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THE ROLE OF EXTENSION IN DYNAMIC ECONOMIC ADJUSTMENTS: THE CASE OF IRISH DAIRY FARMS

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Abstract: EU dairy policy eliminated milk production quotas in 2015, inducing major adjustments in the European dairy industry. This article explores the role of farm extension services in dynamic adjustments on Irish dairy farms. An Arellano-Bond estimation strategy is applied to panel data from a representative sample of Irish dairy farms spanning 2008 to 2014. We find a positive, yet declining, impact of extension services on the dynamics of dairy herd size, specialization, and intensification. Farm-level response changes in relation to length of extension membership and policy implications to re-structure extension services are discussed.

1 Introduction

The evolution of global trade negotiations, including the long-stalled Doha Round of the World Trade Organization, has contributed to efforts in the US and Europe to reduce market distortions in agriculture (Swinnen et al., 2012). Policy reform and greater integration in global markets create the potential for major adjustments in agriculture, with current developments in the European Union (EU) dairy sector providing a leading-edge example. Specifically, in 2015, following through on a 2008 pre-announced commitment, the EU eliminated milk quotas originally put in place in 1984 to halt the expansion of milk production and reduce the budgetary cost of EU farm policy (Bouamra-Mechemache et al., 2002a, 2002b; Bouamra-Mechemache et al., 2008). While removing these quotas may create new opportunities for the European dairy sector to benefit from rising global demand for dairy products, it also sets in motion shifts in EU dairy production based on relative competitiveness and on public and private efforts to shape farm and sector-level adjustments.

From 2014 to 2017, cow numbers on Ireland's dairy farms have grown by more than 20 percent during a period of near zero growth in total EU herd size (IFA, 2017; RLF, 2016). Only the Netherlands initially experienced a similar rate of expansion in the first two years following the quota removal (2015 to 2016). However, because of EU phosphate loading limits, the Netherlands has mandated five percent herd reduction in 2017 while Ireland is continuing its expansion (EuroStat, 2017).

In terms of average unit costs of production, the underlying export competitiveness of dairy farming varies substantively across the world and also across EU countries (Dillon et al., 2008; Bojnec and Fertő, 2014). For example, New Zealand is the world's leading exporter of dairy products. Relying on pasture-based dairy farms, New Zealand is widely regarded as having the lowest cost and most competitive dairy industry in the world (Donnellan et al., 2009; New Zealand Trade and Enterprise 2010). In terms of basic milk production conditions and low-unit costs, Ireland is the closest OECD country to New Zealand (Dillon et al., 2008, Donnellan et al., 2009; Läpple and Hennessy 2012; Bojnec and Fertő, 2014), and more recent post-quota estimates suggest that Ireland has significantly lower unit costs of production than other major EU dairy producers (Thorne et al., 2017).

Realization of export competitiveness (or comparative advantage) can depend on coordinated public and private investment (Porter, 2000), the quality of institutions (Nunn, 2014) and 'infrastructure' (Yeaple and Golub, 2007). Their importance may be magnified for sectors, such as dairy, that involve investments with significant sunk costs (Dong et al. 2016) as well as longstanding market distortions which can give rise to a distinct farm management and investment logic.

This article examines the effect of Irish government supported farm extension efforts during the run-up to quota removal on Irish dairy farm adjustments, specifically on dairy herd size, intensification, and specialization outcomes. At the farm level, there is potential in Irish dairy farms to expand in all three of these outcomes, because Irish dairy farming systems are based on pasture, and often included sheep and beef cattle as diversification strategies to accommodate milk quota limits (Läpple et al. 2012; McDonald et al. 2014). In contrast, the Netherlands already had highly specialized, intensive dairy operations during the quota phase, with a large proportion of milk production occurring in mostly confinement systems (Ooms and Peerlings, 2006; Huettel and Jongeneel, 2011), which put them right up against EU phosphorus limits (Samson et al. 2017).

The Irish dairy sector offers an excellent case study of farmer responses to an extension-led effort to promote comparative advantage. First, EU trade policy changes were initially preannounced in the mid-2000s and then fully confirmed in 2008. This gave national policy makers and farmers time to prepare for a post-quota trade regime. Second, especially after 2008, Irish public extension services were expanded to work directly with farmers to intensify their operations and improve their competitiveness (Läpple and Hennessy, 2015a). Then, between 2010 and 2012, farmers were paid €1,000 per annum to join extension-led, monthly farmer discussion groups emphasizing expansion, intensification and enterprise specialization with a focus on technology transfer. In a quota-based trade environment, previous extension-led farmer discussion groups had focused more on cost minimization strategies and farm diversification efforts. Thus, fundamental shifts in extension program design, and the entry of new farmers into discussion groups (encouraged through payments and policy change), offer the basis for exploring impacts of extension on Irish dairy farm adjustments in the run-up to the quota removal of 2015. These policy shifts provide three groups across which to compare farm structural change outcomes: 1) farmers who had been involved in discussion groups prior to 2009; 2) those who joined discussion groups from 2009[1] onwards (mostly in 2010-2012); and 3) those who did not participate in discussion groups.

Our empirical analysis is based on panel data from a random, representative sample of Irish dairy farms spanning 2008 to 2014. It involves the specification and estimation of a dynamic model of farm-structure management decisions on Irish dairy farms as they adjust to changing market opportunities. Similar to Ooms and Peerlings (2005), the model is estimated using Generalized Method of Moments (GMM) following the Arellano-Bond panel model (Arellano and Bond, 1991). The econometric

[1] While payment for participation was offered from 2010 to 2012, the scheme was announced in 2009, which increased interest in the extension program.

analysis exploits the panel structure associated with seven years of data to help control for endogeneity often attributed to unobserved factors that can influence extension participation (Birkhauser et al., 1991) and possibly other explanatory variables. The panel nature of the data provides an improved identification strategy of extension impact in contrast to cross-sectional efforts (e.g., Davis et al., 2011; Läpple and Hennessy, 2015a). More importantly, it also extends previous extension evaluation efforts based on panel data (e.g. Dercon et al., 2009). That is, we exploit detailed information on the length of farmer participation in extension to address commonly encountered endogeneity concerns associated with evaluating the impacts of extension on farm outcomes.

