EU Milk Quota Elimination: Has the Productivity of Irish Dairy Farms Been Impacted?

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Abstract

Employing Irish dairy farm panel data in 2007-2015, this paper investigates the impact of EU milk quota elimination on productivity of Irish dairy farms by evaluating the total factor productivity during the phasing out of milk quota. A novel structural model is adopted to control for endogeneity in estimation of the milk production function. We evaluate production changes in preparation for the removal of production quota. We will test the hypothesis that the elimination of milk quotas results in significant increased total factor productivity and there are heterogeneous responses to policy change across firms.

Keywords: EU milk quota elimination, Irish dairy, total factor productivity

JEL code: D240, Q180, L110

1 Introduction

April 1, 2015 was a watershed moment for the Irish dairy industry. The European Union (EU) milk quota system was eliminated. Given that the elimination of this system has been known to the industry since 2008, in this paper we would like to answer the question as to whether the Irish dairy industry, in preparation for the removal of production quotas, has increased its overall level of productivity. If so, have there been heterogeneous responses to policy change across firms?

Historically, economists have viewed market deregulation as an important external driver of productivity growth (Syverson, 2011). Previous literature has evaluated the positive correlation and causal impact of production restriction release on productivity growth. Kirwan et al. (2012) investigates the impact of U.S. tobacco quota buyout in 2004 on aggregate productivity growth. They find that resource reallocation is the essential part for productivity improvement. Yu (2015) investigated how reductions in tariffs on imported inputs and final goods affect productivity of Chinese trading firms. Their results show that reductions in both tariffs had a positive effect on productivity of processing firms, while opposite was found for non-processing firms. Davis and Wolfram (2012) analyzes the deregulation and consolidation in the U.S. nuclear power industry and examines the impacts on operating efficiency. The results show that deregulation and consolidation contributed to a 10 percent increase in efficiency, with similar increase across firm types.

We can see that most studies have focused on causal impact to aggregate productivity growth of the whole industry without incorporating heterogeneous impacts across decision making units. There are some papers that dig a little deeper in identifying diversity of firm responses to market liberalization. For instance, Konings and Vandenbussche (2008) find antidumping protection has different effects on productivity of domestic import-competing firms in the European Union: domestic firms with relatively low initial productivity experienced productivity gain from protection while firms with high initial productivity experience productivity reductions. We extend the existing literature by modeling a firms' dynamic preparation regarding policy changes as well as identifying the heterogeneous impacts of deregulation on productivity of continuing firms. As an application, this paper evaluates the impact of EU milk quota elimination on total factor productivity of Irish dairy farms and investigate if there have been heterogeneous responses to the quota elimination process.

Between 1984 and 2015, the European Union (EU) dairy sector has been subject to country specific production quotas. These quotas had as their main objective one of increasing overall dairy farm income. Although these quotas were officially eliminated in March 2015, their future elimination was made known starting in 2008. Thus, the Irish dairy industry had 7 years to adjust to the new policy environment. The elimination of production quota provided an incentive for dairy farms to improve productivity given increasing supplies.

Previous studies have predicted the possible impacts of quota elimination using data prior to the policy implementation. Gillespie et al. (2015) compared Irish dairy productivity before and after milk quota restriction using 1979-2012 data. They find this policy negatively affected dairy total factor productivity obtained from a stochastic frontier model. Frick et al. (2016) estimated the impacts of market deregulation on German dairy industry productivity during the phasing out of quota restrictions. The implicit assumption of these previous analyses is that the impacts of production quota elimination are symmetric to the impacts of their imposition.

The remainder of paper is organized as follows: In Section 2 we describe information concerning the EU milk quota system. Section 3 is used to provide an overview of our empirical model. This model is designed to control for endogeneity issues associated with a quality adjusted milk production function. In Section 4 contains a description of our panel data about Irish dairy farms and development of dairy production during the elimination process. In section 5 we investigate the possible impacts of deregulation on total factor productivity and estimate the heterogeneous effects across dairy farms. Our conclusions are contained in the last section of the paper.

2 Irish Dairy Industry and Policy Background

Irish dairy farms were subject to milk quota regulation between April 1984 until March 2015. This policy had, as its primary objective, the stabilization of milk prices and dairy farmer income. At the beginning of each quota year (i.e., April 1 – March 31), initial quota amounts were assigned to registered dairy farms.[1] After the announcement in 2008 of the future elimination of milk quotas in April 2015, Ireland adopted a *Soft Landing Policy* to prepare for quota elimination. This policy allowed national milk quota to increase 1% annually starting in April 2009. This 1% annual increase was allocated permanently to dairy farms according to their 2009 quota value. In addition to the annual 1% increase, dairy farm operators could adjust their quota through permanent quota purchasing, temporary leasing and regional reallocation of unused quotas. Figure 1 is used to summarize the milk quota adjustment process.

2.1 The Milk Quota Adjustment Process

Ireland permitted milk quota to be traded within each cooperative under a quota exchange system. The quota trades were conducted twice a year in October and the following January.

[1] Quota year begins on April 1st of the first year and ends on March 31st of the next year.

The resulting quota transfers can be used from the beginning of next quota year starting in April and are permanent adjustments. Colman (2000) shows that tradability of milk quota could reduce production inefficiency, but the optimal allocation from the producer perspective may not have been achieved due to continuing quota trade restrictions. Hennessy et al. (2012) highlights these restrictions in an analysis of milk quota transfers under regional restrictions in trade, quota price cooling mechanisms, limits on allowable trade quantities etc.

(1) The quota price cooling mechanisms: Under the quota exchange system, dairy farmers provided a single-bid of price and quantity of quota they were willing to trade. After the initial equilibrium exchange price was calculated based on demand and supply from dairy farmers, bids with price more than 40% above the initial equilibrium were removed and a revised clearing price calculated. In addition, 30% of available quota was allocated to selected producers at a fixed price, which reduced the amount of available quota for purchase.

(2) Limits on allowable quantity of quota to be traded: The maximum quantity per farm of tradable quota was limited to 100,000 liters. This amount is relatively large given that the average per farm milk production in our panel of dairy farms was 300,000 liters.[2]

(3) Dairy farmers subject to regional trade restrictions: Quota exchanges were only allowed within co-operatives. This resulted in clearing prices varying significantly across production.

