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

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Contributed Paper prepared for presentation at the 90th Annual Conference of the Agricultural Economics Society, University of Warwick, England

4 - 6 April 2016

Abstract

Employing Irish dairy farm panel data in 2007-2015, 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. A novel structural model is adopted to control for endogeneity in estimation of the milk production function. We generate a dynamic programming model as well as productivity decomposition to analyze the impact channels through which milk quota elimination impact dairy multi-factor productivity. We will test the hypothesis that the elimination of milk quotas result in significant increased productivity.

Keywords: EU milk quota elimination, Irish dairy, productivity

JEL code: D240, Q180, L110

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1 Introduction

Has the productivity been impacted by market deregulation? If so, are there heterogeneous responses to policy changes across firms? This paper tries to answer these questions that are important for policy analysis as well as production decisions. Market deregulation is viewed as an important external driver of productivity growth (Syverson, 2011). Previous literatures have carefully evaluated the positive correlation and causal impact of this policy relief of production restrictions on productivity growth. Kirwan (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) investigate the effects of reductions in tariffs of imported inputs and final goods on productivity of Chinese trading firms. The results show that reductions in tariffs has a positive effect on productivity, while opposite is true for non-processing firms. Davis (2011) 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 contribute to 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 or to firm-level without incorporating heterogeneity across observations. There are some papers that dig a little deeper in identifying different effects of regulation on different firms. For instance, Konings (2008) find that antidumping protection has different effects on productivity for domestic import-competing firms in the European Union: domestic firms with relatively low initial productivity have productivity gain from protection while firm with high initial productivity experience losses in productivity due to this policy.

We try to extend the existing literature by modeling firms' optimal production decisions regarding policy changes as well as identifying the channels of deregulation impact on continuing firms. Specifically, this paper evaluates the impact of EU milk quota elimination on Irish dairy farms and test if there are heterogeneous responses across dairy farms given the common knowledge of upcoming policy.

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 increasing overall EU 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.

Will the elimination of milk production quota become a driver of productivity growth for Irish dairy farms? Previous studies have predicted this impact 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 defined as a Malmquist productivity index by stochastic frontier model. Frick and Sauer (2016) estimated the impacts of market deregulation on German dairy industry productivity during the phasing out of quota restrictions. The result indicates that aggregate productivity is positive correlated with deregulation.

Syverson (2011) addressed that proper deregulation may drive improvement of productivity as an external drivers. Careful investigate the mechanism of effects and empirically quantify the degree of impacts are of same importance. We attempt to list how productivity is affected by milk quota elimination.

(1) Scales of economics. Without production quota, some farms may increase production to optimal amount, which allows for scales of economics. In general, deregulation will improve total factor productivity, but this effect may vary across dairy farm systems. According to Läpple et al. (2016), dairy production expansion can be achieved in two stage. First is increase specialization in dairy production, which refers to replace male livestock with dairy cows. This is relative low in cost may result in significant efficiency gain from inputs. The second stage is to increase land and other inputs. This stage is high in cost and may not have significant increase in productivity if the production is not increase return to scales. Therefore, rather than general estimation of deregulation effect on productivity, empirically quantify the different impacts across dairy farms is of importance.

(2) Technology adoption and management skills. Related to scale of economics, with expansion of production, farms will have more incentive to invest in adoption of new technology as well as improvement of management skills.

(3) Farm entry and exit. Deregulation of production can result in selection among producers with heterogeneous productivity. It allows farmers with low costs to expand production and tend to have more market shares, while accelerate the exit of less productive farms. The observed productivity will increase. Previous quota endowment is a source of rent to owners, with restrictions in quota trade, this may become barrier for less productive farmers to exit. Therefore, deregulation in production will contribute to the selection of producers based on productivity.

(4) Competition. Related to the selection effects in (3), less restrictions in production will increase competition in dairy markets. With more intense competition, dairy farmers have more incentive to enhance productivity in order to survive.

(5) Management of uncertainty in production. Dairy production has high risk and variations comparing to other industries, since it highly depend on exogenous conditions like

weather and health of milk cows. Previously with significant penalty on over-quota production, farmers may be exposed to waste of inputs and reduction in revenue from exceeding quota. Without production constraints, farmers are more tolerant of production fluctuation.

(6) Productivity spillovers. Productivity improvement of one dairy farm may have externalities on other producers. Previous study indicates that producer practices can have spillover effects on others' productivity level through mechanism like knowledge transfer (Syverson, 2011). Dairy farmers are likely to emulate and learn from other farmers with high level of productivity. Therefore, if deregulation could increase the frontier of productivity levels, it can improve average productivity through spillover effects.