The econometric results demonstrate the positive impact of Irish extension services on dairy herd size, intensification and specialization. We observe heterogeneous farmer responses to extension efforts in relation to the timing of engagement with the extension system, management quality, and initial farm intensity on dairy farm dynamic adjustments. Our econometric results suggest that extension services will continue to have meaningful, yet declining, impact on Irish dairy farm expansions, intensification and resulting milk production growth. Overall, these findings are consistent with current trends of Irish dairy expansion, and point to the potential value of public and private coordination in directly and indirectly fostering comparative advantage.

The article organization proceeds as follows. First, we describe the EU and Irish dairy sector adjustment process that frames our analysis of Irish dairy farm structural change. Next, we introduce our conceptual and empirical approach to modeling the impacts of extension services on dairy herd size, intensification, and specialization. This section includes links to relevant literature on structural change dynamics, the role of extension services in shaping farmers' behavior, and previous dynamic estimation methods in these two lines of research. Third, we introduce the panel dataset, and discuss some descriptive statistics on the recent dynamics of structural change on Irish dairy farms. Fourth, we detail the specification of the Arellano-Bond panel methods used to examine farm-level structural changes, and then we discuss the empirical results. The final section offers concluding remarks on the contributions of the article to the literature and policy implications.

2 Contextual Factors Shaping Irish Dairy Sector Adjustment Prospects

2.1 Background and Expansion Avenues

Beginning in April 2015, European farmers could, for the first time in three decades, expand milk production without facing restrictive quota constraints. While just over a ten percent increase in aggregate EU milk production was anticipated by 2020, most of this growth was expected to come from Germany, Ireland, Poland, the Netherlands, Denmark and France (O'Keefe and Christieson, 2015). Among these countries, Ireland announced in 2010 the most ambitious growth target, aiming to increase its milk production by 50 percent by 2020,[2] with the support of an active extension program and farmer organizations (DAFF 2010).

Ireland has one of the lowest costs of producing milk worldwide (Dillon et al., 2008). Irish dairy competitiveness is based on favorable agronomic and weather conditions that sustain a grass-based, spring calving milk production system and cows grazing from early spring to late autumn (Läpple et al., 2012). Several strategies can be pursued to increase Irish dairy production. As Dillon (2011) explores, higher milk

[2] It is important to note that the 50 percent target was announced in 2010 and is relative to the 2007 to 2009 base. 7.6 percent of this growth has already happened before milk quota removal.

yields per cow, increased stocking rates and cow numbers, as well as more grazing land area allocated to dairy production are the main sources. Increases in milk yields were anticipated purely from increasing (grass) feed intake, changing the length of the lactation period and reducing milk fed to calves but not much from increased use of grains in the dairy cow's diet, given Ireland's scarcity of tillable soils. Milk yields per cow were expected to increase in-the-order-of four percent annually in the two years after quota removal and 1.5 percent per year thereafter (Läpple and Hennessy, 2012). Alone, that adjustment in milk per cow production might reach ten to fifteen percentage points of the 50 percentage point proposed expansion by 2020.

Most of the production growth in Ireland was viewed as likely to come from increasing cow numbers and correspondingly farm stocking rates. Prior to the removal of quota constraints, the average stocking density on Irish dairy enterprises was 1.9 dairy livestock units per hectare, while the national research target for optimal production is 2.9 (Teagasc, 2015a). This comparison is consistent with a quota constrained production environment. Relatedly, substantial substitution effects were also possible on Irish dairy farms, as the majority of farms included alternative livestock (mostly beef cattle) enterprises as a way of diversifying income under milk quota constraints. In other words, cow numbers could be increased by stocking additional animals, substituting dairy cows for beef cattle or reallocating existing land to support a larger dairy herd. In contrast to dairying, beef farming in Ireland is consistently associated with lower farm incomes (Hennessy and Moran 2015); hence substituting beef cattle for dairy cows was also likely to be economically attractive once milk quotas were removed.

In the empirical analysis below, we focus on dairy herd expansion, intensification, and specialization dynamics on Irish dairy farms *prior to the quota* *removal*. That is, we examine three critical expansion paths in the waning years of a binding quota environment, when milk yields per cow and production levels were not expected to increase much given the presence of super levy fines, but farmers could prepare for the post quota era through changing the structure of their operations.[3]

2.2 Fostering Comparative Advantage through Extension Services

For Ireland to fully exploit its potential comparative advantage in dairy after decades of constrained production conditions, investments in cows, land, management, technology and human capital were all potential pathways to complement the availability of cheap grass. In 2009, the Irish government launched a program promoting a sustainable and competitive expansion of Irish dairy farms. They incentivized participation by providing a financial reward to farmers for joining extension-led discussion groups, on the order of €1,000/annum for three years (2010 to 2012). In turn, about a third of the subsidy was to be paid to the extension agent for their service.

Extension in the form of discussion groups was not a new idea; extension programs had been in place since the mid-1990s, and had previously involved about a quarter of Irish dairy farmers. These discussion groups typically consist of about 18 farmers who meet on a monthly basis and discuss farm related issues. They are led by an extension officer, who facilitates the discussion, actively engaging farmers in learning, decision making and problem solving. While these groups are based on the principle of peer learning, participation in groups provides much more detailed information than pure spillover to non-participating farmers (i.e. groups operate under the principle that "everything stays within the groups").

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[3] We do not observe increases in milk yield per cow in our data over the sample period, which is consistent with the observation that farmers deliberately dried cows off to adhere to quota restrictions.

Prior to 2009, discussion group strategies focused on how to maximize returns in a quota-driven environment. After 2009, the Irish extension service adjusted its focus in response to changes in national dairy policy. Once EU quota removal was confirmed, Irish extension services began to actively promote a path toward sustainable growth in milk production through expansion of the dairy herd, increased specialization in dairying, and encouraging farmers to intensify dairy production in an otherwise land constrained environment, while continuously emphasizing the longstanding three core technologies of grassland management, breeding, and cost control (O'Dwyer, 2015). The rest of this article examines whether these public investments in extension helped drive structural change on dairy farms and in turn a fuller realization of comparative advantage in dairy exports.

