy cows present at each holding (Fig. 1). This concentration process is, therefore, quite prevalent in the case of Finland, Portugal, Malta, Slovenia, Hungary, France, Sweden and the United Kingdom.

Bearing in mind the above, Fig. 3 provides a start for clustering the EU Member States in view of the evolution of milk supply and the dairy herd size. As shown below, a similar pattern has been followed by countries such as Romania, Bulgaria, Croatia, Lithuania and Slovakia, which went through a process of declining milk production. The relatively high farm exit rates dominate the impact of farm herd size and milk yield increases, resulting in a decline of aggregate milk production at Member State level. In contrast, the milk production was exhibiting strong rates of growth in the case of some key producers such as Ireland and the Netherlands. Although Fig. 3 reports strong increases in milk supply production in the case of Belgium and Luxembourg, these increases are of less interest since the dairy sector in both countries is small. Also the achieved milk production growth rate of Poland, also a large dairy producer, is remarkable and clearly distinct from that of most other 'new' EU Member States. Fig. 3 reports that large dairy producers such as France and the UK, show relatively low milk supply increases, while Germany, another key-player has a mid-position. Fig. 3 suggests that there is a positive relationship between average farm herd size and aggregate milk supply growth

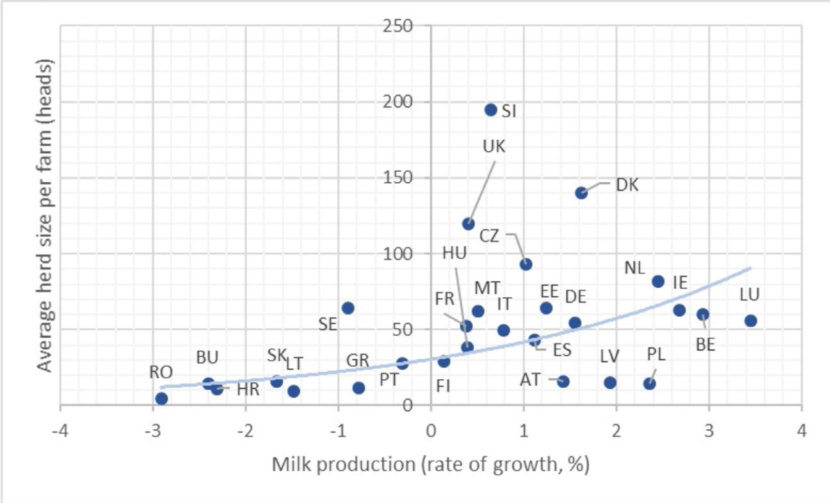

Fig. 3. Average milk production growth at Member State level versus average farm size (2007–2017).
Source: Authors' elaboration based on annual FADN and Eurostat data.

(see curve drawn in Fig. 3). This suggests on the one hand that economies of scale play a role in milk production, and on the other hand that in countries with small farm dairy herd sizes the negative impact of structural change (farm exits) on milk supply dominates the effect of farm scale and dairy cow milk yield increases.

Supplementing the above analysis with further background research on the agronomic characteristics of dairying in each Member State, the countries above can be grouped into five dairy regions in view of similar trends that were described for the dairy herd. More specifically, we proceed to define the following five dairy regions: (i) Belgium, Denmark, Finland, France, Germany, Ireland, the Netherlands, Sweden and the United Kingdom; (ii) Austria, Greece, Italy, Portugal and Spain; (iii) Bulgaria and Romania; (iv) Estonia, Latvia, Lithuania and Poland; and (v) Croatia, Czech Republic, Hungary, Slovakia and Slovenia. This typology will be the basis for grouping the EU Member States within the econometric analysis that is presented in Section 4. More specifically, these five groups will be used as the basis to divide the dataset into groups of Member States that displays similar herd dynamics (i.e. market integration, supply chain linkages, responsiveness to price, etc.); and therefore can be represented by identical elasticities. This typology is along the lines of the one presented by Poczta et al. (2020) who present a detailed assessment of EU dairy sector based on cluster analysis at micro level, paying special attention at the farm structure characteristics.

4. Methodological approach

As advanced earlier, estimating the herd equations is a challenging task in view of the structural break that the abolition of the quota has imposed.[18] Therefore, in order to overcome this challenge, for each of the dairy regions defined in Section 3, we propose to estimate a separate herd equation by combining the logic behind a traditional panel-data estimator with the STATA mixed estimator command which is only available for time series. The operationalisation of the computation of this 'quasi'-panel estimator involves several steps. First of all, the exploratory analysis of the data permitted us to divide our sample in 5 'dairy' regions as indicated in Section 3. Within each dairy region (in which herd dynamics has shown a common pattern), we assume that the equation for each of the Member States will have identical responses to changes in milk prices, feed prices and beef prices although trends and intercepts will be country specific. The latter is compatible with the idea of a fixed-effect model with constants that are individual-specific.[19] Then, we proceed to apply the 'tgmixed' estimator to the data of all the countries that are included in the dairy region as if they were a 'stacked' system of equations, with prior information used for milk and feed prices respectively. The modelling of intercepts that are country-specific within the 'tgmixed' estimator is carried out by including dummy variables. For estimating individual trends, 'artificial' variables that show a 'trend' character only for the observations that relates to the country under consideration (being the variable set to zero otherwise) are used.