The rest of paper is organized as follows. Section 2 introduces Irish dairy industry and policy background of EU milk quota restrictions. Section 3 is the empirical models, which proposes a structural model to control for endogeneity issues in estimation of quality adjusted milk production function. Section 4 is description of dataset. We estimate the heterogeneous impacts of quota elimination on productivity across dairy farms in section5. Finally, section 6 is the conclusion and discussion.

2 Irish Dairy Industry and Policy Background

Irish dairy farmers are restricted by milk quota regulation since 1984. This policy aims to stabilize milk prices and the incomes of dairy farmers. Milk output is restricted to quota assigned, otherwise "superlevy" is imposed as a punishment of overproduction (Gillespie et al., 2015). After the announcement of milk quota elimination in 2008, Ireland adopts the "Soft Landing Policy" to prepare for the imminent deregulation. National milk quota is allowed 1% annually increase from April 2009. This 1% annual increase remains until the expiry of the quota system on April 2015.

Along with the production quota regulation, Ireland permits milk quota to be traded within each co-operative under a quota exchange scheme (Hennessy, 2012). Dairy farmers give a single-bid of price and quantity of quota they are willing to trade. The equilibrium exchange price is determined based on demand and supply as well as regulation interventions. Colman (2000) shows that tradability of milk quota could reduce production inefficiency, but the optimal allocation was not achieved due to quota trade restrictions. The transfer of quota in Ireland are also subject to restrictions as follows. First restriction is quota price cooling mechanism. After initial equilibrium exchange price is calculated based on demand and supply from dairy farmers, bids with price more than 40% of the initial equilibrium will be removed and the new clearing price is calculated again. Moreover, 30% of available quota is allocated to certain producers at a fixed price, which induces distortion from equilibrium. Second, there are quantity limitation in the trade. The maximum quantity of traded quota is limited to 100,000 liters for each buyer. Comparing to average milk production, quota trade only allows for structural change to some extent. For instance, average production of Irish farms in 2014 is 300,000 liters. Third, dairy farmers are subject to regional restrictions in trade. Quota exchange is only allowed within co-operatives, clearing prices vary significantly across production regions (Hennessy et al., 2012). Figure 1 presents the development of quota exchange price, in which we divide data into four production regions: border, midlands and western (BMW), the south-west (SW), the east and the south[1]. The average exchange prices are calculated by clearing prices for each cooperative weighted by the total volume of quota exchanged within the cooperative. We can see that there is significant variation across production regions. East and South regions have relatively high and volatile exchange prices as they are the main production regions for dairy, price of BMW region is relatively low with less variance, where is characterized by poorer condition for dairy production.

We propose to adopt the milk quota exchange prices to quantify the milk quota regulation power for the following reasons. First, the descending trend of clearing price along time is consistent with the phasing out of milk quota regulation. As shown in Figure 1, the quota exchange price in general decreases during 2008-2014, especially from 2012. Second, milk quota exchange price is an additional cost for farmers to expand their production due to quota restriction. Lower exchange price indicates less restriction and barriers for dairy farmers to adjust milk production (Frick and Sauer, 2016). Third, annual and regional specific quota exchange prices provide enough variation across observations in the analysis. Since quota trade scheme is eliminated along with quota restrictions in 2015, the clearing price takes value zero from 2015 afterward. In sum, different quota exchange prices incorporate the variation in regulation power during the phasing-out as well as after quota elimination. We also adopt other measurement of regulation power, such as total amount of quota assigned, in section of robustness check.

3 Empirical Models

3.1 Production Function Estimation

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 log of each side yields the log form as:

$$y_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \beta_f h_{it} + \beta_c c_{it} + \omega_{it} + \epsilon_{it} \tag{1}$$

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

where y_{it} is the log of output and l_{it}, k_{it}, m_{it}, f_{it} and c_{it} are the logs of inputs. $\beta = \{\beta_0, \beta_l, \beta_k, \beta_m, \beta_f, \beta_c\}$ is a vector of parameters to estimate. ϵ_{it} represents idiosyncratic shocks. ω_{it} denotes productivity shocks, which are observed by farmers, but not by econometrician, and therefore is potentially correlated with input choices.

To deal with the endogeneity problem, 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 $\omega_{it} = f_t^{-1}(k_{it}, c_{it}, \omega_{it})$. Plugging into the value-added production function and collecting terms, we have: $\tilde{r}_{it} = \beta_l l_{it} + \beta_f h_{it} + \Phi_t(k_{it}, c_{it}, m_{it}) + \epsilon_{it}$. ACF proposes that labor coefficient can not be identified in the first stage of LP model, since the decison on labor inputs is 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 stage. Moreover, it provides an easy way to obtain robust standard errors. Therefore, we adopt the Wooldridge (2009) LP modification approach (WLP) to estimate the production function and evaluate multi-factor productivity.