Figure 2 is used to present average quota exchange prices between 2007-2014 period where Ireland is divided into four production regions: Border-Midlands-Western (i.e., BMW), South-west (SW), East and South[3]. For each region, average exchange prices are calculated by having regional co-operative clearing prices weighted by the total volume of quota exchanged within that cooperative as a proportion of regional total production. There is significant variation across production regions. The East and South regions are the main dairy producing regions and exhibited relatively high and volatile exchange prices. Average quota prices and volatility of BMW cooperatives was found to be relatively low.

Besides the quota exchange system, Irish dairy farms can adjust the amount of available quota through annual leasing. The allocation procedure is conducted during quota year and was valid only for the current period. There was also reallocation of unused quota to over-quota producers within each co-operative at the end of the quota year.

[2]Source: http://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/saveselections.asp

[3]*BMW* region: Louth, Leitrim, Sligo, Cavan, Donegal, Monaghan, Dublin, Galway, Mayo, Roscommon; *South-west* region: Cork, Kerry, Clare, Limerick and Tipperary North; *East* region: Kildare, Meath, Wicklow, Laois, Longford, Offaly and Westmeath; *South* region: Carlow, Kilkenny, Waterford, Tipperary South, Wexford and Waterford.

If the quantity of marketed milk exceeded the amount of available quota, penalties (often referred to as the "Superlevy") might be imposed as a punishment of overproduction (Gillespie et al., 2015).[4] In Ireland, dairy producers were penalized in proportion to their contribution to the overproduction during the quota year only when Ireland exceeded its national milk quotas.

2.2 Measures of Milk Quota Regulation

Based on the milk quota adjustment process, the amount of milk sold of farm i at period t can be decomposed into adjustments through milk quota trading and temporary leasing systems, as well as reallocation of unused quota and superlevy of over quota marketing. That is,

$$\begin{aligned}\text{Milk sold}_{i,t} =& \text{Initial Quota Owned}_{i,t} + \text{Purchased}_{i,t-1} - \text{Sold}_{i,t-1} + \text{Leasing}_{i,t} \\ & - \text{Rented Out}_{i,t} + \text{Inherited}_{i,t} + \text{Gifts}_{i,t} + \text{Over Quota Marketing}_{i,t}\end{aligned} \tag{1}$$

where $\text{Purchased}_{i,t-1}$ and $\text{Sold}_{i,t-1}$ denote the amount of milk quota purchased and sold at period $t-1$, which are available for use from period t onward. $\text{Leasing}_{i,t}$ and $\text{Rented Out}_{i,t}$ are adjustments via temporary leasing program at period t. $\text{Inherited}_{i,t}$ and $\text{Inherited}_{i,t}$ are extra quota acquired from inherit and given at period t. $\text{Over Quota Marketing}_{i,t}$ equals the amount of milk sold exceeding total available quota after all adjustments.

We create a variable that measures the extent to which a dairy farm is restricted by annual milk quota regulation. A potential measure of strength of quota regulation limitation for farm i at period t, $\text{PEM}_{i,t}$, is the percentage of milk marketed in excess of initial quota owned.

$$\text{PEM}_{it} = \frac{\text{Milk sold}_{i,t}}{\text{Initial Quota Owned}_{i,t}} - 1 \tag{2}$$

A relative large value of $\text{PEM}_{i,t}$ indicates the amount of available quota initially assigned each quota year is not sufficient compared with farm's optimal amount of milk sold. Alternatively, dairy farms with small value of $\text{PEM}_{i,t}$ face a less or even non-binding milk quota.

3 Empirical Models

3.1 Production Function Estimation

A farmer is assumed to produce Y units of milk with five inputs: labor (L), capital (K), materials and energy (M), feed (H) and cows (C). Consider a Cobb-Douglas production function: $Y_{it} = L_{it}^{\beta_l} K_{it}^{\beta_k} M_{it}^{\beta_m} H_{it}^{\beta_h} C_{it}^{\beta_c} e^{\omega_{it}+\epsilon_{it}}$. Taking logarithms of each side yields the log

[4]Superlevy is € 27.83 per 100kg. (http://europa.eu/rapid/press-release_IP-14-1086_en.htm)

form as:

$$y_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \beta_h h_{it} + \beta_c c_{it} + \omega_{it} + \epsilon_{it} \tag{3}$$

where y_{it} is the natural log of output and l_{it}, k_{it}, m_{it}, h_{it} and c_{it} are the natural logs of inputs. $\beta = \{\beta_0, \beta_l, \beta_k, \beta_m, \beta_h, \beta_c\}$ is a vector of parameters to estimate. ϵ_{it} is used to represent idiosyncratic error terms. The term ω_{it} denotes productivity shocks, which is observed by producers, but not by the econometrician and hence potentially correlated with input choices.

To account for the selection and simultaneity problem associated with input decisions and output levels, we adopt the methods of Levinsohn and Petrin (2003, LP) and Ackerberg et al. (2015, ACF) to obtain consistent estimation of productivity, ω_{it}. LP uses the intermediate material demand (m_{it}) as a proxy for productivity, the optimal amount of which is determined by $m_{it} = f_t(k_{it}, c_{it}, \omega_{it})$. Assuming f_t is strictly increasing in ω_{it}, we have $\omega_{it} = f_t^{-1}(k_{it}, c_{it}, \omega_{it})$. Substituting this into the production function in Equation (3), we have:

$$\begin{aligned} y_{it} &= \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \beta_h h_{it} + \beta_c c_{it} + f_t^{-1}(k_{it}, c_{it}, m_{it}) + \epsilon_{it} \\ &= \beta_l l_{it} + \beta_h h_{it} + \Phi_t(k_{it}, c_{it}, m_{it}) + \epsilon_{it} \end{aligned} \tag{4}$$

where $\Phi_t(k_{it}, c_{it}, m_{it}) = \beta_0 + \beta_k k_{it} + \beta_m m_{it} + \beta_c c_{it} + f_t^{-1}(k_{it}, c_{it}, m_{it})$ is a flexible functional form for which we adopt a third-order polynomial approximation. ACF assert that the labor coefficient cannot be identified in the first stage of the LP model given that the decision on labor inputs are collinear with other variables. Wooldridge (2009) solves this problem by developing a joint GMM estimation of the system, which enable the estimation of production function in one step. Moreover, the GMM estimation provides an easy method from which to obtain robust standard errors. Therefore, we adopt Wooldridge (2009)'s modification for the LP approach, i.e., Wooldridge-LP method, to estimate the production function specified in Equation (4).