When defining the length of the period considered to 'built' each 'unbalanced' panel, a consistent approach was applied in the case of all countries. First of all, we proceed to identify the period for which the quota in each country was a

18 The strong limiting data environment in which the estimations were carried out prevent the authors to add quadratic terms within the model. This is so in order to preserve sufficient degrees of freedom. Exploring non-linear effects in this context is not a standard practice in the relevant literature.

19 See, Baltagi (2008) for further details on the modelling of fixed effects.

limiting factor. In other words, in case of over-quota production the quota can be argued to have been binding. If not, when production was under quota and especially if this was systematically the case, we proceed to consider the quota as non-binding. In the case of a Member State in which the quota was non-binding, it can be argued that the Member State was already on its 'normal' supply curve.[20] If that is the case, this type of observations can be included in the panel for the estimation of the herd equation. Therefore, the poor data availability requires the combination of sample information with non-sample information, which is one the strengths of the Theil–Goldberger Mixed Estimator.[21]

Moreover, to account for the limited degrees of freedom as much structure has been imposed on the system as was possible. Farmers react to expected prices where the expected price is usually approximated by a distributed lag scheme of past prices. Since Nerlove schemes (Nerlove, 1956) perform well from an econometric point of view but might introduce unrealistic patterns in a forecasting context, a fixed weighting scheme has been imposed in the case of milk and feed prices. More specifically, 0.45, 0.35 and 0.25 are the weights that were assigned to prices in *t-1*, *t-2* and *t-3* respectively.[22] These weights have been chosen taking into account information about the lags in the production dynamics and an assessment of previous empirical estimates.

Apart from the data availability problem, the Mixed Estimator approach (Theil and Goldberger, 1961; Theil, 1963) seems a suitable econometric technique to improve the plausibility of the estimates and increase the efficiency of the estimated parameters. This technique is also used to estimate the milk yield equations, although in this case we proceed to estimate individual equations for each country. An important remark is that the choice of the lag length is linked to the underlying agronomic process and the understanding of the farmer decision-making process related to this context. More specifically, when looking at the responsiveness of the herd size to changes in feed and milk prices the inclusion of only three lags is consistent with LaFrance and De Gorter (1985) who also concentrate on explaining herd dynamics.

Before moving onto the discussion of the econometric results, the Theil–Goldberger Mixed Estimator is described. For simplicity, a linear regression model as presented in (4) is assumed as the starting point:

$$y = X\beta + \epsilon \tag{4}$$

in which y stands for the dependent variable (*Tx1*), X is a *TxJ* matrix of explanatory variables, β is the *Jx1* parameter vector, and ϵ is a *Tx1* error vector which has a multivariate normal distribution with expectation 0 and covariance matrix Ω. Associated to the expression in (4), the OLS estimator, β_{OLS}, can be calculated as per below:

$$\beta_{OLS} = (X'X)^{-1}X'y \tag{5}$$

In order to produce the Theil–Goldberger Mixed Estimator, prior information needs to be incorporated in the linear model formulated in (4). This addition is done by means of a set of stochastic restrictions comprising the non-sample prior information, as indicated in (6):

$$z = Z\beta + \upsilon \tag{6}$$

in which **Z** is as a N × J matrix which contains the linear prior constraints, **z** represents a N × 1 vector of prior estimates and υ is a J × 1 unobservable normally distributed random vector, with mean δ (N × 1) and (N × N) covariance matrix Φ, with Φ known. In this case, δ represents the degree to which the prior information embodied in $\mathbf{Z}\,\beta = z$ holds in the model.[23] In this context, the Theil–Goldberger Mixed Estimator, β_{TGME}, can be computed as indicated in expression (7):

$$\beta_{TGME} = (X'\Omega^{-1}X + Z'\Phi^{-1}R)^{-1}\,(X'\Omega^{-1}y + Z'\Phi^{-1}z) \tag{7}$$

Being the estimated (K × K) covariance matrix C_{TGME} as shown in (8):

$$C_{TGME} = (X'\Omega^{-1}X + Z'\Phi^{-1}Z)^{-1} \tag{8}$$

By assuming an *i.i.d.* errors matrix $\Omega = \sigma^2 I_T$ and σ^2, it can be replaced by its consistent OLS estimate s^2 when computing Ω^{-1}.

Finally, we refer to Theil (1963) which defines scalar measures to measure the shares of the prior (sample) information in the posterior precision of the estimator. The share due to sample information, θ_S, can be calculated as in (9):

$$\theta_S = \frac{1}{K} tr(s^{-2}\boldsymbol{X}'\boldsymbol{X}(s^{-2}\boldsymbol{X}'\boldsymbol{X} + Z'\Phi^{-1}Z))^{-1} \tag{9}$$

As an alternative, if we were of a Bayesian persuasion, we might choose to incorporate this non-sample information explicitly into the estimation problem by means of an informative prior.[24]

20 The quota suppliers are on the vertical quota constraint line (which is the relevant part of the supply curve in the case of binding quota). When quota are abolished the dairy sector will return to its 'normal' supply curve and a combination of production expansion and milk price decline would be expected. An implicit assumption is that abolishing quotas will not change the form of the 'normal' part of the supply curve significantly.

21 This econometric technique allows the researcher to account for uncertainty in terms of different model specifications and parameter values.