3 Modeling Extension Impacts on Farm-Level Structural Change

Models of structural change on dairy farms revolve around the dynamic nature of investment decisions that farmers face when they decide to expand their herd or invest in facilities and structures to house and milk the cows. Two types of modeling approaches prevail in the literature. The most common, especially among recent studies of structural change across EU dairy herds, involves estimating Markovian transition probabilities that track the evolution of herd size changes over time, using sector, but not farm level data (Huettel and Jongeneel, 2011; Groeneveld et al. 2016). The other common approach involves specifying farm-level decisions of expansion, investment or exit decisions utilizing efficiency measures and/or life-cycle considerations as a basis for examining dynamic investment choices (Dong et al. 2016; Weiss, 1999; Kislev and Peterson, 1982) or supply/farm adjustment responses to dairy policy (Francksen et al., 2012; Boere et al. 2015).

Consistent with these approaches, we model dairy herd management changes as a dynamic process, where adjustment rates over time depend on previous decisions. We focus our attention on the determinants of three key outcome variables: dairy herd size, dairy intensity, and dairy specialization. For the i-th farm at time t, each of these variables is treated as the dependent variable (y_{it}). Many factors affect management decisions. They include lagged values ($y_{i,t-1}$) capturing dynamic adjustments, managerial skills along with farm characteristics (X_{it}), regional differences (R_i) as well as economic and policy variables (P_t) (Francksen et al., 2012; Akimowicz et al., 2013; Boere et al., 2015). They also include the role of participation in extension programs (E_{it}), which to date has received scant attention in the farm growth/structural change literature. Specifically, for the i-th farm at time t, the farm adjustment processes are represented as:

$$y_{it} = f_{it}(y_{i,t-1}, E_{it}, X_{it}, R_i, P_t), \tag{1}$$

where y_{it} denotes either herd size, dairy intensity, or dairy specialization. The explanatory variables ($y_{i,t-1}, E_{it}, X_{it}, R_i, P_t$) in equation (1) capture the factors affecting farm adjustment decisions. The exact nature of these effects are evaluated subsequently.

Of special interest is the effect of extension participation E_{it}. In equation (1), extension participation (E_{it}) is akin to a 'treatment' variable in the experimental literature, insofar as it represents the idea that participation in a farmer discussion group in time t holds the potential to contribute to structural change outcomes on farm i. In fact, as discussed further in the empirical analysis section, this variable is incorporated both as a continuous variable representing the years of discussion group participation in time t for farmer i and as a switching variable that is interacted with measures that reflect heterogeneity across farmers according to initial 'intensity', management experience, and whether they joined groups before or after a financial incentive was introduced.

Examining the impacts of extension services on farmer decisions is a longstanding theme in the technology adoption literature. Most of this research draws on cross-sectional data (e.g. Akoboundou et al. 2004; Davis et al. 2011; Läpple et al., 2013) with relatively little use of panel data. It is well known that cross-sectional studies are limited by measurement and identification problems as well as the lack of data to capture dynamic periods of change on farms (Birkhauser et al., 1991). The fundamental value of panel data to help control for endogeneity of key explanatory variables including extension participation is hard to overstate.

A handful of panel data applications research the impact of extension on farm management choices. Feder et al., (2004a, 2004b) use two years of farmer data to examine the impact of farmer field schools on input use and yields in Indonesia, with the former comparing farmers' performance before and after the introduction of the field schools and the latter exploring spillover effects from the program on other members in the village. Neither of these studies had sufficient panel observations to allow for a longer-term dynamic treatment of extension impacts, only enough for basic difference-in-difference estimations.

By contrast, Goodhue et al., (2010) utilize a ten-year panel to investigate the effect of the Biologically Integrated Orchard Systems program on Californian almond growers' use of a specific pesticide and replacement with a less harmful option. Similar to what we do below, they exploit the panel data structure in their estimation strategy to account for unobserved heterogeneity that could influence farmer use and intensity of the pesticide. They also deploy panel methods to account for heterogeneity in unobserved time-varying factors such as regulations that might drive farmer's pesticide use decisions heterogeneously across the sample. While their panel estimation strategy is distinct from ours, their findings highlight the importance of panel data methods for helping to control for the effects of both time invariant and time varying unobservables that otherwise give rise to endogeneity issues.

Another example of panel methods applied to extension program impacts is evident in Krishnan and Patnam (2014). They focus specifically on the role of learning from extension agents versus learning from peers in the adoption of improved seeds and fertilizer in Ethiopia between 1999 and 2009. Similar to our panel data estimation efforts, they use lagged measures to help identify impacts, but given that they are studying decisions that are readily reversible year to year (seed and fertilizer use) they do not make use of lagged dependent variables, such as our use of ($y_{i,t-1}$), to capture 'persistence'.

The final study mentioned here, Dercon et al., (2009), is probably closest to our approach. Using the same data as Krishnam and Patnam, they explore the effect of extension and roads on poverty and consumption growth among rural households in Ethiopia. These outcomes, like land and herd adjustments on a dairy farm, are more comprehensive and structural measures that are well supported by estimation methods using lagged dependent variables or in their case lagged instruments for the dependent variable. Specifically, they use a dynamic fixed-effects GMM model to account for endogeneity concerns of extension services and find positive and significant effects of extension services on consumption growth and poverty reduction among rural Ethiopian households.

Another important gap in research on extension services that our study addresses is exploring the possibility that farmers might be heterogeneous in their ability to learn from extension. Specifically, we exploit temporal and farm-level variations in the panel data set with an Arellano-Bond GMM estimation approach to overcome measurement issues in the extension literature, such as sample selection, heterogeneous responses, and time-dependent impacts (Birkhauser et al., 1991). In other words, our panel data estimation methods allow for more complete attention to endogeneity concerns, incorporation of farm-level heterogeneity in the analysis, and temporal dimensions of how extension services help to shape dairy farm adjustments.

4 Data and Descriptive Statistics

Detailed data on extension group membership and farm outcomes were received from the Irish National Farm Survey (NFS) (Hennessy and Moran 2015), that is part of the EU Farm Accountancy Data Network (FADN). The NFS was established in 1972 and has been published on an annual basis since. Overall, a statistically representative random sample of approximately 900 farms participate in the survey on a voluntary basis each year. This sample represents a farming population of approximately 80,000 farms. Data are collected through a series of face to face interviews with farmers by a professional data collection team.