We generate a Markov process that allows for different function forms when the farmer produces with or without milk quota constraints (Doraszelski and Jaumandreu, 2013). q_{it} denotes quota regulation measure for farm i at period t. The Markov process can be written as follows:

$$\omega_{it} = \mathbb{1}(q_{it}^T = 0)(g_{00} + g_{01}(\omega_{it-1}) + \mathbb{1}(q_{it}^T > 0)(g_{10} + g_{11}(\omega_{it-1}, q_{it}^T)) \tag{2}$$

When estimating equation (1) with equation (2), constants g_{00}, g_{10} and β_0 cannot be separated. We estimate $\beta_0 + g_{00}$ and include dummy for farmers with $\mathbb{1}(q_{it-1}^T > 0)$ to measure $g_{10} - g_{00}$.

After obtaining the productivity innovation ε_{it}, a system GMM estimation method is applied to the following moment condition:

$$E\begin{pmatrix} & m_{it-1} \\ & k_{it} \\ \varepsilon_{it}(\beta) & c_{it} \\ & f_{it-1} \\ & l_{it} \end{pmatrix} = 0 \tag{3}$$

3.2 Adjustment for Output Quality

Equation (1) assumes that outputs are of the same quality and output prices are constant across observations. The unit price of milk is based on its components and quality in Irish dairy market, hence dairy farms may make production decisions to improve milk component compositon and quality to increase revenue from dairy, especially under production quota restrictions. Therefore, we deveoped a quality index based on method proposed by Atsbeha et al. (2012) to adjust output measurement in production function estimation.

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 quantity, i.e. $v_{it} = \frac{R_{it}}{Q_{it}}$. According to milk pricing system in Ireland, three main related to milk quanliy are considered: percentages of butterfat and protein and the somatic cell counts (SCC). In Ireland, milk prices are based on an average SCC of 252,000[2], which implies there is value deduction if somatic cell counts exceed this standard. We generate a SCC index to measure the exceeding amount of actual somatic cell counts to standard amount, which takes value zero when not exceeding: $I_{it}^{scc} = \max\{0, I_{it}^{scc_0} - 252000\}$, where I_{it}^{scc} is generated SCC index and $I_{it}^{scc_0}$ is the actual value of SCC. We assume linear effect of these attributes on milk value and use truncated regression model to estimate the following equation.

$$v_{it} = \alpha_0 + \alpha_1 I_{it}^{fat} + \alpha_2 I_{it}^{protein} + \alpha_3 I_{it}^{scc} + \varepsilon_{it} \tag{4}$$

where I_{it}^{fat} and $I_{it}^{protein}$ are respectively percentages of butterfat and protein and ε_{it} is a random shock with mean zero. With estimated coefficients, a predicted unit value $\hat{v}_{it}$ for farm i at period t is recovered as $\hat{v}_{it} = \hat{\alpha}_0 + \hat{\alpha}_1 \hat{I}_{it}^{fat} + \hat{\alpha}_2 \hat{I}_{it}^{protein} + \hat{\alpha}_3 \hat{I}_{it}^{scc}$.

Secondly, the unit value for milk with average quality is calculated as $\bar{v} = \hat{\alpha}_0 + \hat{\alpha}_1 \bar{I}_{it}^{fat} + \hat{\alpha}_2 \bar{I}_{it}^{protein} + \hat{\alpha}_3 \bar{I}_{it}^{scc}$, where the average value of quality attributes of all farms are denoted as $\bar{I}_t^{fat}$, $\bar{I}_t^{protein}$ and $\bar{I}_t^{scc}$. Therefore, we can get milk quality index for farm i at period t, $\varphi_{it} = \frac{\hat{v}_{it}}{\bar{v}}$. The milk quality index equals one if farm has average qulity of milk, the value is less than one if farm has below average quality and more than one with above average quality of milk.

Suppose $\tilde{Y}_{it} = \varphi_{it} Y_{it}$ 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:

$$\widetilde{y}_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \beta_f h_{it} + \beta_c c_{it} + \omega_{it} + \epsilon_{it} \tag{5}$$

[2]Source: Teagasc Sectorial Road Map for Dairy 2013.