We generate a Markov process that allows production quota to affect productivity when a farm is restricted by quota regulation. Following De Loecker (2011), we assume milk quota can impact total factor productivity via the following:

$$\omega_{it} = g_t(\omega_{it-1}, \text{PEM}_{it-1}) + \varepsilon_{it} \tag{5}$$

where ε_{it} is the productivity shock obtained as a residual by nonparametrically regressing ω_{it} on ω_{it-1} and PEM_{it-1}. After obtaining term ε_{it}, a system GMM estimation method is applied to the following moment condition:

$$E\begin{pmatrix} & m_{it-1} \\ & k_{it} \\ \varepsilon_{it}(\beta) & c_{it} \\ & h_{it-1} \\ & l_{it} \end{pmatrix} = 0 \qquad (6)$$

3.2 Adjustment for Output Quality

Equation (3) assumes that outputs are of the same quality and output prices are constant across observations. In Ireland, the unit value of milk is depended on the value of its components (i.e., butterfat, protein) and the milk's Somatic Cell Count[5] (SCC). This implies that Irish dairy farm operators make production decisions not only with respect to the amount of milk to produce but also the quality of that milk to increase revenue from dairy, especially when production quota restrictions are binding. This quality can be adjusted through breeding, use of genetic technology and AI and to some degree feed ration changes.

Given that milk value differs across farms due to component and SCC concentration, we need to develop a quality adjusted measure of milk production. For example, the value of a liter of milk from a herd with relatively high milk components (i.e., a Jersey cow herd) will be worth significantly more than a liter of milk from a Holstein cow.

In order to estimate Equation (3), we developed an endogenous quality index based on method proposed by Atsbeha et al. (2012) to adjust our output measure.

Suppose v_{it} is the unit value of milk for farm i at period t, which is calculated as revenue from milk divided by total milk sold, i.e. $v_{it} = \frac{R_{it}}{Q_{it}}$. With unit value being determined, in part, by milk's physical characteristics, we define milk quality as being defined by the percent composition of butterfat (I_{it}^{fat}) and protein ($I_{it}^{protein}$) and the somatic cell counts (I_{it}^{scc}). Assuming a linear relationship between these attributes and milk value we have:

$$v_{it} = \alpha_0 + \alpha_1 I_{it}^{fat} + \alpha_2 I_{it}^{protein} + \alpha_3 I_{it}^{scc} + \gamma_{it} \qquad (7)$$

where γ_{it} is a white noise error. Given the estimation of the coefficients in Equation (7), we

[5] Somatic Cell Count is a main indicator of milk quality. Somatic cells become present in increasing numbers in milk as an immune response to a mastitis-causing pathogen. The SCC is quantified as the number of cells per ml of milk. An individual cow SCC of 100,000 or less indicates an 'uninfected' cow, where there are no significant production losses due to subclinical mastitis. A threshold SCC of 200,000 identifies whether a cow is infected with mastitis. Cows with a result of greater than 200,000 are highly likely to be infected. Cows infected with significant pathogens have a SCC of more than 300,000 cells per ml or greater.(AHDB-Dairy webpage accessed 4/3/2017)

can generate a quality index for farm i at period t, $\varphi_{it} = \frac{\hat{v}_{it}}{\bar{v}}$, where $\bar{v}$ is the average milk quality and $\hat{v}_{it}$ is the non-stochastic farm/year specific milk quality.

Suppose $\widetilde{Y}_{it} = \varphi_{it} Y_{it}$ is quality adjusted milk production, with log form as $\widetilde{y}_{it} = y_{it} + \ln \varphi_{it}$. The quality adjusted production function can be specified as:

$$\widetilde{y}_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \beta_h h_{it} + \beta_c c_{it} + \omega_{it} + \epsilon_{it} \tag{8}$$

4 Irish Dairy Farm Data Used in this Analysis

The Irish dairy farm data used in this analysis was obtained from the EU Farm Accountancy Data Network (FADN), collected from the Irish National Farm Survey (NFS). The dairy farm component of the FADN data provides specific information about farm operator decisions as to input utilization and outputs produced, as well as cost and returns from milk production. It also includes detailed data concerning use of milk quota adjustment. A unique feature of this data is that it allows us to account for milk quality, specifically butterfat, protein and somatic cell count, as these milk characteristics determine, to a large degree, milk's value.

Each year are approximately 900 farms interviewed by Teagasc, representing the 80,000 Irish farms (Läpple et al., 2016). For this analysis, we focus on dairy farms surveyed over the 2007-2015 period.[6] A balanced panel data of 216 dairy farms is constructed using the above data which results in 1944 (= 216 × 9) observations.

4.1 Milk Quota Allocation Data

Table 1 is used to present the average per farm quota initially assigned, available quota amount after adjustment and quantity of milk sold each quota year (2007-2014) across all Irish dairy farms. Adjustments of milk quota shown in this table include permanent exchanges (purchased or sold), temporary transfers (leased and rented out) as well as other transfers (inherited or gifts).

In our dairy panel, initial quota assigned to dairy farms increased by 16.5% between 2007 - 2014. The amount of quota purchased decreased significantly after 2007. Since the milk quota elimination was confirmed in 2008, dairy farmers had less incentive to invest in permanent quota. Milk quota acquired from temporary lease decreased by 66.6% over this period. The average annual quantity of marketed milk increased by 17.1%, from 308,930 to

[6] In 2007-2009, a farm is defined as being a dairy farm if the Standard Gross Margin (i.e. value of output minus costs) associated with the dairying operation accounts for at least two-thirds of the total SGM for the farm. From 2010-2015, the classification is based on the Standard Output, (i.e., average monetary value of the agricultural output at farm-gate price). Over the study period, the range in number dairy farms surveyed each year was from 244 in 2010 to 407 in 2007. In 2015, the last year we have data there were 319 farms designated as dairy farms.