Farms are classified into farming systems, based on the dominant enterprise that is calculated on a standard gross margin basis. The NFS collects data on all prominent farm systems in Ireland, and for purposes of this analysis we restrict our sample to dairy farms (i.e. specialized dairying and dairying other). While these farms are specialized in dairy production, there was (as mentioned) typically a significant alternative enterprise also operating on the farm. To be more explicit, about 65 percent of gross output of farms in the sample came from dairying, while the remaining 35 percent was earned by alternative enterprises, typically beef cattle, but also grain tillage to a much lesser extent.

When restricting the overall data to dairy enterprises only, the sample reduces to 324 observations in 2008. We use an unbalanced panel, which amounts to a total of 2,293 pooled observations from 2008 to 2014. On average farms stay in the sample for approximately six years.

In addition to data on the farm business and the farm operator, data on discussion group membership, including date of initial membership, are also recorded since 2008. This information is important in the sense that it allows us to assess the possible heterogeneous effects of extension participation across farmers. That is, observing years of participation in discussion groups offers greater variability in the extension measures and helps to identify the impact of extension participation in a panel data model. This extension membership duration measure stands in contrast to simply observing a binary and typical variable on whether or not the farmer has extension contact (see Dercon et al., 2009; Krishan and Patnam, 2014). Information on the date of initial membership also allows us to distinguish between three groups of farmers: 1) those who joined before the financial incentive was announced ('old members', i.e. all farmers who joined before or in 2008); 2) those who joined after the incentive was announced or introduced ('new members', i.e. all farmers who joined in or after 2009) and 3) those who never joined an extension program during the study period ('non-members'). Extension participation rates increased considerably over the observation period. For example, just over a third of farmers participated in discussion groups in 2008, while this number increased to over half of the sample in 2014.

A description of variables used in the empirical analyses as well as summary statistics of data are provided in Table 1, divided by the previously described three treatment groups. There are considerable differences between the three groups. For example, old members have larger farms (both measured in herd size and UAA) than new- and non-members. Furthermore, for somatic cell count (SCC), our measure of managerial ability, both old and new members have lower counts than non-members. It is also worth noting that a larger proportion of new-members is located in the North-West region, which is in contrast to old members who are mainly located in the South and East.[4] More broadly, dairy production intensity shows regional differences. The South and the South West are Ireland's "typical" dairy regions, while the North West region is seen as a more disadvantaged dairying region, one characterized by lower stocking density based on poorer soils and higher rainfall areas. One objective of the financial incentive for extension services was to increase participation in more disadvantaged dairy regions (Läpple and Hennessy, 2015b).

[4] It is important to note that farmers in all regions participated in discussion groups before and after the program change.

Table 1: Variable description and summary statistics of the sample divided by group membership (2008-2014)

Variable	Description	"Old members"	"New members"	Non-members
		n=617	n= 394	n = 1,282
		Mean (std)	Mean (std)	Mean (std)
Dependent variable and components				
Herd size	Number of dairy cows	84.73 (39.85)	73.60 (35.51)	54.44 (32.15)
Dairy intensity	Dairy cows per pasture area+	2.01 (0.44)	1.98 (0.47)	1.81 (0.50)
Dairy specialization	Dairy cows per total livestock units x 100	61.53 (10.66)	63.15 (12.98)	58.11 (16.96)
Extension variable				
Extension participation	Number of years farmer participates in discussion groups (= 0 if farmer is not a member)	11.21 (6.71)*	3.22 (1.53)	0
Managerial ability				
SCC	Somatic cell count /1,000	207.82 (87.73)	201.69 (72.42)	246.97 (112.79)
Farmer characteristics				
Age	Age of the farmer in years	51.92 (10.72)	53.39 (10.73)	55.36 (10.18)
Successor	= 1 if the farm household has at least 1 child, 0 otherwise	0.66	0.61	0.54
Farm characteristics				
UAA	Utilizable agricultural area in hectares	75.20 (35.11)	64.57 (31.07)	57.68 (32.23)
Soil	= 1 if soil is good quality, 0 otherwise	0.62	0.64	0.57
Regions				
South	= 1 if farm is located in the south region	0.35	0.35	0.26
South West	= 1 if farm is located in the south west region	0.18	0.12	0.24
East	= 1 if farm is located in the east region	0.29	0.23	0.26
North West	= 1 if farm is located in the north west region	0.17	0.30	0.24

+ Pasture area is measured in hectares. * Some of the farmers in our sample joined the extension groups before 2008 and thus do not start with 1 in 2008.

5 Empirical Approach

Building on equation (1), we consider the following econometric specification

$$y_{it} = \alpha\, y_{i,t-1} + \delta_1\, E_{it} + \delta_2\, E_{it}^2 + \beta\, X_{it} + \theta\, R_i + \gamma\, P_t + (\mu_i + v_{it}) \qquad (2)$$

where y_{it} denotes either dairy herd size, dairy intensity or dairy specialization for the i-th farm at time t, $(\mu_i + v_{it})$ denotes the error term which includes μ_i, the time-invariant unobserved effects and v_{it} is a disturbance assumed to be identically and independently distributed. Finally,$(\alpha, \delta, \beta, \theta, \gamma)$ are parameters to be estimated.

As mentioned above, the explanatory variables in (2) include previous values of the dependent variables to account for farm adjustment decisions $(y_{i,t-1})$, extension participation (E_{it}) (and its squared term E_{it}^2), management quality and other farm and farmer characteristics (X_{it}) regional characteristics (R_i) as well as policy (P_t) influence. The extension variable E_{it} denotes membership in discussion groups for farmer i at time t. This variable is equal to zero prior to joining the group and *increases by one* each year the farmer is a member in the extension group (meaning that E_{it} equals zero for all time-periods if farmer i is not a discussion group member at all, but has a positive integer value if the farmer is in a discussion group). SCC is included in X to control for management quality. R_i are regional dummy variables, while P_t are time dummies used to control for changes in the economic and policy environment (specifically capturing the effects of approaching the 2015 date of quota abolition).

Applied to panel data, we estimate equation (2) using an Arellano-Bond GMM estimator. GMM estimation has been previously applied in agricultural contexts (e.g., Ooms and Peerlings, 2005; Zhengfei and Oude Lansink, 2006), however, with the exception of Dercon et al. (2009), the use of dynamic panel estimation methods to study how extension affects farm structural changes appears to be new.