3.3 Evaluating impact of milk quota elimination

We specify a linear regression to quantify the change in productivity with respect to regulation change. The dependent variable, ω_{it}, is total factor productivity estimated from production function.

$$\omega_{it} = \alpha_0 + \alpha_q q_{it} + \alpha_X \mathbf{X}_{it} + f_t + f_i + \mu_{it} \tag{6}$$

where q_{it} is quota exchange price for firm i at peorid t representing regulation power and α_q is corresponding coefficient of our main interests. $\mathbf{X}_{it}$ is a vector of farm characteristics. It includes herd size, age of operator, features related to management skills and features related to dairy production. α_X is a vector of corresponding coefficients. f_t and f_i are fixed effect for time and farm respectively. α_0 is intercept. μ_{it} is i.i.d shock that are not correlated with quota regulation.

We future investigate if the elimination of milk quota has different impacts on dairy farms of various production characteristics. Specifically, we expand equation (6) with interaction terms of quota exchange price and farm characteristics, $\mathbf{X}_{it} * q_{it}$. α_{X*q} denotes the vector of coefficients for interaction terms. The estimated equation are specified as follows:

$$\omega_{it} = \alpha_0 + \alpha_q q_{it} + \alpha_x \mathbf{X}_{it} + \alpha_{X*q} \mathbf{X}_{it} * q_{it} + f_t + f_i + \mu_{it} \tag{7}$$

In this way, we can test if there exists various response of farms and identify the characteristics that enhance the impacts of quota deregulation on productivity. Based on the theoretical section, our hypothesis is that if a farm is with a characteristic that contributes to the increase of productivity, this farm will benefit more from policy deregulation. That is to say, if $\alpha_X > 0$ then $\alpha(X * q) > 0$ and if $\alpha_X < 0$ then $\alpha(X * q) < 0$.

4 Data

The main data source about Irish dairy production is from the EU Farm Accountancy Data Network (FADN) collected by National Farm Survey (NFS). The FADN data provides specific information about household decisions on inputs used and outputs produced, as well as cost and returns from milk production. It also includes detailed data about milk quota trade, such as cost and quantity of quota exchange. Another unique feature of this data is that it allows us to account for milk quality, such as milk butterfat, protein and somatic cell count on milk value. We focus on continuing dairy farms[3] during the phasing out of quota

[3]In 2007-2009, farms are defined to be specialized in dairy production if the Standard Gross Margin, average value of output minus costs, from dairying accounts for at least two-third of the total gross margin. From 2010, the classification is based on the Standard Output, average monetary value of the agricultural output at farm-gate price.

regulation. A balanced panel data of 216 dairy farms is constructed over the period from 2007 to 2015, yielding 1944 observations.

Table 1 provides the descriptive statistics of inputs and output variables used in the production function estimation. To investigate the change of dairy production during the preparation for milk quota elimination, we specify the inputs and output variables by year in Panel A of table 2 and variables transformed into per cow basis in Panel B.

Output is measured as milk sold in liters. The average quantity of milk sold is 342,923 Liters, ranging from 11491 Liters to 1641593 Liters. After the elimination of milk quota, quantity of milk sold increases by 14.01% in 2015, while the average annual growth rate is 4.15% from 2007 to 2014. 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 after the release of quota restrictions, revenue from dairy decreases by 7.55% comparing to 2014.

Variables used as inputs in production function are herd size, labor units in dairy production, value of fixed capital, material inputs, land used for pasture and concentrates feed allocated to dairy. Herd size is measured as the average number of cows in dairy herd, with mean 68 and range from 7 to 282. The scale of dairy farms in Ireland is relatively small comparing to of other countries. During the phasing-out of milk quota, there was significant increase in herd size, especially after quota elimination in 2015. Number of dairy cow increased by 7.36% in 2015, comparing to the 3.25% annual increase during 2007 to 2014. We also notice various changes for dairy farms with different herd size scale. Figure 2a presents the herd size distribution for four years (2007, 2010, 2013 and 2015). We can see that the proportion of dairy farms with more than 100 cow increased with increasing marginal rate during the eight years, while proportion of small farms with less than 30 cows yielded a descending trend. Along with this market deregulation, there emerging more and more relatively large dairy farms with small dairy farms gradually shrinking. Figure 2b presents the herd size growth rate of dairy farms with different scales. From 2007 to 2010, there are around 14% herd size increase for dairy farms with more than 70 cows, while the growth rate for small dairy farms is less than 2% and even with negative growth. From 2013 to 2015, dairy farms with different herd sizes all have significant scale expansion.