365,890 liters.

4.2 Dairy Production Data

For our dairy panel, Table 2 is used to provide descriptive statistics concerning input use and output produced. To investigate the change of dairy production during the study period, we specify average input/output values on an aggregate year-specific (Panel A) and per cow basis (Panel B).

For this analysis, output is measured as milk sold (liters). The average quantity of milk sold is 342,923 liters, with a range of 11,491 to 1,641,593 liters. The average annual milk output per cow is 4,889 liters, with minimum value of 1,393 and maximum of 7,687 liters per cow. From 2007 to 2014, the annual average percent change of milk sold was 2.8%, while in 2015, the increase in milk sold was 14.0%.

Revenue from dairy includes the value milk sold or used on farm plus net returns from dairy animal sales. Contrary to the significant increase in milk quantity during the study period, in 2015, revenue from dairy decreases by 7.6% compared to the 2014 value of milk production. Inputs identified in our production function include herd size, labor units in dairy production, value of fixed capital, material inputs, land used for pasture and use of concentrated feed. The average annual per farm herd size over the study period was 68 cows with a range from 7 to 282 cows. During the study period, there was significant increase in herd size, especially after quota elimination in 2015. In 2015, the average number of dairy cows per farm increased by 7.4%, comparing to the average annual growth rate of 2.7% observed over the 2007-2014 period.

Figure 4a is used to show the distribution of dairy farms by different herd size in our panel over the years (2007, 2010, 2013 and 2015). There is an obvious shifting trend towards large sized operations over the study period. The proportion of dairy farms with more than 100 cows increased in nine years, while the proportion of small farms with less than 50 cows declined. Distribution of dairy cows associated with farms, as presented in Figure 4b, is concentrated in the larger size operations.

Figure 4c presents the percentage change in herd size of dairy farms with different scales. From 2007 to 2011, herd size increases averaged 3% for farms with more than 70 cows, while the growth rate for small dairy farms is insignificant and even some with negative growth. Between 2014 and 2015, dairy farms with different scales all have significant scale expansion. Dairy farms with more than 70 cows experienced 13% increase in herd size and the herd size percentage change for small dairy farms is around 5%.

Pasture land for the dairy enterprise, including owned and rented, is measured as the total area under grass plus common area for the dairy enterprise. The average pasture size was 34.9 hectares (HA), ranging from 2.2 to 121.9 HA. Panel B of Table 2 shows the positive relationship between pasture land area and the number of dairy cows in the herd. Herd size growth was facilitated by this increased pastureland as the amount of pastureland per cow did not change appreciably over the study period.

Concentrated feed allocated to dairy production is defined as a separate input in our empirical production function. The amount of concentrates fed varied from year to year.

Our labor input is the number of labor units working in dairy production. A labor unit is defined as 1,800 hours. The total labor units used here include the sum of unpaid and paid labor age[7]. The change in labor input is relatively small comparing to other inputs and it varies across observation periods. There is not significant change in labor input along quota policy.

The material input includes total annual expenditures on fuel, lubricants, water, electricity and fertilizer. The average level of material inputs was €4,870, ranging from €302.37 to €28,867. There isn't much fluctuation in costs of material per dairy cow during study periods and it experiences a slight average decrease in 2015. Fixed capital inputs are represented by the valuation of machinery and buildings (Petrick and Kloss, 2013). The average annual growth of fixed capital was found to be 6.0%. FADN data includes farm's inputs on a whole farm basis, consequently allocation of input costs for dairy are calculated according to the share of dairy revenue in total farm output. Monetary input, material and capital items, are deflated using the Agricultural Price Indices as reported by Irish Central Statistics Office[8].

4.3 Development of Milk Components and Quality

Figure 3 is used to show the frequency distribution of butterfat, protein and SCC's for our 2007-2015 panel. There is significant variation in milk quality across farms as well as over the study period. In 2015, more than 50% of dairy farms in the sample produce milk with more than 4.1% butterfat. In 2008, less than 10% of the panel had more than 4.1% butterfat. Similar to the increase in butterfat content, the proportion of dairy farms with above 3.4% protein composition increases from 45% to 83%. In 2015, the SCC of more than 80% dairy farms is under 252,000 cells per ml, the national standard of raw milk. Only 42% of dairy farms satisfied this requirement in 2008.

[7]No one person can be more than one labor unit even if he/she works more than the 1800 hours. Persons under 18 years of age are given the following labor-unit equivalent: 16-18 years = 0.75, 14-16 years = 0.50.

[8]Data source of input price index: http://www.cso.ie/en/statistics/prices/archive.

5 Analysis of Milk Production on Irish Dairy Farms

5.1 Estimation of Quality Adjusted Milk Production Functions

Table 4 is used to present the parameter estimates of the production function shown in Equation (2) and associated quality adjusted production function represented in Equation (6). We estimate these production functions via OLS and incorporating farm-specific fixed effects. The estimated elasticities are shown in columns (1) and (3), respectively. Columns (2) and (4) contain the results estimated using the Wooldridge (2009) LP modification approach (WLP).

Compared to the WLP based results, we find that the OLS fixed effects method tends to yield higher values for the flexible input coefficients (e.g., material inputs, number of cows) and lower values for the quasi-fixed input coefficients (e.g., capital inputs).

5.2 Milk Quota Elimination and Total Factor Productivity

To quantify the change in productivity with respect to regulation change, we first estimate a linear regression as specified in Equation (9). The dependent variable, ω_{it}, is total factor productivity obtained from the production function via Equation (8).

$$\omega_{it} = \alpha_0 + \alpha_1 \omega_{it-1} + \alpha_{\text{PEM}} \text{PEM}_{it} + \alpha_X \mathbf{X}_{it} + f_t + f_i + \mu_{it} \tag{9}$$

where PEM_{it} is the percentage of milk marketed in excess of initial owned quota for farm i at period t as defined in Equation (2). Control variables $\mathbf{X}_{it}$ is a vector of farm characteristics. α_X is a vector of corresponding coefficients. f_t and f_i are farm and time fixed effects, respectively. μ_{it} is an error term that are uncorrelated with independent variables.