The Arellano-Bond estimator starts with first-differencing equation (2) and we utilize our detailed panel-data information on the length of extension group participation to deal with endogeneity issues that might be associated with extension participation. Specifically, first-differencing equation (2) leads to the following equation, which eliminates all time-invariant factors:

$$\Delta y_{it} = \alpha \Delta y_{i,t-1} + \delta_1 \Delta E_{it} + \delta_2 \Delta E_{it}^2 + \beta \Delta X_{it} + \gamma \Delta P_t + \Delta v_{it} \tag{3}$$

Note that the transformed disturbance ($\Delta v_{it} = v_{it} - v_{i,t-1}$) in equation (3) is correlated with the transformed lagged dependent variable ($\Delta y_{i,t-1} = y_{i,t-1} - y_{i,t-2}$), which requires an instrumental variable estimation method. In the difference GMM estimator, lagged levels of the transformed lagged dependent variable are used as instruments, as $y_{i,t-2}$ is correlated with $\Delta y_{i,t-1}$ but not with Δv_{it}. An underlying required assumption is that y_{it} is uncorrelated with subsequent disturbances v_{it+j} for $j = 1,2, \dots J$ and that disturbances v_{it} are serially uncorrelated. An Arellano-Bond test is routinely applied to test for correlation in differences of the idiosyncratic term of the disturbances. Noting that the differenced disturbance has an expected first order correlation, the test focuses on second order serial correlation. Testing the validity of these assumptions is discussed in the results section. With our panel data spanning seven years, additional instruments are also available, including previous observations of y_{it} prior to $t-2$.

Combining the set of moment conditions in the differenced equations and the set of moment conditions in the level equations (explained below), leads to the system GMM estimator, which is a mixed model approach (Arellano and Bover, 1995; Blundell and Bond, 1998; Bond, 2002). By including additional moment conditions, the system GMM estimator provides more efficient estimates of the parameters in (2), see Bond (2002) for a discussion of Arellano-Bond estimators. The system GMM estimator exploits the additional moments conditions stating that first differences in dependent variables are uncorrelated with the error terms: $E\left[\left(\Delta y_{i,t-1}(\mu_i + v_{it}\right)\right] = 0$. This assumption implies a valid moment condition in the level equations, which must also hold for any endogenous explanatory variables. That is, the estimator differences the instruments to make them exogenous to the fixed effects, instead of transforming the regressors (Roodman, 2009).[5]

We take into account that the variables extension participation and its squared term, as well as our proxy for managerial ability are potentially endogenous by generating instruments for them. We probe the validity of this assumption with C test statistics, which perform estimations with and without the subset of instruments, under the assumption of joint validity of the full instrument set (Roodman 2009).

Bellemare et al (2017) question the use of lagged explanatory variables to address endogeneity concerns and argue that this approach is only consistent under the assumption of "no dynamics among unobservables". In line with previous use of the Arellano-Bond models, we apply a test for serial correlation that does test for dynamics among unobservables, and find supporting evidence of no serial correlation.

System GMM estimators can have the advantage that a richer set of variables, specifically time-invariant measures, can be included, because it is based on a mixed model that combines moment conditions specified for the first differenced equation with moment conditions specified for the level equations. As Roodman (2009, p.115) writes, "one can include time-invariant regressors, [...]. Asymptotically, this does not affect the coefficient estimates for other regressors because all instruments for the levels equation are orthogonal to fixed effects, indeed to all time-invariant variables."

[5] This assumption is weaker than assuming that the level of x_{it} is uncorrelated with the individual effects (Bond, 2002).

As long as the previously outlined moment conditions hold, this statement justifies inclusion of time-invariant regressors. Thus, in contrast to the difference GMM estimator, the system GMM estimator allows us to estimate the effects of time-invariant variables (e.g., soil type, regional effects).

We estimate all of our models with system GMM applying a two-step method with Windmeijer corrected standard errors (Windmeijer, 2005) and the maximum lag on any variable used as instrument being two periods. We also test that all coefficient values of the lagged dependent variables are between the coefficient values for the lagged dependent variables obtained from OLS and fixed effects estimates.[6] This is a condition for consistent estimates (Bond, 2002) and it is fulfilled in all of the models presented in this article.

6 Results

Before examining the results from our econometric model, we present summary statistics in Table 2 to give insights into the expansion strategies of Irish dairy farmers in the period 2008-2014 before quota abolition.

Table 2: Description of key dependent variables (2008-2014)

% Δ 2008-2014	Mean (st dev)	Min	Max
Herd size	15.28 (22.09)	-39.50	113.10
Dairy intensity	5.28 (21.71)	-70.21	89.26
Dairy specialisation	4.27 (14.98)	-47.26	71.11

[6] OLS methods to estimate equation (1) are inconsistent as $y_{i,t-1}$ is correlated with μ_i, which generally leads to an upward bias. Using a fixed effects estimator eliminates μ_i , but the fixed effects transformation introduces correlation between the transformed lagged variable and the error term v_{it}. This correlation introduces a downward bias (Bond, 2002).

Herd size increased by over 15 percent over the six-year span. These herd size increases were large relative to the gradual one to two percent annual increases in milk production allowed under quota restrictions. Farms intensified their operations by over five percent. They also became more specialized in dairy production (4.3 percent).

Next, we explore specific adjustment strategies of Irish dairy farms in more detail. Table 3 shows a cross-tabulation of all herd- and pasture changes above ten percent within the observation period from 2008 to 2014.

Table 3: Observed changes in selected variables from 2008 to 2014

	Pasture decrease	Pasture no change	Pasture increase	Sum herd
Herd decrease	2 (0.9)	14 (6.1)	5 (2.2)	21 (9.2)
Herd no change	6 (2.6)	45 (19.7)	20 (8.8)	71 (31.1)
Herd increase	8 (3.5)	58 (25.4)	70 (30.7)	136 (59.6)
Sum pasture	16 (7.0)	117 (51.3)	95 (41.6)	228 (100)

Absolute numbers and % in parentheses. Note: this information is based on farms that are in the sample from 2008 to 2014. "No change" implies changes of less than 10 percent.