Pasture land for dairy enterprise, including owned and rented, is measured as the total adjusted area under grass plus adjusted commonage area. The mean is 34.94 acreages, ranging from 2.16 acreages to 121.94 acreages. It also experienced 3.68% annual growth from 2007 and even significant increase (7.34%) in 2015 after quota elimination. Panel B of table 2 indicates more inputs in pasture land is consistent with herd size growth, there isn't much change in pasture land use per dairy cow along the period.

Concentrates feed, including purchased and homegrown feed, allocated to dairy production is adopted as a separated input in production function estimation and it is measured in 50 kilograms. Concentrates feed is a flexible input to adjust milk production. There are fluctuations in concentrates feed used per cow with in sample years.

Labor input is the number of labor units working in dairy production on the farm, including the sum of unpaid and paid labor units. 1800 hours is equivalent to one labor unit and it is also adjusted by labor's age . 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 expenditures on fuel, lubricants, water and electricity in the accounting year. Value is deflated based on price index in 2005. The mean is £4869.94, ranging from £302.37 to £28867.33. Fixed capital inputs are represented by the valuation of machinery and buildings(Petrick and Kloss, 2013). The average annual growth of fixed capital is 6.04%. 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 by Agricultural Price Indices reported by Irish Central Statistics Office[4].

5 Empirical Result

5.1 Estimation of production function

Table 3 presents the estimation results of production function in equation (1) and value-added production function in equation (3) estimated by OLS and WLP. Results in column (1) and (3) are output elasticities estimated by OLS. Column (2) and (4) are results of production function and value-added production function estimated by Wooldridge (2009) LP modification approach (WLP).

Empirical result of production function is shown in table 3. Production function estimated by OLS in column (1) is used as benchmark. Column (2) and (3) are estimation results for production function and quality-adjusted production function using WLP method. It is well known that the OLS tends to overestimate the coefficients on flexible inputs and underestimate those on quasi-fixed inputs. This is the case when comparing the OLS results with the other two using WLP estimates. We see that OLS substantially overestimates the coefficients on material inputs and number of cows, it underestimates coefficients on capital inputs. It implies that the selection is negatively associated with capital but positively with herd size. When comparing estimation of production function with quality-adjusted one, the

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

distance elasticities for all inputs and outputs are not significantly different.

5.2 Productivity before and after milk quota elimination

Table 4 reports descriptive productivity regressions. The dependent variable is log of total factor productivity from quality-adjusted production function estimation. The explanatory variables are dummy variables for each year before and after quota elimination. The omitted variable is for year 2007. Wald test is used to compare the coefficients of different time periods, hence evaluate the statistic differences of productivities for each year. Column (1) reports results of OLS model, indicating that dairy farms are less productive several years after 2007 and become more productive as the approach of quota elimination. The productivity in 2015 is tested to be higher than the rest of sample. Model in column (2) includes farm fixed effect to account for productivity changes within farm. The results are similar to first column. The descriptive comparison of total factor of productivity before and after quota elimination yields limited implications on the impact of quota deregulation on productivity growth. However, it provides evidence for the hypothesis that growth of total factor productivity for dairy farms interacts with the change in milk quota regulation. In 2007, dairy farms have reached a production equilibrium under quota restriction. However, in 2008 Irish dairy farms are confirmed with the elimination of milk quota. Some dairy farms may start to prepare for the change in production environment, especially these in our sample who choose to continue dairy production. The observed decline in productivity during 2008 to 2013 may be caused by additional investment to increase dairy production scales while still subject to production limitation. This inefficiency effect from investment is diminishing along with the gradually reduced regulation restriction. To evaluate the statistical difference of productivity across years, Wald test is adopted to compare the coefficients.

5.3 Evaluating impact of milk quota elimination

The result is shown in Table 4 column (2), suggesting that the quota elimination did not have significant effect on productivity when pooling the whole sample. Coefficient of previous year's productivity is positive and significant, indicating that farm's productivity is highly correlated with the production history. It is consistent with theoretical prediction.

As discussed in Introduction section, one of our hypothesis indicates that with acknowledge of the coming elimination policy, farms that are more productive in dairy production will be more active in preparation, such as expand production scales or increase investment. Following Konings and Vandenbussche (2008), we generate an index to represent the initial ranking of dairy farms' productivity within the sample before confirmation of quota elimination policy. The initial "distance-to-frontier" index is defined as the ratio of farm i's productivity over the maximum productivity of the first year in our sample, 2007.

$$\text{Distance}_{i,2007} = \frac{\omega_{i,2007}}{Max_j \omega_{j,2007}} \tag{8}$$

where $\omega_{i,2007}$ is the total factor productivity of farm i in year 2007, the denominator of RHS denotes frontier value of productivity in 2007. If the distance equals one, the dairy farm is defined to be the efficient one locating at the frontier.