The results of Equation (9) are shown in Table 5 column (1) and (2). The first column specifies an AR(1) productivity process, where productivity for farm i at period $t-1$, ω_{it-1}, is included as a control variable. The statistically significant and positive lagged productivity measure, provides evidence that a farm's productivity is highly correlated with the production history and consistent with the theoretical result shown in Equation (5).

Column (2) of Table 5 incorporates farm characteristics such as herd size, age of operator, features related to management skills and features related to dairy production. Results suggest that coefficient of the percentage of milk over marketed (PEM) is negative and statistically significant. Total factor productivity of dairy farms is negatively correlated with the strictness of milk quota regulation. For dairy farms operating under the environment of milk quota phasing out, less restrictions in production will enhance the development of total factor productivity.

5.3 Heterogeneous impact of quota elimination across dairy farms

We future investigate if the elimination of milk quota has heterogeneous impacts across dairy farms and identify the farm characteristics that enhance impacts of quota deregulation on productivity. Specifically, we expand Equation (9) with interaction terms of the measurement of quota regulationPEM_{it} and farm characteristics, $\mathbf{X}_{it} * \text{PEM}_{it}$. $\alpha_{\mathbf{X}*\text{PEM}}$ denotes the vector of coefficients for interaction terms. The estimated Equation is specified as follows:

$$\omega_{it} = \alpha_0+\alpha_1\omega_{it-1}+\alpha_{\text{PEM}}\text{PEM}_{it}+\alpha_X\mathbf{X}_{it}+\alpha_{\omega*\text{PEM}}\omega_{it-1}*\text{PEM}_{it}+\alpha_{\mathbf{X}*\text{PEM}}\mathbf{X}_{it}*\text{PEM}_{it}+f_t+f_i+v_{it} \quad (10)$$

In this way, we can test if there exists various response of farms and assess which kinds of dairy farms benefit more from milk quota elimination. Estimation results for Equation (10) is shown in Table 5 column (3).

(1) Herd size and farm operator's age

Dairy herd size is used to interacted with regulation measure. The coefficient of herd size is positive and statistically significant, while coefficient of interaction term is statistically insignificant. Larger dairy farms show advantage in productivity but do not benefit more from milk quota deregulation.

Coefficient for dairy farm operator's age is not significant and neither is the interaction term with regulation measure, implying that age of dairy farmers is not correlated with productivity.

(2) Dairy specialization

Dairy specialization is represented by the ratio of revenue from dairy production to total farm revenue. The positive coefficient for dairy revenue ratio is positive, indicating that farms that are more focused on dairy production tend to be more productive. One explanation is that the more dairy-specialized farms may make more efforts to enhancing productivity and become more competitive.

The interaction term with regulation measure is positive and statistically significant. This result indicates the marginal effect of milk quota phasing-out increases as the ratio of revenue from dairy production increases. Farms with more specification on dairy production may benefit more in productivity enhancing from the change of milk quota policy.

(3) Dairy livestock density

When expanding dairy herd size, dairy farms can choose to invest in more pasture land or increase the proportion of concentrate feed. We define dairy livestock density as the ratio of dairy livestock numbers to pasture land hectare. The negative coefficient indicates farms with more pasture land per dairy cow tend to be more productive. Interaction term of dairy livestock density with regulation measure is statistically insignificant, indicating dairy farms with more pasture land per livestock do not seem to benefit more from production liberalization.

(4) Management skills

Another potential channel for productivity growth is improvement in management skills, which we propose to measure by SCC index and feed conversion rates. As discussed in the empirical model section, SCC is an important index for milk quality. Lower SCC value indicates less harmful bacteria and is highly correlated with a dairy farmer's management skills. Feed conversion rates denotes ratio of milk sold (liters) to concentrate feed (kg) inputs. Higher value of feed conversion is associated with better management skills Läpple et al. (2016). Coefficient of SCC is significantly negative and coefficient of feed conversion is significantly positive. Both indicates dairy farms that have advantage in management are more productive. When regulation measure is interacted with SCC index and feed conversion, the coefficient is statistically insignificant.

6 Conclusion and Discussion

This paper investigates the impact of EU milk quota abolition on productivity of Irish dairy farms by evaluating the total factor productivity pre vs. post quota elimination employing Irish dairy farm panel data in 2007-2015. A novel structural model is adopted to control for endogeneity in estimation of the milk production function and total factor productivity. We adopt the percentage of milk marketed in excess of initial owned quota as a measurement of quota regulation and hence evaluate the correlation between milk quota elimination and productivity of Irish dairy farms.

The results indicate that dairy herd size experience significant increase along the deregulation. Production of milk increased by 14% in 2015 comparing to the production in 2014. There was also significant improvement in milk quality during the phasing out of milk quota regulation. Estimation results indicates impose of milk quota restriction hinders the development of dairy farm productivity. Dairy farmers have heterogeneous responses with the preparation for this production liberalization and hence the impact on productivity is various across dairy farms. Dairy farmers with relatively high revenue ratio in dairy production experience more positive impact from milk quota elimination.