22 From an economic point of view, this can be interpreted as a form of adaptive expectations (Fisher, 1911; Nerlove, 1958) in which farmers 'build' their expectations for the future based on what happened over the past three years.

23 For $\delta = 0$, it is assumed that the prior information is fully applicable.

24 The Theil–Goldberger Mixed Estimator has some similarities with the Bayesian estimator, but is more restrictive (for example in terms of the distributional assumptions on parameters that can be made), but is also more simple and convenient to work with. For further discussion on this topic the reader is referred to Mittelhammer and Conway (1988) and Mittelhammer et al. (2000).

Table 1
Overview of prior information for MS milk supply.

Item	Elasticity	Estimated variance
Milk supply	Milk price - Current: [0.05, 0.2]	0.0156
	Milk price - Lagged: [0.1, 0.2]	0.0225
	Feed price - Current:[−0.05, −0.1]	0.0056
	Feed price - Lagged:[−0.15, −0.45]	0.0900
	Beef price - Current: [−0.1, 0.05]	0.0006
	Beef price - Lagged:[0.01, 0.1]	0.0030
Milk yield	Milk price - Current: [0.05, 0.1]	0.0056
	Milk price - Lagged: [0.0, 0.0]	N.A.
	Feed price - Current:[−0.05, −0.1]	0.0056
	Feed price - Lagged:[−0.10, −0.25]	0.0306
	Beef price - Current: No impacts found	N.A.
	Beef price - Lagged: No impacts found	N.A.
	Trend: 0.8–1.8 per cent	1.6900
Dairy herd	Milk price - Current: [0.0, 0.1]	0.0025
	Milk price - Lagged: [0.1, 0.2]	0.0225
	Feed price - Current:[−0.05, −0.1]	0.0056
	Feed price - Lagged:[−0.1, −0.20]	0.0225
	Beef price - Current: [−0.1, 0.05]	0.0006
	Beef price - Lagged:[0.01, 0.1]	0.0030

Note(s): This table is reproduced from Jongeneel (2018). The reader is referred to the Annex included in the original source for a detailed description of the findings of each of the papers that were reviewed to produce the synthesis above.

The Theil–Goldberger Mixed Estimator can be implemented by using the STATA routine ‘tgmixed’. Further discussion and applications of a systems-mixed estimator are presented in Jongeneel (2000), while an illustration of the Mixed Estimator in the case of the supply of several crops that are represented in the AGLINK-COSIMO model is provided by Jongeneel and Gonzalez-Martinez (2020).

Once the econometric technique has been described, a key item becomes the prior information that needs to be used to populate the Theil–Goldberger Mixed Estimator. In this regard, we make use of the outcomes of the literature review that was carried out by Jongeneel (2018) in order to update the milk supply elasticities of the AGLINK-COSIMO model for the EU-15 and EU-NMS region. For the purpose of Jongeneel (op. cit.), a set of contributions were reviewed, with a summary of their findings being provided in Table 1.

Although the ‘expected values’ above were used to ‘enlighten’ the present econometric exercise, they were supplemented with country expert agronomic knowledge to produce more specific priors in the case of particular Member States. With regard to the prior standard error (σ) that is needed to feed the STATA routine ‘tgmixed’, the formula presented in (10) was used:

$$\sigma = (\xi - 0)/2 \tag{10}$$

where ξ stands for the prior expected elasticity.

5. Results

After discussing the conceptual framework and elaborating on the econometric technique, this section concentrates on the estimated elasticities that could be used for updating a partial equilibrium model that covers the EU dairy sector such as AGMEMOD. The STATA ‘tgmixed’ estimator produces two set of parameters, OLS and Theil–Goldberger Mixed Estimator coefficients for each specification. The OLS results are not reported in the main body of this paper since many of them are not theoretically consistent and/or not-statistically significant. Nevertheless, they are mentioned in the discussion of the parameters when relevant.

Table 2 focuses on the milk yield which is modelled as being a positively related to milk prices and negatively related to the feed cost. As shown below, only in 15 out of 100 cases the estimated parameters are not statistically significant, compared to 20 cases when looking at the OLS parameters.

In general terms, the estimated parameters are consistent with economic theory, i.e. they are signed as expected. However, the milk price elasticity in the case of Latvia is not significant, while the trend parameter is not statistically significant in the case of Romania. As shown in the table, countries such as Belgium, Croatia, France, Greece, Ireland, Italy, Poland and Portugal present elasticities that are in the range of 0.2–0.36. Focusing on the feed price responses, the estimated elasticities are larger than −0.1 in the case of Belgium, Estonia, France, Greece, Hungary, Italy, Portugal, Slovenia, Slovakia and Spain. No feed prices elasticities above −0.31 were identified. A comparison with the OLS results reveals that the Theil–Goldberger Mixed Estimation results are much more suitable than the OLS ones for a market outlook/simulation context, in which parameters that violate economic theory can lead to non-sensible outcomes or unrealistic predictions. Drawing attention to the contribution of the non-sample information to the estimation, on average the share of prior

Table 2
Summary estimated parameters — milk yield per head (Theil–Goldberger mixed estimation).
Source: Authors' elaboration based on the AGMEMOD database.