First, as one would expect, increases in herd or pasture are much more common than decreases. For example, only two sample farms simultaneously decreased pasture land and herd size, while less than ten percent of farms decreased herd size. In contrast, almost 60 percent of farms increased their herd size by at least 10 percent (see last column of Table 3). Also, increases in herd size are more frequently observed than increases in pasture (59.6 vs 41.6 percent). This reflects the general difficulties in expanding land base of dairy enterprises in Ireland, despite the fact that increases in pasture can also arise based on rearranging existing land from other uses to pasture without expanding overall farmland. While land constraints may be severe in Ireland (where grass based dairy systems require pasture to be in walking distance to the milking parlor), they are not a purely Irish phenomenon. These issues are also highlighted in the Netherlands by Boere et al. (2015) and Groeneveld et al. (2016).

6.1 Estimation Results

The first set of estimation results are presented in Table 4, while selected more refined heterogeneity estimations are presented in Table 5. The three results columns in Table 4 examine the impact of extension services on herd size (column A), dairy intensity (column B) and dairy specialization (column C). Validity of Arellano-Bond estimators hinges on no second-order auto-correlation of the disturbances v_{it} and exogeneity of instruments. Results of statistics that test these assumptions are reported at the bottom of Tables 4 and 5. The hypothesis of no-second order correlation in the disturbances v_{it} was not rejected at the five percent significance level for any estimated models as suggested by p-values in the order of 0.416 and 0.909 (see AR (2) at the bottom of Tables 4 and 5).

The Hansen test for over-identification provides information on the general suitability of the model specification and exogeneity of any instruments used in the models. Again, in all our models we cannot reject the null hypothesis of orthogonality conditions related to over-identification restrictions, thus not providing sufficient evidence that the instruments are invalid (see Hansen test statistics at the bottom of Tables 4 and 5).

As we are particularly concerned about potential endogeneity of extension participation and the proxy variable for managerial ability, we conduct additional tests to validate our results. As previously mentioned, we use C test statistics [7] that specifically test for the orthogonality of a sub-set of instruments (Baum et al., 2003);

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[7] C test statistic is also known as “difference-in-Sargan/Hansen” test. The C test statistic tests the exogeneity or validity of instruments, while a Hausman test is generally focused on testing endogeneity. However, in this case the tests are equivalent (Baum et al., 2003).

i.e. extension participation and the proxy for managerial ability, as well as all explanatory variables.[8] Results from the C test statistics (also at the bottom of Tables 4 and 5) indicate that we fail to reject the null hypotheses of exogeneity of our instrumental variables.

[8] Variables assumed to be exogenous are instrumented by themselves, hence the term instruments.

Table 4: Estimation results from unbalanced panel data models

	Herd size	Dairy intensity	Dairy specialization
	A	B	C
	System GMM	*System GMM*	*System GMM*
$y_{(t-1)}$	0.87 (0.04)***	0.58 (0.06)***	0.74 (0.06)***
Extension participation	0.72 (0.15)***	0.016 (0.005)***	0.42 (0.10)***
Extension participation squared	-0.03 (0.007)**	-0.0005 (0.0002)**	-0.02 (0.005)***
SCC	-0.0007 (0.003)	-0.0001 (0.0001)	0.0004 (0.003)
Age	-0.41 (0.24)*	-0.009 (0.01)	-0.07 (0.13)
Age squared	0.003 (0.002)	0.00 (0.00)	0.0004 (0.001)
Successor	0.83 (0.56)	0.03 (0.02)	0.59 (0.003)
UAA	0.11 (0.04)***	-0.002 (0.0009)**	-0.08 (0.02)***
UAA squared	0.00 (0.00)	0.00 (0.00)	0.0003(0.001)**
Soil	0.94 (0.63)	0.08 (0.02)**	0.41 (0.42)
2009	-0.97 (0.59)	-0.06 (0.02)**	-0.34 (0.48)
2010	-1.78 (0.59)***	-0.06 (0.02)***	0.07 (0.45)
2011	-0.70 (0.52)	-0.08 (0.02)***	0.57 (0.45)
2012	-0.68 (0.50)	-0.08 (0.02)***	0.51 (0.37)
2013	-0.85 (0.48)*	-0.02 (0.02)	0.01 (0.37)
South	-0.77 (0.70)	-0.00 (0.02)	0.68 (0.58)
South West	-0.23 (0.70)	-0.02 (0.03)	1.06 (0.69)
East	-0.87 (0.82)	0.08 (0.03)***	-1.16 (0.67)*
Constant	14.00 (6.59)**	1.10 (0.30)**	20.83 (6.36)***
N	1,860	1,860	1,860
Instruments	77	77	77
AR(2)[1]	0.780	0.829	0.416
Hansen[1]	0.213	0.715	0.220
C test[2]	0.642	0.643	0.575
C test[3]	0.303	0.620	0.681

[1]p-values are reported; [2] C test statistic for the orthogonality assumption of extension participation and managerial proxies; [3] C test statistic for exogeneity of all instruments

Turning to the estimation results, the coefficients of the lagged dependent variables are positive and highly significant in the three estimations reported in Table 4. This implies that previous farm adjustment choices matter and should be accounted for. However, the adjustment processes are quite different across models, but they all indicate that the effect weakens over time. For example, the coefficient estimate for the lagged dependent variable for dairy herd size is 0.87, while the same coefficient estimates for dairy intensity and specialization adjustments are lower with 0.58 and 0.74, respectively.

As previously stated, we are concerned with whether and how extension participation influences dairy farm adjustment processes over time; hence, we mainly center our discussion of the estimation results on these variables. The linear coefficient estimate of extension participation is positive and significant in dairy herd size, intensity and specialization adjustments. We also observe diminishing returns to extension participation, as indicated by the negative significant squared terms in all models.[9] More specifically, the "herd size" model (Column A in Table 4) predicts a positive effect of extension membership until 12 years of membership. The "dairy intensity" model (Column B in Table 4) predicts a positive impact on dairy intensity up until 16 years of membership, while the "dairy specialization" model (Column B in Table 4) predicts that the impact of extension membership will become negative from 10 years extension experience onwards. The median participation time for all extension members is 5 years (the mean is 8 years), implying a positive impact for the majority of extension group members. However, it is worth considering the impact for

[9] We also estimated a cubic specification where a cubic term for extension participation E was also included. While the cubic term was sometimes statistically significant, the cubic specification generated results (including extension effects) that were qualitatively similar to the ones reported in Tables 4 and 5. On that basis, our analysis focuses on quadratic specifications in E. The estimates from the cubic specifications are available from the authors upon request.

old members in more details. Over the full sample, 50 percent are members for longer than 10 years, while 25 percent are members for longer than 16 years. This implies a negative impact for over a quarter of the old members in relation to dairy herd expansion, a negative impact on dairy intensity for a quarter of old members, while 50 percent of old members experience a negative impact of extension participation on dairy specialization. As such, our results indicate that the extension programme has become counter-effective for a significant proportion of old members in relation to dairy expansion and intensification, although this could also reflect a life-cycle effect of farmers growing older and beginning to reduce their farm size.[10] It should be pointed out that our analysis of dairy herd expansion, intensification, and specialization trends does not cover the full landscape of goals that extension is pursuing by working with farmers. There are many other productivity, sustainability and welfare outcomes in the mix. In addition, end of year evaluations of discussion groups revealed that social interaction is the main reason for participation, while learning from peers was less important, which further supports our findings.