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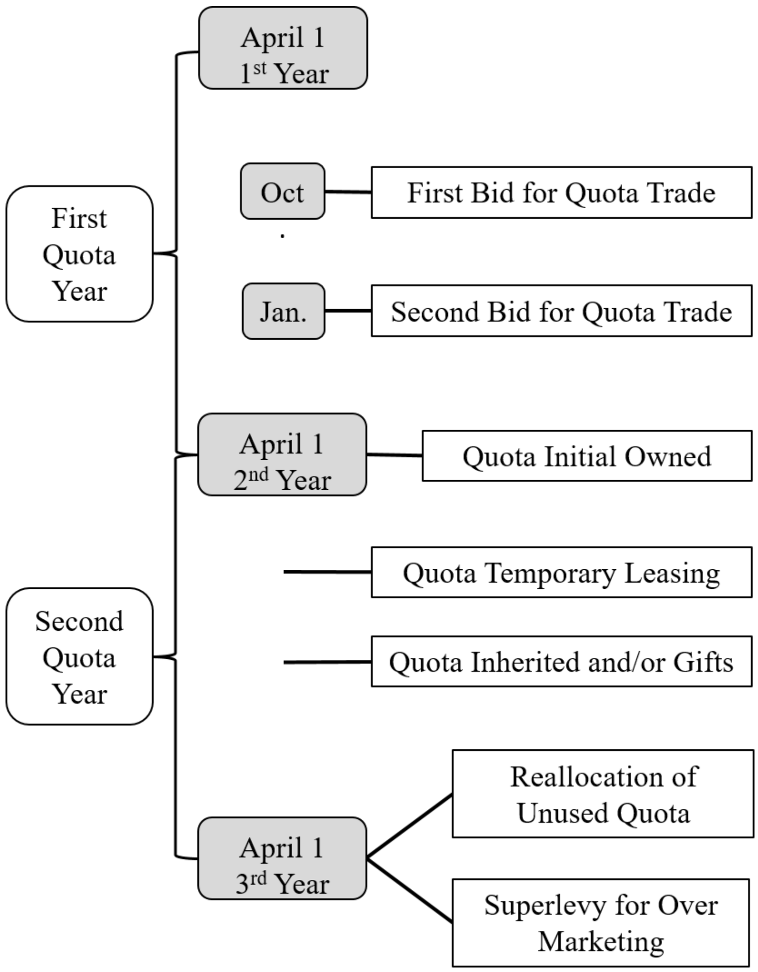


Figure 1: The Milk Quota Allocation Process

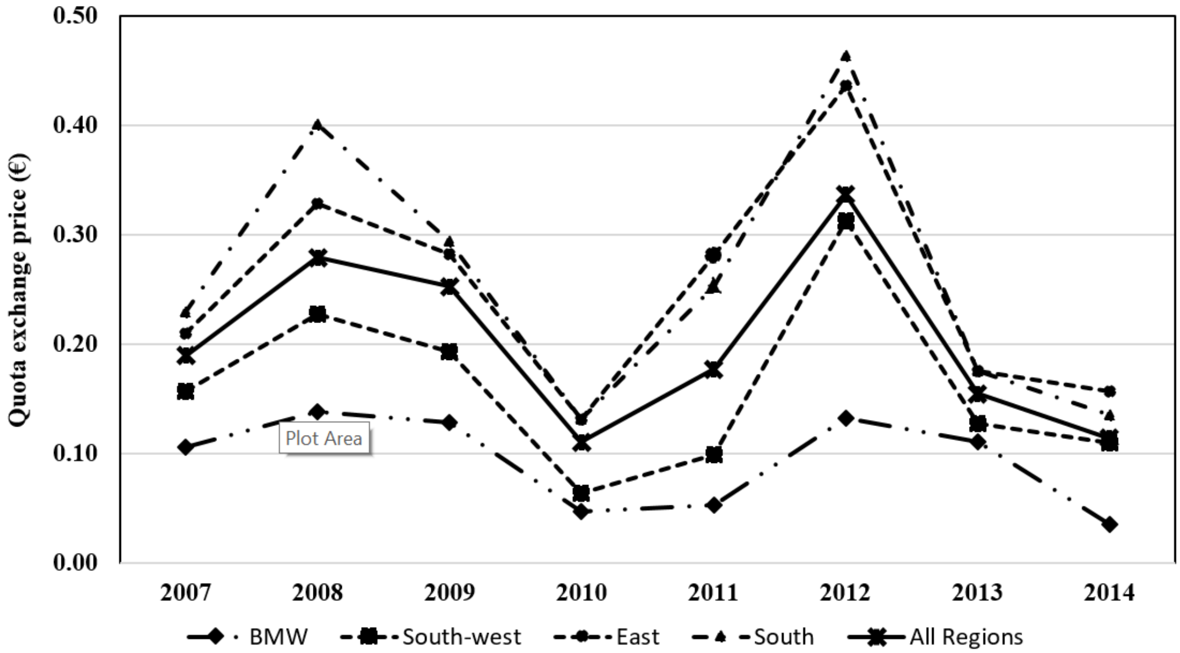
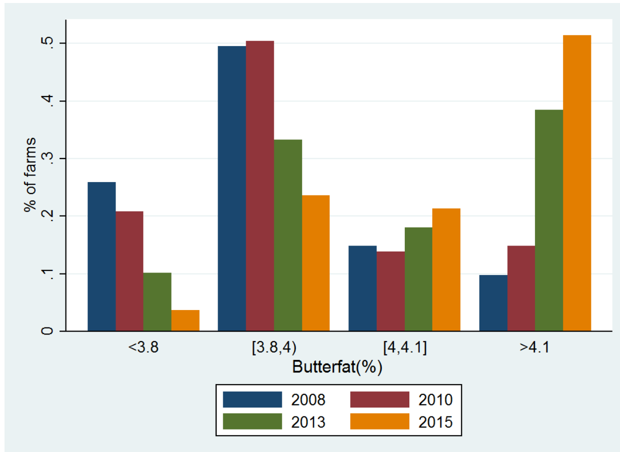
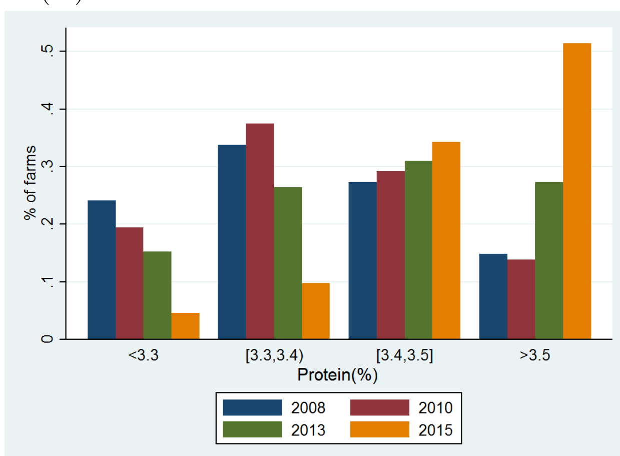