	Intercept, *C*	Milk prices, *mp*	Feed cost, *fc*	Trend, *t*	*R*-squared	Share of prior information	Number of obs.
Austria	8.0637***	0.0150	−0.0483	0.0189***	0.9723	0.066	44
Belgium	8.1771***	0.2792***	−0.3099***	0.0136***	0.9291	0.181	34
Bulgaria	8.1513***	0.0230	−0.0752**	0.0045	0.4413	0.068	12
Croatia	5.2067***	0.3507***	−0.0652	0.0364***	0.9526	0.294	21
Czech Republic	8.2638***	0.0062	−0.0862**	0.0269***	0.9813	0.073	26
Denmark	8.0110***	0.1470***	−0.0420	0.0163***	0.9866	0.030	42
Estonia	7.2485***	0.1710**	−0.1785**	0.0380***	0.9529	0.214	12
Finland	7.9742***	0.1416**	−0.0732**	0.0177***	0.9695	0.106	42
France	7.6374***	0.2918***	−0.1811***	0.0176***	0.9754	0.070	45
Germany	8.1610***	0.0770***	−0.0615***	0.0156***	0.9872	0.022	41
Greece	7.5207***	0.3599***	−0.2633***	0.0131***	0.6960	0.395	33
Hungary	8.8886***	0.0618	−0.2755***	0.0475***	0.8593	0.276	34
Ireland	7.3821***	0.2820***	−0.0369	0.0090***	0.9321	0.084	41
Italy	8.0502***	0.2267***	−0.2200***	0.0123***	0.9465	0.096	42
Latvia	7.4727***	−0.0060	−0.0380	0.0296***	0.9743	0.059	22
Lithuania	7.5295***	0.1221**	−0.0549	0.0184***	0.9467	0.098	22
Netherlands	8.3626***	0.0920***	−0.0924***	0.0135***	0.9859	0.014	43
Poland	7.2569***	0.2556***	−0.0213	0.0029***	0.9760	0.043	24
Portugal	7.3464***	0.2531**	−0.1998***	0.0340***	0.9672	0.243	28
Romania	7.6592***	0.1705**	−0.0243	−0.0003	0.4963	0.116	21
Slovenia	6.9168***	0.1122	−0.1316*	0.0410***	0.7886	0.336	15
Slovakia	8.7354***	0.1417*	−0.3090***	0.0225***	0.7642	0.235	25
Spain	7.4602***	0.1697*	−0.1377*	0.0312***	0.8929	0.302	25
Sweden	8.4574***	0.1135	−0.1036***	0.0103***	0.8513	0.101	19
United Kingdom	8.2346***	0.0492	−0.0280**	0.0160***	0.9784	0.020	43

Note(s): All the variables are logged terms with the exception of the trend term, so that the parameters can be easily interpreted as elasticities. ***, ** and * indicate that the corresponding regression coefficients are statistically significant at the 1%, 5% and 10% levels respectively. The contribution of sample information in each case can be calculated as 1 minus the share of prior information. The estimation period is 1973–2017. This dataset has been validated by national experts and makes use of national and Eurostat official statistics. The country-coverage of the above results only refer to those countries that were included in the baseline of the AGMEMOD that was used as the basis for gathering the data.

information is around 0.14. In particular, the lowest share of prior information is observed in the cases of the United Kingdom and Germany (around 0.02); while the largest share is observed in the case of Greece (0.4 approximately). Overall, the goodness of fit of the yield equations is high, with the *R*-squared being above 90% in the 17 out of 25 cases. The lowest *R*-squared is observed in the case of Bulgaria (44%), while the highest *R*-squared is shown for the German case.

Table 3 provides an overview of the estimated elasticities in the case of the dairy cow stock. As in the yield case, the Theil–Goldberger Mixed Estimation results are correctly signed. Nevertheless, the fact that some trend parameters are negatively signed can be interpreted as a reflection of the strong concentration process that the dairy sector has been experiencing in the last decade in some countries. The estimated parameters indicate milk price responses close to 0.1 in all the cases, i.e. it can be expected that 1% increase in farmers' expectations of future milk prices leads to 0.1% increase in the size of the herd. Regarding farmers' expectations of the cost of feed, the strongest responses were identified for the 'dairy belt' countries in which a −0.22% decline in the herd is associated to a 1% increase in the cost of feed prices.[25] In terms of the impact of rising beef prices, the econometric results point to a decrease in the herd size in the case of Bulgaria, Estonia, Latvia, Lithuania, and Romania.

In terms of the additional statistics reported in Table 3, the *R*-squared indicator is above 90% for all the estimated models, while the reported shares of prior information are in the range of 0.039–0.143. The highest contributions of prior information, which are endogenously determined, are found in Croatia, Estonia, Greece, Hungary, Portugal, Slovenia, Slovakia and Spain, for which shares are between 20%–40%. The Theil–Goldberger Mixed Estimation (TGME) is designed in such a way that the strength of the prior information influences the degree of precision of the estimator. As indicated by Amato and Gerlach (2001, p. 267), the 'precision of the mixed estimate is at least as high as the precision of the estimate based solely on the data, with the former converging to the latter as the degree of prior uncertainty increases.' In a forward-looking context, this implies than the TGME can be more precise than OLS. Compared to the shares reported in Table 3, shares of prior information are higher in the case of the milk yield than in the case of the herd size. This finding may be surprising as in the case of milk yield more data observations were available than for the herd equations, which would suggest a relatively more important role for the sample data. An explanation for the mentioned result might be

[25] The so-called 'dairy belt' includes the following countries: UK, Ireland, (North of) France, Denmark, the Netherlands, Belgium, Luxembourg, Germany, Poland, Estonia, Latvia and Lithuania. This region is well-known for being highly competitive in dairy production and amounts around 70% of production at EU level.