In relation to economic significance of our estimation results, we calculated marginal effects of extension participation on relative changes of the dependent variables. For a discussion group member who has 5 years of extension experience and farms 72 dairy cows, has a dairy intensity of 2.0 livestock units per hectare and a dairy specialization of 62 percent[11], one additional year of extension participation results in an increase of the dairy herd of approx. 0.58 percent, an increase of the dairy intensity of approx. 0.56 percent and increase of dairy specialization of approx. 0.35 percent. In relation to dairy intensity, it is important to realize that we focus on existing dairy cows,

[10] As mentioned, we also conducted cubic terms of extension participant to test the robustness of our results. Of course, more simulations could be done to further test for robustness of our results.

[11] These are median values of an extension member over the full sample period.

implying that there might be a lag in intensification due to heifers entering the dairy herd at a later stage.

With regard to time dummy variables that are included to account for impending quota abolition, we find mixed results in our models depicted in Table 4. The estimation results from the "dairy intensity" model (Column B in Table 4) indicate that intensity increased over time, as indicated by negative and significant coefficient estimates compared to 2014 as the base year. The importance of time effects on dairy farm choices have also been established by Francksen et al. (2012) and Boere et al. (2015). We find similar effects for regional variables, in the sense that they show mixed effects in the three models shown in Table 4. Specifically, we do not find a significant regional effect in the "herd size" model, which can be explained by the fact that herd size changes were quite homogeneous across regions during our sample period. However, Irish dairy farms in the East appear to be (ceteris paribus) more intensive when compared to farms in the North West region, which can be explained by the fact that the North West region is less suited to dairy production and dominated by mixed livestock enterprises.

We previously raised the possibility that farmers might be heterogeneous in their ability to learn from extension services; hence, we are also interested in evaluating how the effects of extension participation change for different groups. The results are reported in Table 5 for dairy herd size and intensification[12].

We run several sets of regressions that focus on new versus old members, good versus bad managers, and farms that were intensive at the beginning of the panel versus those that were not. Length of extension participation is accounted for in all of

[12] For brevity, we did not include the results for dairy specialization. These are similar to the results from dairy intensity and are reported in the Appendix.

these models. When we include all of the interaction possibilities reflected in Table 5, our results suffer from severe multicollinearity, and so we present them separately, with the observation that they may suffer from omitted variable bias[13].

First, we are interested in studying how extension participation in general, and financial incentives in particular, influence expansion and intensification decisions of dairy farmers. For that purpose, we create interaction terms between extension participation and our previously defined extension groups, i.e. old and new-members. The results are reported in columns A in Table 5.

For both new and old extension group members, herd size and intensification are positively influenced by length of participation in extension services, yet at a decreasing rate. For example, the effect of extension membership on dairy herd size and dairy intensity for "new members" becomes negative at 3.3 and 3.7 years, respectively, while "old members" enjoy positive returns for much longer. More specifically, our model predicts that the effect of extension experience on herd size becomes negative for "old members" after 14 years, while the quadratic terms is not statistically significant for "old members" in the dairy intensity model. We also find that the extension effect is significantly stronger for "new members" than for "old members" in relation to both, herd size and intensification.

Next, we examine the interaction of extension participation and managerial ability in columns B (in Table 5). Here, farmers in the sample are divided based on SCC content of milk in the first year they joined the sample. That is, farmers who had below average SCC in their respective base year are considered "good managers", while farmers with above average SCC are classified as "poor managers". In relation to dairy expansion (Column B in Table 5), the coefficient estimates of extension participation

[13] A reviewer expressed concern about omitted variable bias.

are statistically different from each other at the 5 percent level. Specifically, it appears that extension participation has a stronger effect on ”good managers” in relation to herd size than on ”poor managers”. More detailed data analysis reveals that this difference is not driven by membership participation rates in the groups. In contrast, we do not find a significantly different effect of managerial quality on dairy intensification choices, both groups seem to be positively influenced by group membership to intensify their operations.

Table 5: Results of group heterogeneity for dairy herd size and intensity models

	Dairy herd size			Dairy intensity		
	A	B	C	A	B	C
$y_{(t-1)}$	0.89 (0.04)***	0.86 (0.03)***	0.87 (0.04)***	0.63 (0.05)***	0.59 (0.06)***	0.69 (0.05)***
Extension×new members	1.67 (0.47)***	--	--	0.06 (0.02)***	--	--
Extension squared×new members	-0.25 (0.08)***	--	--	-0.008 (0.003)***	--	--
Extension ×old members	0.56 (0.15)***	--	--	0.009 (0.005)**	--	--
Extension squared ×old members	-0.02 (0.007)***	--	--	-0.0002 (0.0002)	--	--
Extension × good manager	--	0.94 (0.22)***	--	--	0.02 (0.007)***	--
Extension squared ×good manager	--	-0.04 (0.01)***	--	--	-0.0007 (0.0003)*	--
Extension ×poor manager	--	0.43 (0.16)***	--	--	0.016 (0.007)**	--
Extension squared ×poor manager	--	-0.01 (0.008)	--	--	-0.0005 (0.0004)	--
Extension× intensive	--	--	0.93 (0.22)***	--	--	0.02 (0.006)***
Extension squared × intensive	--	--	-0.04 (0.009)***	--	--	-0.0008 (0.0003)***
Extension× extensive	--	--	0.41 (0.18)**	--	--	0.002 (0.005)
Extension squared ×extensive	--	--	-0.02 (0.01)*	--	--	0.00006 (0.0002)
Time, regional dummies and other covariates	Yes	Yes	Yes	Yes	Yes	Yes
N (n)	1,860	1,860	1,860	1,860	1,860	1,860
AR(2)	0.799	0.824	0.766	0.885	0.846	0.909
Hansen	0.397	0.217	0.409	0.618	0.586	0.702
C test[2]	0.395	0.473	0.639	0.423	0.836	0.518
C test [3]	0.283	0.240	0.629	0.387	0.761	0.362
Instruments	104	109	108	104	109	108