The first two model in table 5 implies that initial level of productivity has a positive and significant impact on farm's productivity growth. The interaction term between initial productivity distance and quota price is also significantly positive. The closer a farm is from the productivity frontier in initial year, the more positive effect he will have from milk quota deregulation. With control of the initial distance effect, coefficient for quota exchange price is negative and significant, indicating that impose of milk quota restriction hinders the development of dairy farm productivity.

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 regional exchange price of milk quota trade as a measurement of regulation power and hence evaluate the impact of milk quota elimination on productivity of Irish dairy farms. The results indicate that dairy herd size experience significant increase along the deregulation. Dairy farmers have heterogeneous responses with the preparation for this trade liberalization and hence the impact on productivity is various across dairy farms. Dairy farmers with relatively high productivity experience more positive impact from milk quota elimination.

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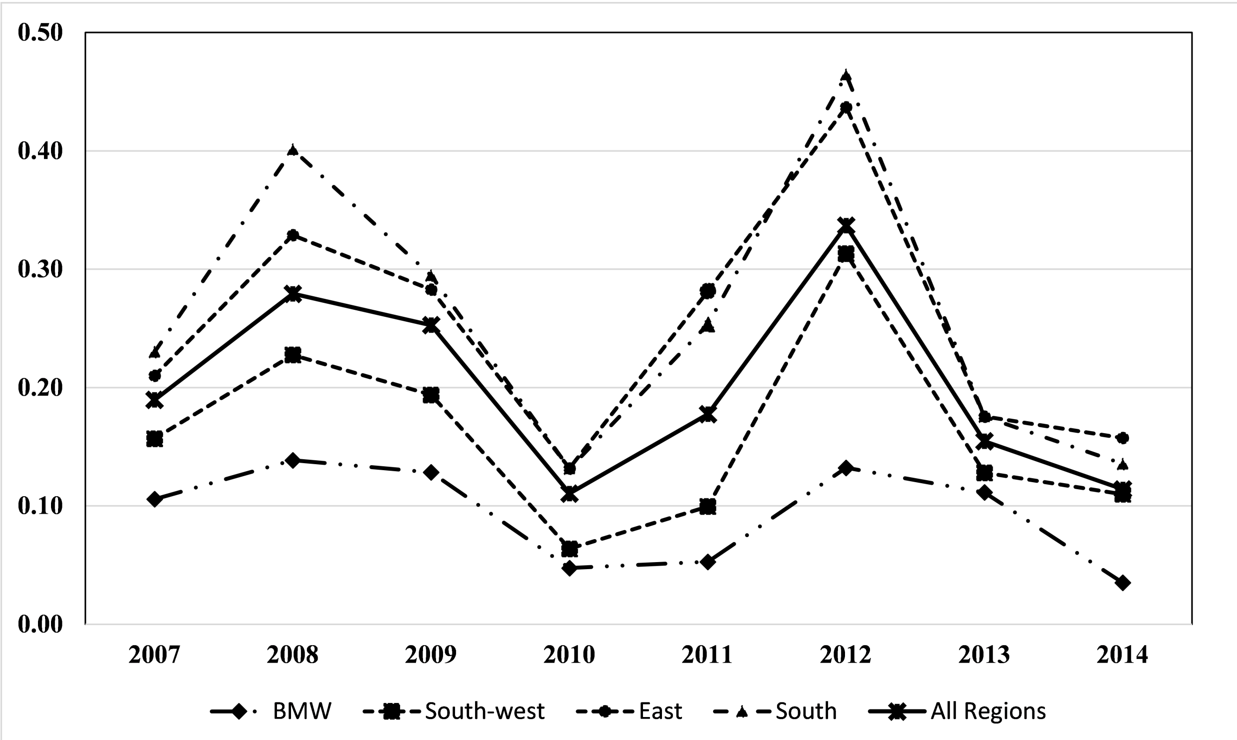
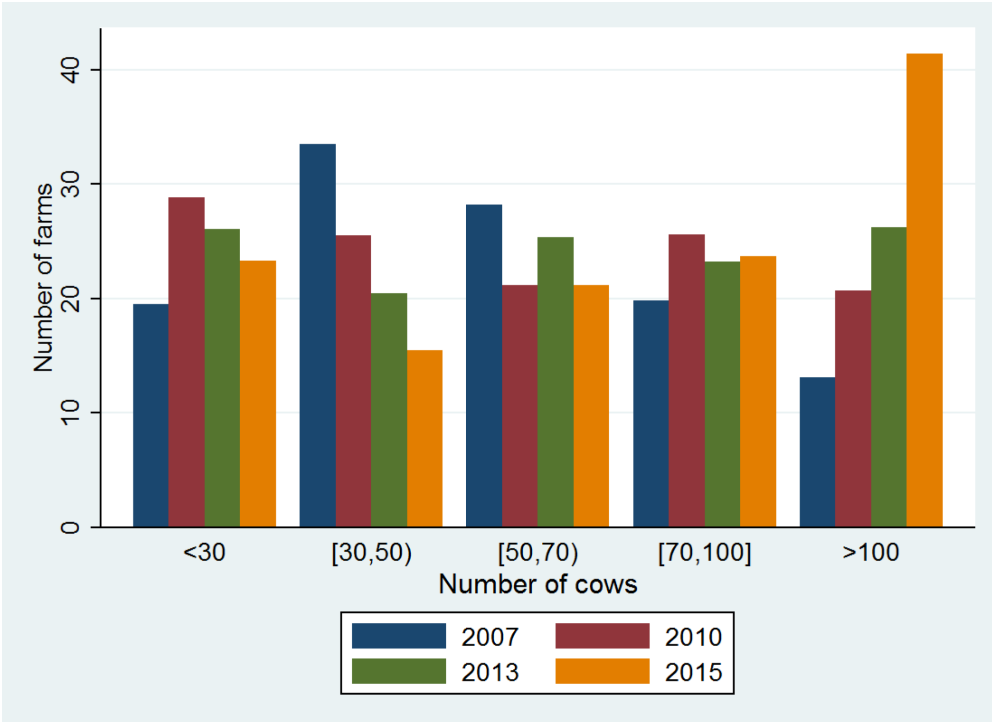