Table 3
Summary estimated parameters — herd size (Theil–Goldberger mixed estimation).
Source: Authors' elaboration based on the AGMEMOD database.

	Intercept, C	Milk prices, mp	Feed cost, fc	Beef price, bp	Trend, t	R-squared	Share of prior information
Austria	5.0167***	0.0648	−0.0651	0.1807*	0.0075	0.9961	0.084
Belgium	4.8818**	0.0892*	−0.2240**	0.3277*	−0.0065	0.9390	0.0760
Bulgaria	6.5847***	0.0590	−0.0960**	−0.0957**	−0.0115**	0.9955	0.1430
Croatia	5.4279	0.0968***	−0.0117	0.0157	−0.0369***	0.9839	0.053
Czech Republic	5.4569***	0.0968***	−0.0117	0.0157	−0.0100**	0.9839	0.053
Denmark	5.0078***	0.0892*	−0.2240**	0.3277*	0.0006	0.9390	0.0760
Estonia	5.1522***	0.0743**	−0.0793**	−0.0165	−0.0235***	0.9993	0.039
Finland	4.6306***	0.0892*	−0.2240**	0.3277*	−0.0294***	0.9390	0.0760
France	7.2294***	0.0892*	−0.2240**	0.3277*	−0.0224*	0.9390	0.0760
Germany	−2.1955***	0.0892*	−0.2240**	0.3277*	0.2361***	0.9390	0.0760
Greece	4.2315***	0.0648	−0.0651	0.1807*	−0.0218***	0.9961	0.084
Hungary	5.3229	0.0968***	−0.0117	0.0157	−0.0340***	0.9839	0.053
Ireland	5.9766***	0.0892*	−0.2240**	0.3277*	−0.0025	0.9390	0.0760
Italy	6.3680	0.0648	−0.0651	0.1807*	0.0003	0.9961	0.084
Latvia	5.5303***	0.0743**	−0.0793**	−0.0165	−0.0156***	0.9993	0.039
Lithuania	6.5485***	0.0743**	−0.0793**	−0.0165	−0.0297***	0.9993	0.039
Netherlands	5.4881	0.0892*	−0.2240**	0.3277*	0.0169	0.9390	0.0760
Poland	8.3711***	0.0743**	−0.0793**	−0.0165	−0.0222***	0.9993	0.039
Portugal	4.9016***	0.0648	−0.0651	0.1807*	−0.0205***	0.9961	0.084
Romania	8.0530***	0.0590	−0.0960**	−0.0957**	−0.0125***	0.9955	0.143
Slovenia	4.5873***	0.0968***	−0.0117	0.0157	−0.0109***	0.9839	0.053
Slovakia	5.1631***	0.0968***	−0.0117	0.0157	−0.0377***	0.9839	0.053
Spain	6.3487***	0.0648	−0.0651	0.1807*	−0.0251***	0.9961	0.084
Sweden	4.1230**	0.0892*	−0.2240**	0.3277*	−0.0138	0.9390	0.0760
United Kingdom	6.9741***	0.0892*	−0.2240**	0.3277*	−0.0333*	0.9390	0.0760

Note(s): All the variables are logged terms with the exception of the trend term, so that the parameters can be easily interpreted as elasticities. ***, ** and * indicate that the corresponding regression coefficients are statistically significant at the 1%, 5% and 10% levels respectively. The contribution of sample information in each case can be calculated as 1 minus the share of prior information. The results above only refer to those countries that were included in the baseline of the AGMEMOD that was used for collecting the data. The STATA 'tgmixed' routine is design to work with time series. Therefore in this case, our 'panel' is used as a system of stacked linear equations.

that yields vary due to weather conditions for example (especially in pasture-based systems), which makes the empirical data 'more noisy'. As a result, irrespective of the larger number of observations, the sample information may be less informative in co-determining the price trade-offs with respect to the yield than with respect to the herd.

Give the inference procedure that has been used one should expect the estimated price responses to be in line with the broader literature, as this has been integrated into the estimation procedure via the prior information. The yield and herd responses are characterised by short-run milk price elasticities of 0.2 and 0.1 respectively. These results suggest that two thirds of the impact of a milk price change are due to dairy cow yield changes, while one third is resulting from a change in the number of dairy cows. For the US, a country where the dairy sector operates already for a longer time in a market-oriented context, Mosheim (2012) found yield and herd response elasticities with respect to the milk price of 0.03 and 0.01 respectively. This suggests that the milk supply is even more inelastic than in the EU, while yield and dairy herd stocks are of equal importance in explaining the milk supply response to milk price changes. The absolute value of the feed elasticities is smaller than that of the milk price (on average 30% smaller) suggesting that is the most important price-determinant in the EU milk supply.

A final remark in terms of the goodness of fit of the different techniques is needed. The comparison of the OLS and Theil–Goldberger Mixed Estimator models reveals similar R-squared values for all countries in the case of the herd equations, while a similar exercise in the case of the milk yield equations shows a decline in the goodness of fit for certain countries such as Slovenia. In this particular case, the R-squared in the OLS model is around 12% higher than in the Theil–Goldberger Mixed Estimator model. Nevertheless, even for those countries where the OLS model has a higher goodness of fit, the Theil–Goldberger Mixed Estimator elasticities are preferred since this technique permits to obtain coefficients that are more plausible from an agronomic point of view, e.g. a positive responsiveness of the milk yield to changes in milk prices.