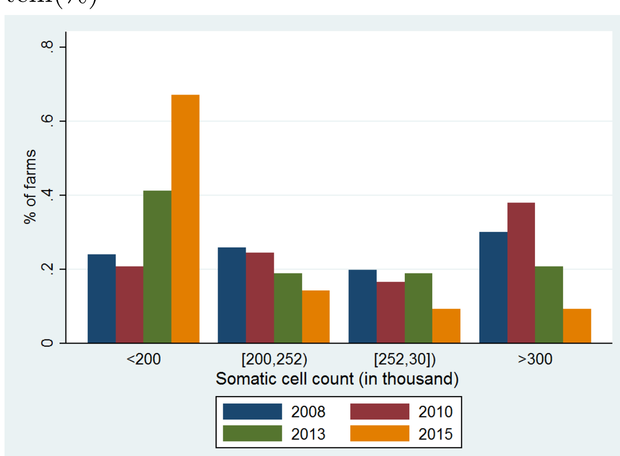
Figure 2: Average Quota Exchange Prices by Production Region



(a) Distribution of Whole Herd Average Butter-fat(%)

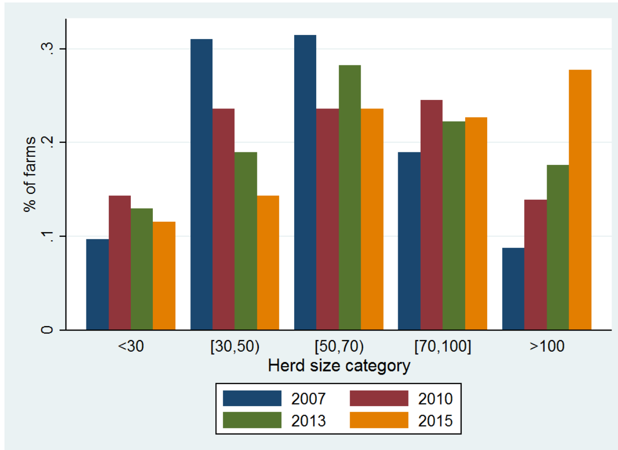


(b) Distribution of Whole Herd Average Protein(%)

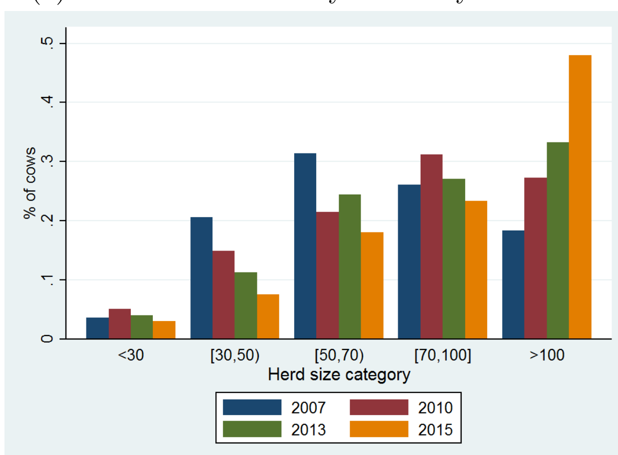


(c) Distribution of Whole Herd Average Somatic Cell Count (in thousand)

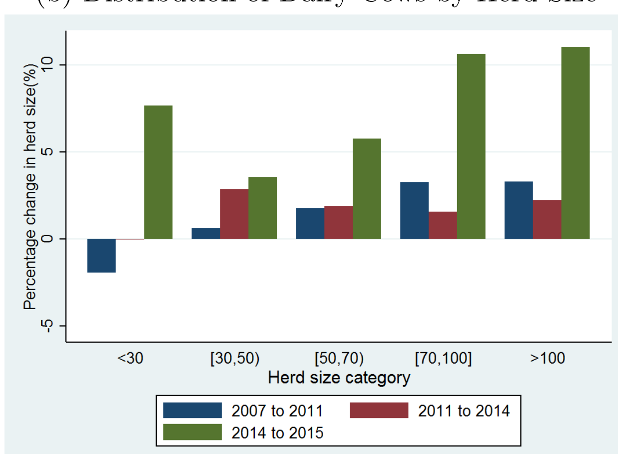
Figure 3: Distribution of Whole Herd Average Milk Components (%) for Selected Years, Irish Panel



(a) Distribution of Dairy Farms by Herd Size



(b) Distribution of Dairy Cows by Herd Size



(c) Percentage Change in Herd Size of Dairy Farms with Different Scales

Figure 4: Herd size development of Irish dairy farms

Table 1: Milk Quota Allocation and Amount Sold by Year (1,000 litres)

	Whole Sample	2007	2008	2009	2010	2011	2012	2013	2014
Initial Quota Owned	325.03	295.01	312.18	315.22	334.39	328.09	333.24	338.36	343.75
	(212.94)	(224.98)	(234.16)	(184.36)	(249.66)	(193.01)	(197.78)	(204.45)	(206.00)
Purchased	5.19	15.50	9.73	3.61	2.48	2.73	3.91	2.14	1.40
	(18.19)	(31.10)	(23.79)	(15.56)	(11.02)	(11.42)	(17.08)	(10.60)	(7.56)
Leased	6.69	14.99	11.86	2.59	3.04	5.83	6.47	3.71	5.00
	(24.71)	(36.83)	(38.82)	(17.90)	(12.29)	(18.46)	(24.97)	(14.67)	(15.87)
Rented to Other Producers	0.84	0.32	1.31	0.37	–	1.49	0.69	1.18	1.33
	(7.19)	(2.79)	(7.22)	(3.55)	–	(9.07)	(6.89)	(8.45)	(11.82)
Inherited and/or Gifts	1.21	0.66	2.28	2.11	0.93	1.07	1.00	1.13	0.50
	(4.23)	(6.78)	(3.43)	(6.98)	(1.63)	(2.60)	(2.85)	(2.64)	(3.12)
Total Quota Available	337.20	325.20	334.60	323.25	340.83	336.25	343.96	344.15	349.32
	(223.09)	(247.97)	(254.02)	(192.75)	(252.09)	(201.63)	(209.43)	(208.43)	(210.88)
Milk Sold	333.05	308.93	312.44	305.42	333.15	345.10	337.41	356.09	365.89
	(214.38)	(187.27)	(200.68)	(197.55)	(221.54)	(219.40)	(216.45)	(233.10)	(229.86)

[1] Unit of variables listed is one thousand liters;
[2] Standard deviation in parentheses;
[3] Our balanced panel consists of 216 dairy farms with 1728 total observations (2007-2014).