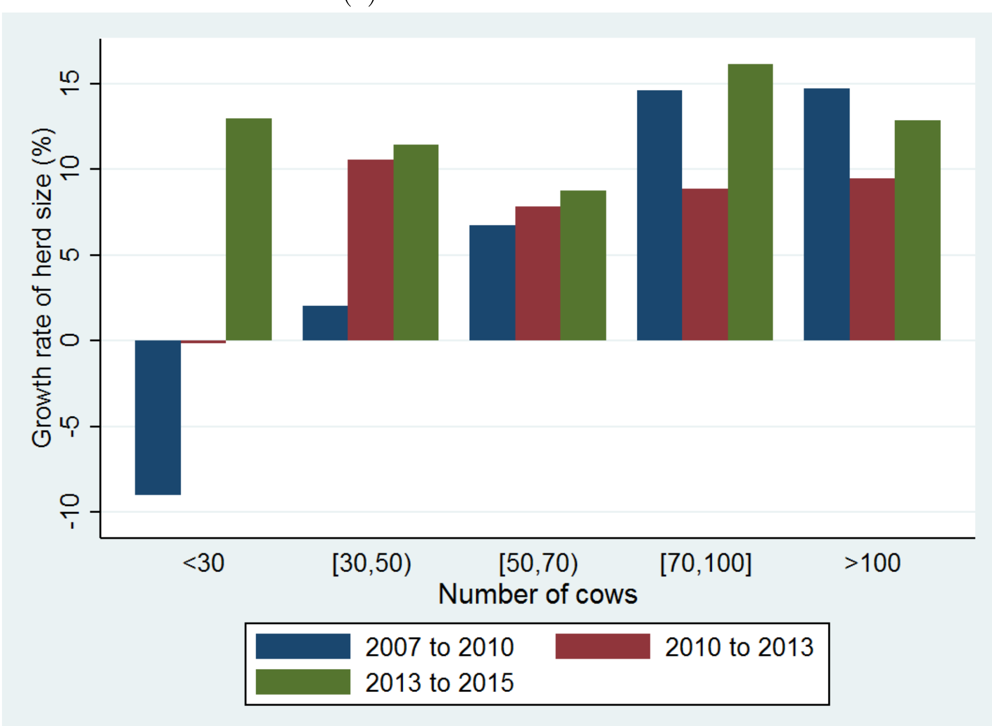
Figure 1: Development of quota exchange price

Table 1: Descriptive statistics of input and output variables in production function.