6. Further discussion

From Tables 2 and 3 it can be deduced that on average the milk and feed price are of similar importance in terms of determining the responsiveness of milk yields, while on average the feed price is the dominant price in explaining herd responses. However, these averages hide that for individual Member States this can be different, as for example in the case of Austria the beef-price responsiveness of the herd dominates that of the milk and feed prices (see Table 2, first row).

Table 4
Elasticity comparison.
Source: Bouamra-Mechemache et al. (2008), Jongeneel and Tonini (2009) and authors' calculations.

	AGMEMOD (quota period, previous estimates)	CAPSIM	EDIM	Bouamra-Mechemache et al. (2008)	This study (non-quota period, updated estimates)
Austria	0.750	0.229	0.292	0.172	0.0150
Belgium	0.760	0.352	0.280	0.216	0.2792
Bulgaria	0.500	0.264	0.170	NA	0.0230
Croatia	NA	NA	NA	NA	0.3507
Czech Republic	0.160	0.253	0.561	0.273	0.0062
Denmark	0.550	0.308	0.420	0.181	0.1470
Estonia	0.500	0.347	0.576	0.284	0.1710
Finland	0.520	0.331	0.428	0.237	0.1416
France	0.590	0.288	0.341	0.215	0.2918
Germany	0.630	0.218	0.373	0.210	0.0770
Greece	0.570	0.284	0.313	0.226	0.3599
Hungary	0.560	0.235	0.664	0.284	0.0618
Ireland	0.770	0.349	0.402	0.206	0.2820
Italy	0.830	0.294	0.337	0.179	0.2267
Latvia	0.540	0.234	0.576	0.292	−0.006
Lithuania	0.50	0.277	0.576	0.284	0.1221
Netherlands	0.780	0.272	0.442	0.216	0.0920
Poland	0.540	0.235	0.650	0.292	0.2556
Portugal	0.550	0.310	0.421	0.249	0.2531
Romania	0.500	0.295	0.159	NA	0.1705
Slovenia	0.500	0.307	0.576	0.283	0.1122
Slovakia	0.500	0.150	0.576	0.283	0.1417
Spain	0.710	0.329	0.284	0.183	0.1697
Sweden	0.590	0.238	0.459	0.243	0.1135
United Kingdom	0.600	0.278	0.387	0.189	0.0492
Production-weighted average	0.634	0.278	0.399	0.217	0.1610
Coefficient of variation	0.230	0.170	0.330	0.180	0.670

Note(s): Elasticities for AGMEMOD (previous estimates), CAPSIM and EDIM are reproduced from Jongeneel and Tonini (2009). Elasticities from Bouamra-Mechemache et al. (2008) and Jongeneel and Tonini (2009) are only available at 3-decimal position level.

This may reflect the differences in dairy cow breeds used throughout the EU, in particular the shares of pure-milk breeds, e.g. Holstein-Friesian, and dual-purpose breeds, e.g. Fleckvieh cattle. In the latter case the meat part is a more important component in dairy profitability than in the case of the pure-milk breeds. Moreover, in countries where organic milk production is relatively important, a more intensive use of dual purpose cattle is likely since these breeds better fit into organic dairy farming systems (Delaby et al., 2009).

As advanced earlier, an additional comparison of the present results and those already reported in the existing literature is provided in Table 4. Several studies are considered for the period in which the milk quotas were still binding, using different methods, estimated or calibrated milk price supply responses, etc. As Table 4 shows, the 'updated' elasticities found in this study are now lower than the ones that were estimated for the quota period for AGMEMOD (see first column). This lower price responsiveness of milk supply found in this research is now 'closer' to the price reactions that were already represented in other models such as CAPSIM and EDIM. As the (production-) weighted average shows, the milk supply responses to milk price found in this study in the EU has become more price inelastic since the quota was abolished in 2015. The milk price responsiveness more than halved relative to the average price responsiveness associated with the four 'pre-quota abolition period' studies. As regards the decline in price responsiveness reductions of a similar order of magnitude were found for the EU-15 ('old' Member States) as well as for the EU-NMS ('new' Member States). An important implication of the lower milk price responsiveness found in this study is that when they would be used to simulate a quota abolition scenario, the projected milk supply increases would have been lower than those based on the elasticity results from the previous studies (Jongeneel and Tonini, 2009).

A priori, it could be expected that the abolition of policy restrictions could lead to a 'pure' market context in which supply would be reacting to prices in a stronger manner. However, an interesting finding of the above is that there is no evidence that supports the previous hypothesis in the case of the EU. This is particularly relevant when looking at the period under investigation which was characterised by strong price fluctuations, e.g. the milk crisis in 2016 with extreme milk price lows. A possible explanation for this lack of responsiveness could come from the existence of some price asymmetry in the market that has prevented supply to decline rapidly when prices were falling. In other words, as quotas were abolished in 2015, 'expanding' countries had 'committed' to this. When prices declined in 2016, they could not immediately react supply-wise, especially as younger cows were entering the herd as part of their 'commitments' to the mentioned expansion. On the contrary, when looking at price increases, it could have been that in this new situation, dairy farmers are more conservative when taking decisions for expanding the dairy herd in a market with stronger competition and higher price uncertainty. A detailed study of price uncertainty and price asymmetry go beyond the scope of this article.