Table 2: Descriptive Statistics of Input and Output Variables in Production Function.

	Unit	Mean	Std. Dev.	Minimum	Maxium
Quantity of Milk Sold	liter	342,924	223,936	11,491	1,641,593
Revenue from Dairy	€	116,138	80,405	3619	574,638
Herd Size	#	68	36	7	283
Labor	labor unit	1.10	0.49	0.17	4.83
Material	€	12,168	8338	392	64,008
Capital	€	113,862	93,295	499	633,048
Concentrated Feed	kg	68,188	61,523	100	491,300
Pasture Land	ha	34.9	16.6	2.2	121.9

[1] A labor unit is defined as 1800 hours;
[2] Our balanced panel consists of 216 dairy farms with 1944 total observations (2007-2015).

Table 3: Descriptive Statistics of Input and Output Variables by Year and Per Cow Basis.

	Unit	Whole Sample	2007	2010	2013	2015
Panel A: Variables by Year						
Quantity of milk sold	liter	342,923 (223,936)	308,932 (187,269)	333,147 (221,544)	356,095 (233,102)	421,878 (277,453)
Revenue from dairy	€	116,138 (80,405)	106,780 (65,769)	104,118 (71,421)	141,380 (92,869)	132,898 (90,557)
Herd size	#	68 (36)	60 (29)	65 (35)	70 (38)	79 (45)
Labor	labor unit	1.10 (0.49)	1.08 (0.46)	1.08 (0.48)	1.16 (0.54)	1.16 (0.53)
Material	€	12,168 (8338)	10,762 (6997)	10,980 (7029)	13,659 (9025)	14,941 (10,187)
Capital	€	113,862 (93,295)	100,880 (82,050)	109,429 (90,053)	123,357 (100,442)	125,797 (99,340)
Concentrated feed	kg	68,188 (61,523)	57,454 (53,026)	68,907 (65,201)	83,339 (68,451)	74,970 (66,330)
Pasture land	ha	34.94 (16.61)	31.14 (13.72)	33.90 (15.97)	35.74 (16.99)	39.70 (20.22)
Panel B: Variables in Per Cow Basis						
Quantity of milk sold	liter/cow	4889 (1015)	4985 (960)	4913 (1042)	4898 (989)	5142 (1006)
Revenue from dairy	€/cow	1641 (438)	1719 346)	1525 (347)	1940 (405)	1605 (350)
Labor	labor unit/cow	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Material	€/cow	175 (51)	173 (47)	166 (44)	192 (54)	185 (46)
Capital	€/cow	1601 (791)	1614 (815)	1603 (754)	1662 (814)	1521 (764)
Concentrated feed	kg/cow	966 (484)	914 (481)	983 (502)	1138 (483)	922 (433)
Pasture land	ha/cow	0.55 (0.18)	0.54 (0.13)	0.55 (0.16)	0.55 (0.21)	0.55 (0.24)
Observations		1944	216	216	216	216

[1] Standard deviation in parentheses;
[2] A labor unit is defined as 1800 hours;
[3] Our balanced panel consists of 216 dairy farms with 1944 total observations (2007-2015).

Table 4: Production Function Estimates.

	Production Function		Quality-Adjusted Production Function	
	(1)	(2)	(3)	(4)
	OLS FE	WLP	OLS FE	WLP
Cow	0.762***	0.709***	0.813***	0.739***
	(0.024)	(0.045)	(0.026)	(0.048)
Labor	0.144***	0.090***	0.156***	0.114***
	(0.015)	(0.033)	(0.017)	(0.033)
Capital	0.029***	0.109**	0.041***	0.099**
	(0.010)	(0.043)	(0.012)	(0.045)
Material	0.075***	0.045	0.079***	0.043
	(0.009)	(0.044)	(0.010)	(0.047)
Feed	0.074***	0.155***	0.076***	0.146***
	(0.007)	(0.023)	(0.008)	(0.024)
Land	0.070***	0.043	0.079***	0.043
	(0.018)	(0.038)	(0.020)	(0.041)
Constant	8.384***	8.460***	8.044***	8.583***
	(0.087)	(1.187)	(0.095)	(1.274)

[1] Standard errors in parentheses;
[2] * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 5: Impacts of Milk Quota Elimination on Dairy Farm Total Factor Productivity.

	Dependent Variable: TFP		
	(1)	(2)	(3)
PEM	-1.775**	-1.953***	-7.267
	(0.579)	(0.567)	(5.597)
Previous productivity	0.806***	0.720***	0.715***
	(0.016)	(0.016)	(0.017)
PEM × Previous productivity			0.0562
			(0.076)
Age		-0.180	-0.195*
		(0.093)	(0.094)
PEM × Age			-0.594
			(0.475)
Herd Size		0.817**	0.735*
		(0.292)	(0.295)
PEM × Herd size			-2.392
			(1.603)
Dairy Revenue Ratio		3.433***	3.885***
		(0.803)	(0.839)
PEM × Dairy revenue Ratio			11.91**
			(4.138)
Dairy Livestock Density		-0.287	-0.193
		(0.202)	(0.205)
PEM × Dairy Livestock Density			-1.053
			(0.875)
SCC		-0.940***	-0.917***
		(0.103)	(0.110)
PEM × SCC			0.719
			(0.491)
Feed Conversion		3.811***	3.954***
		(0.468)	(0.500)
PEM × Feed conversion			1.484
			(3.011)
Constant	4.339***	7.778***	7.584***
	(0.670)	(1.104)	(1.117)
Time FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Adj. R-squared	0.657	0.689	0.692

[1] Standard errors in parentheses;
[2] * significant at 10%; ** significant at 5%; *** significant at 1%;
[3] The estimation consists of 1505 total observations (2007-2014);
[4] PEM is the percentage of milk marketed in excess of initial owned quota;
[5] Feed Conversion = $\frac{\text{Milk Sold (liters)}}{\text{Concentrate Feed (kg)}}$;
[6] Dairy Livestock Density = $\frac{\text{Dairy Livestock Units}}{\text{Pasure Area (ha)}}$.