[1]p-values are reported; [2] C test statistic for the orthogonality assumption of extension participation and managerial proxy; [3]C test statistic for exogeneity for all instruments

Finally, in columns C in Table 5 we present results from a comparison of farmers that already had an intensive system in the first year they joined the sample ("intensive", i.e. farmers that had above average dairy stocking rate in their respective base year) to "extensive" farmers (who had below average stocking rates). Again, beginning our discussion with dairy herd size, the coefficient estimate of membership for the "intensive" group is positive and significant. It is also significantly larger than the extension effect for "extensive" farmers, which is also positive and significant. The squared term for both groups is also significant and negative which is in line with our previous findings. The coefficient estimates suggest that the effect on dairy herd size of extension participation becomes negative after more than 11 years of participation for "intensive" farmers and after more than 10 years for "extensive" farmers. Finally, extension participation has a positive effect on dairy intensification for "intensive" farmers, which, however turns negative after 12.5 years of membership, while extension participation is not statistically significant for "extensive" farmers. Overall, the analysis reveals considerable heterogeneity of the impact of extension services.

7 Concluding Remarks

The 2015 elimination of EU milk production quotas is inducing major adjustments in the agricultural sector. We have investigated Irish dairy farm-level responses to market liberalization in the presence of active extension efforts. We applied an Arellano-Bond GMM estimation strategy to a seven year unbalanced panel data set of representative sample of Irish dairy farms. Our empirical findings confirm the importance of extension services in inducing adjustments in the dairy sector in terms of dairy herd expansion, intensification, and specialization. Overall, our findings suggest that farmers who participate in extension programs adapt faster than others and may therefore be better equipped to enhance their comparative advantage.

While this is true for the initial years of membership, our findings indicate a declining impact of extension participation on dairy expansion and intensification in the long run. This is an important result that should be taken into consideration when reviewing extension services, as these changes are often targeted at increasing members but also working with continuing "old members" who may not be as dynamic in their later years of participation in the sector. That said, it also has to be kept in mind that our study evaluated a partial effect of the extension program only, and these programs often have much wider goals that include, among other things, better sustainability, breeding, and grassland management. Older members may be valuable sources of information an experience on these themes. Evaluating the overall long run impact of sustained extension programs remains an important topic for future research.

More generally, our findings indicate that, in the face of major policy changes, Ireland has successfully introduced an institutional context that facilitates structural adjustment in the dairy sector. Our results suggest that these adjustments are in line with the government's ambitious milk production growth targets. Ireland's national extension program has a strong focus on technology transfer and it undertook significant expense on the program to increase participation rates. Although we find a 'catch-up' effect of newer extension group members, it remains to be seen whether this new group will continue to innovate in the coming decades, and whether non-participants will join groups or learn and innovate via spillovers and diffusion.

Our results show that dairy farmers in Ireland started to significantly intensify before quota abolition. The focus of our analysis was on the existing dairy herd, hence expansion and intensification may likely be underestimated as many dairy farmers prepare for expansion through increasing heifer numbers. This can also lead to significant expansion and intensification of their dairy enterprises in the medium term, which, due to data constraints, we were not able to model.

Overall, our findings provide clear evidence that the Irish dairy sector is in the midst of a major expansion of milk production, based on strong support of its extension system. This expansion currently stands in contrast to the Netherlands where EU-based nitrate regulations proved to be an impediment and forced a retreat from initial expansion efforts (Samson et al. 2017). While nitrates will likely become of increasing concern in Ireland, currently on-farm grass growth (and as such access to additional land) is the limiting factor for further dairy expansion. In this article, we only explicitly analyzed herd size, intensification and specialization and their impacts on overall milk production potential. We did not consider the potential for Ireland to hit against EU environmental regulations. While on average Irish dairy farmers are within optimal stocking rates that would accord with EU nitrate regulations, continued intensification of their grazing systems could well become a constraint. Moreover, a significant proportion of Irish dairy farms already make use of a nitrogen derogation allowing higher nitrogen limits per hectare. Given Ireland's impressive dairy sector growth, this trend raises concerns for the future and the experience in the Netherlands underlines the importance of pursuing sustainable growth. Moreover, as the agricultural sector remains a major source of water pollution, on-going intensification of the Irish agricultural sector needs attention (Mockler et al 2017). Likewise, how the Irish extension system's advice on herd, pasture, and feeding management may shape these outcomes also need to be addressed and updated. This line of inquiry provides a compelling direction for future research.

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Table A1: Results of group heterogeneity for dairy specialization

	Dairy Specialization		
	A	B	C
y$_{(t-1)}$	0.79 (0.05)***	0.77 (0.04)***	0.71 (0.05)***
Extension×new members	1.11 (0.36)***	--	--
Extension squared ×new members	-0.17 (0.07)**	--	--
Extension ×old members	0.36 (0.09)***	--	--
Extension squared ×old members	-0.01 (0.004)***	--	--
Extension × good manager	--	0.38 (0.11)***	--
Extension squared ×good manager	--	-0.02 (0.005)***	--
Extension ×poor manager	--	0.24 (0.11)**	--
Extension squared ×poor manager	--	-0.01 (0.005)*	--
Extension× intensive	--	--	0.52 (0.05)***
Extension squared × intensive	--	--	-0.02 (0.005)***
Extension× extensive	--	--	0.40 (0.14)**
Extension squared ×extensive	--	--	-0.02 (0.008)**
Time and regional dummies and other covariates	Yes	Yes	Yes
N (n)	1,860	1,860	1,860
AR(2)	0.413	0.405	0.422
Hansen	0.393	0.544	0.438
C test[2]	0.395	0.799	0.831
C test [3]	0.604	0.819	0.849
Instruments	104	109	108

[1]p-values are reported; [2] C test statistic for the orthogonality assumption of extension participation and managerial proxies; [3] C test statistic for exogeneity of all instruments