The coefficient of variation (CoV) associated with the results reported in this article is 0.67 (see, Table 4), which is three times the average CoV-value of the four pre-quota abolition cases. This suggests that the variation in supply responses has increased and therewith the heterogeneity in milk supply responsiveness of the EU Member States.

7. Conclusions

The abolition of the milk quota regime in April 2015 has changed the traditional EU dairy landscape at various levels. At operational level, the opening of the market has created room for the emergence of new market forces such as the strong Asian demand that has been recently observed. Farmers that have been in most cases off their supply curve for many years due to the binding quota constraints are now again moving along their supply curves, but these are largely unknown. As such there is a need to get insight into the new supply curves and the underlying factors and drivers of EU milk supply, even though the information that is available is still limited (short data series) and partly disturbed (extraordinary milk price declines in 2016). By using the Theil–Goldberger Mixed Estimator procedure, it turned out to be feasible to estimate behavioural equations for milk yield and dairy cow stocks at Member State level. Member State milk supplies are found to be inelastic. The yield and herd responses are characterised by short-run elasticities of 0.2 and 0.1 respectively, which suggest that two thirds of the impact of a milk price change is resulting from dairy cow yield changes and one third is resulting from a change in the number of dairy cows.

By combining sample and non-sample information in a systematic and informative manner, the Theil–Goldberger Mixed Estimator method helped to overcome data limitations. Another 'value added' of the applied estimation approach is that it helps to overcome an important drawback of using a 'pure' econometric procedure in that it avoids parameter estimates beyond the limits of what is agronomically feasible. Moreover, by delivering parameters that are at the same time consistent with the economic theory, this improves the plausibility of the projections, ensures controlled dynamics, and permits modellers to track the recent development of the market in a more transparent way than when using *ad hoc* corrections. Finally, the role of the prior information can be clearly indicated and its use turned out to provide improved estimates (relative to OLS), even though the prior information never dominated the sample information.

Understanding the drivers of milk supply within the EU are important for policy makers when addressing the dairy market at local, regional and international level. At local scale, elements such as extreme weather events that can strongly disrupt expected yields require public interventions to help farmers to manage or off-set their negative consequences. At regional/national level the implementation of new pieces of regulation in terms of biodiversity protection, ensuring animal welfare, feed requirements or environmental impacts regarding air and soil quality as well as nitrate, ammonia and phosphate emissions could change the 'rules of the game' that farmers need to follow. At international level, a proper design of trade agreements is crucial to shape trade flows, which is of particular relevance to the dairy market. This is so since the dairy market at the global level could change in the coming years reflecting among others the current and upcoming trade regulation between the EU and the UK and of the UK with the rest of the world (future trade agreements). Specifically, it is important to make some remarks in terms of the trade flows between Ireland and the UK. As per April 2021, there were no disruptions in Irish exports to the UK, with customs checks on imports from the EU delayed until January 2022. At the same time, there has been an increase in Irish products reaching the EU by maritime transportation in order to avoid delays occurred in the case of road freight from the UK to the EU. Looking at Northern Ireland, we refer to the 'mixed origin' milk issue which could lead to exclude around 8% of Irish processed products from the EU Single Market. More specifically, while 'raw' milk produced by farmers located in Northern Ireland is labelled as 'EU' milk, Irish processed products that are elaborated using as input milk from the mentioned origin will be treated as production from a third country. Therefore, these processed products will need to adhere to the rules that regulate trade between the UK and the EU.

Apart from that, from the trade perspective, other important elements are the negotiations on an EU-New Zealand free trade agreement, further trade agreements in North America, the implementation of import bans between China and Oceania similar to the ones that were put in place in the past, etc. Moreover, increases of Chinese demand for dairy products and the participation in the international market of countries such as India and Pakistan could also contribute to shape the dairy market. Therefore, it is important for policy-makers to be aware of the role that the different elements play within the market, and how their policies could affect them, eventually leading to changes in total supply and its consumption.

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Appendix. Additional information

See Tables A.1–A.3.

Table A.1
Overview of years in which actual milk production was lower than the milk quota.
Source: Authors' elaboration based on DG AGRI's statistics.

Member state	Period
Austria	2010–2015
Belgium	2006–2015
Bulgaria	1994–2015
Croatia	1994–2015
Czech Republic	2005–2015
Denmark	2006–2015
Estonia	1994–2015
Finland	1994–2015
France	1994–2015
Germany	2009–2015
Greece	1994–2015
Hungary	1994–2015
Ireland	1999–2015
Italy	2010–2015
Latvia	1994–2015
Lithuania	1994–2015
Netherlands	2013–2015
Poland	1994–2015
Portugal	1994–2015
Romania	1994–2015
Slovenia	1994–2015
Slovakia	1994–2015
Spain	1994–2015
Sweden	1994–2015
United Kingdom	2001–2015

Note(s): These periods have been considered for the estimation of the herd equations. Nevertheless, it is possible that during the period the quota was binding for a particular year, e.g. Belgium in 2015, Spain in 1996 and 1997. If that was the case, the observation for that particular year was included in order to identify a longer period.