	Mean	Std. Dev.	Minimum	Maxium
Quantity of Milk Sold	342924	223936	11491	1641593
Revenue from Dairy	116138	80405	3619	574638
Cow	68	36	7	283
Labor	1.10	0.49	0.17	4.83
Material	4869.94	3834.78	302.37	28867.33
Capital	112211	91990	491	630516
Concentrates Feed	1363.87	1230.35	44.00	9826.00
Pasture Land	34.94	16.61	2.16	121.94



(a) Herd size distribution



(b) Herd size growth rate

Figure 2: Herd size development of Irish dairy farms

Table 2: Descriptive statistics of input and output variables by year and per cow basis.

	Whole Sample	2007	2010	2013	2015
Panel A: Variables by year					
Quantity of milk sold	342923 (223936)	308932 (187269)	333147 (221544)	356095 (233102)	421878 (277453)
Revenue from dairy	116138 (80405)	106780 v65769)	104118 (71421)	141380 (92869)	132898 (90557)
Herd size	67.69 (36)	60.15 (29)	65.15 (35)	70.26 (38)	78.89 (45)
Labor	1.10 (0.49)	1.08 (0.46)	1.08 (0.48)	1.16 (0.54)	1.16 (0.53)
Material	44.64 (34.06)	43.18 (32.98)	44.24 (31.93)	48.23 (36.56)	49.35 (35.94)
Capital	1138.62 (932.95)	1008.79 (820.50)	1094.29 (900.53)	1233.57 (1004.42)	1257.97 (993.40)
Concentrates feed	1363.87 (1230.35)	1149.53 (1060.04)	1378.14 (1304.02)	1666.78 (1369.01)	1499.86 (1326.09)
Pasture land	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	4889 (1015)	4985 (960)	4913 (1042)	4898 (989)	5142 (1006)
Revenue from dairy	1641 (438)	1719 346)	1525 (347)	1940 (405)	1605 (350)
Labor	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Material	0.65 (0.26)	0.70 (0.28)	0.66 (0.25)	0.68 (0.27)	0.62 (0.22)
Capital	16.01 (7.91)	16.14 (8.15)	16.03 (7.54)	16.62 (8.14)	15.21 (7.64)
Concentrates feed	19.33 (9.67)	18.29 (9.61)	19.67 (10.03)	22.76 (9.67)	18.45 (8.64)
Pasture land	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

Table 3: Different Effects of Quota Elimination on Productivity.

	(1)	(2)
Productivity Lag		0.168∗∗∗
		(0.028)
P_Quota		0.0482
		(0.050)
2008.year	-0.0560∗∗∗	
	(0.009)	
2009.year	-0.0592∗∗∗	0.00885
	(0.009)	(0.009)
2010.year	-0.0340∗∗∗	0.0411∗∗
	(0.009)	(0.013)
2011.year	-0.00239	0.0639∗∗∗
	(0.009)	(0.010)
2012.year	-0.0574∗∗∗	-0.00407
	(0.009)	(0.009)
2013.year	-0.0747∗∗∗	-0.00240
	(0.009)	(0.011)
2014.year	-0.0416∗∗∗	0.0356∗∗
	(0.009)	(0.013)
2015.year	0.0178∗	0.0950∗∗∗
	(0.009)	(0.017)
_cons	7.695∗∗∗	6.330∗∗∗
	(0.006)	(0.214)
N	1944	1728

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)
cons	8.384***	8.460***	8.044***	8.583***
	(0.087)	(1.187)	(0.095)	(1.274)
Observation	1944	1296	1944	1296

Table 5: Heterogeneous impacts of milk quota elimination on productivity.

	Dependent Variable: $ln(TFP_{it})$						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pquota	0.0695	-0.415**	0.0660	0.149*	0.0676	0.275*	-0.174
	(0.050)	(0.130)	(0.050)	(0.062)	(0.050)	(0.112)	(0.156)
Initial Distance	1.070***	0.932***					0.869***
	(0.055)	(0.064)					(0.065)
Pquota		0.712***					0.737***
*Initial Distance		(0.176)					(0.173)
Herd Size			-0.0913***	-0.0831***			-0.0702***
			(0.019)	(0.019)			(0.016)
Pquota				-0.123*			-0.0632
*Herd Size				(0.053)			(0.053)
Revenue ratio					0.275***	0.327***	0.294***
					(0.040)	(0.047)	(0.044)
Pquota						-0.310*	-0.328*
*Revenue Ratio						(0.151)	(0.153)
Constant	6.982***	7.072***	7.707***	7.700***	7.482***	7.449***	6.969***
	(0.037)	(0.043)	(0.023)	(0.023)	(0.032)	(0.035)	(0.049)
Observations	1944	1944	1944	1944	1944	1944	1944

Notes: Pquota: Quota exchange clearing price;
Revenue ratio = Percentage of revenue from dairy.