Table A.2
Summary estimated parameters — milk yield per head (OLS).

	Intercept, *C*	Milk prices, *mp*	Feed cost, *fc*	Trend, *t*	*R*-squared	Number of obs.
Austria	8.1506***	−0.0627	0.0012	0.0197***	0.9739	44
Belgium	8.1686***	0.3030**	−0.3305***	0.0131***	0.9293	34
Bulgaria	8.1909***	−0.0138	−0.0670**	0.0060	0.4896	12
Croatia	4.4778***	0.4138**	0.0605	0.0313***	0.9580	21
Czech Republic	8.5761***	−0.0798	−0.0452	0.0276***	0.9832	26
Denmark	8.0129***	0.1314***	−0.0237	0.0163***	0.9868	42
Estonia	7.2298***	0.0445	−0.0700	0.0425***	0.9632	12
Finland	8.1555***	0.0133	−0.0016	0 .0205***	0.9714	42
France	7.6033***	0.2938***	−0.1685***	0.0173***	0.9755	45
Germany	8.1880***	0.0593***	−0.0515***	0.0158***	0.9873	41
Greece	4.4948***	1.3505***	−0.2646*	−0.0035	0.7541	33
Hungary	9.3156***	−0.3284**	0.0691	0.0565***	0.8880	34
Ireland	7.2672	0.2678	0.0064	0.0088	0.9336	41
Italy	8.0356	0.2109	−0.2007	0.0127	0.9467	42
Latvia	7.5085***	−0.0633	−0.0015	0.0308***	0.9768	22
Lithuania	7.5188***	0.0444	−0.0056	0.0217***	0.9516	22
Netherlands	8.3718***	0.0841***	−0.0873***	0.0136***	0.9860	43
Poland	7.8336***	−0.1667***	0.0566*	0.0313***	0.9791	24
Portugal	7.5637***	0.1561	−0.1621**	0.0342***	0.9677	28
Romania	7.6765***	0.1262	0.0112	0.0001	0.5248	21
Slovenia	9.9516***	−0.8560**	−0.1903*	0.0508***	0.9014	15
Slovakia	9.3908***	0.0270	−0.3085***	0.0258***	0.7779	25
Spain	8.3944***	−0.2882	0.0709	0.0340***	0.9175	25
Sweden	8.9173***	0.0085	−0.0702**	0.0099***	0.8671	19
United Kingdom	8.2636***	0.0276	−0.0206*	0.0163***	0.9787	43

***, ** and * indicate that the corresponding regression coefficients are statistically significant at the 1%, 5% and 10% levels respectively.

Table A.3
Summary estimated parameters — herd size (OLS).

	Intercept, *C*	Milk prices, *mp*	Feed cost, *fc*	Beef price, *bp*	Trend, *t*	*R*-squared
Austria	6.4940***	−0.2862**	−0.0055	0.0864	0.0134	0.9964
Belgium	7.4884**	−0.8408*	−0.0113	0.2974	0.0019	0.9410
Bulgaria	6.9292***	−0.2640*	−0.0106	−0.0323	−0.0047	0.9963
Croatia	5.3370	0.0693	0.0477	0.0127	−0.0378***	0.9841
Czech Republic	5.3607	0.0693	0.0477	0.0127	−0.0118**	0.9841
Denmark	7.7445	−0.8408*	−0.0113	0.2974	0.0037	0.9410
Estonia	5.1550***	0.0529	−0.0605*	−0.0132	−0.0235***	0.9993
Finland	7.4000**	−0.8408*	−0.0113	0.2974	−0.0156	0.9410
France	9.9431***	−0.8408*	−0.0113	0.2974	−0.0203	0.9410
Germany	0.3159***	−0.8408*	−0.0113	0.2974	0.2435***	0.9410
Greece	5.8416***	−0.2862**	−0.0055	0.0864	−0.0170	0.9964
Hungary	5.1603	0.0693	0.0477	0.0127	−0.0364***	0.9841
Ireland	8.3633***	−0.8408*	−0.0113	0.2974	0.0011	0.9410
Italy	7.8930	−0.2862**	−0.0055	0.0864	0.0063	0.9964
Latvia	5.5301***	0.0529	−0.0605*	−0.0132	−0.0156***	0.9993
Lithuania	6.5394***	0.0529	−0.0605*	−0.0132	−0.0293***	0.9993
Netherlands	8.5815	−0.8408*	−0.0113	0.2974	0.0059	0.9410
Poland	8.3641***	0.0529	−0.0605*	−0.0132	−0.0219***	0.9993
Portugal	6.4917***	−0.2862**	−0.0055	0.0864	−0.0201	0.9964
Romania	8.3800***	−0.2640*	−0.0106	−0.0323	−0.0076*	0.9963
Slovenia	4.5670***	0.0693	0.0477	0.0127	−0.0126***	0.9841
Slovakia	5.0246***	0.0693	0.0477	0.0127	−0.0384***	0.9841
Spain	7.8216	−0.2862**	−0.0055	0.0864	−0.0217667	0.9964
Sweden	8.4813	−0.8408*	−0.0113	0.2974	−0.0031392	0.9410
United Kingdom	8.5359	−0.8408*	−0.0113	0.2974	0.0015673	0.9410

***, ** and * indicate that the corresponding regression coefficients are statistically significant at the 1%, 5% and 10% levels respectively.

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