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Impact of Decoupled Payments on Production: Policy Briefing Report

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Myles Patton, Kehinde Oluseyi Olagunju and Siyi Feng (AFBI)

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1. Introduction

There is considerable uncertainty concerning the future of direct payments to farmers as the UK leaves the European Union. Currently, farmers receive support payments of approximately €327 million per annum under Pillar I of the Common Agricultural Policy (CAP). These payments are not linked to current production (i.e. are decoupled) and are fully funded by the EU budget. The UK government has provided assurances to continue this form of support in cash terms until the end of the existing parliament (2022). However, the UK's exit from the EU means that agriculture's share of the Treasury budget may be reduced in the future to focus spending on higher priority areas, resulting in reductions in Pillar I direct payments. In addition, Pillar I payments may be diminished by transfers of monies from Pillar I to Pillar II (rural development schemes that assist farm businesses) under future agricultural policy reforms. While the system for paying Pillar I direct payments was fundamentally changed in 2005, little empirical evidence exists on the impact of these decoupled payments on agricultural production. It is important to quantify the impact of these payments in order to provide a better understanding of the implications of changes in Pillar I payments in the post-Brexit era. The quantitative analysis undertaken as part of this study provides an indication of the supply response to changes in Pillar I payments.

Historically, direct payments under Pillar I of the CAP have exerted a strong influence on production as they were directly linked to activity levels (livestock numbers/crop area). However, the introduction of the decoupled Single Farm Payment (SFP) under the 2005 CAP reforms separated financial support to farmers from their level of production of farm commodities. This was superseded by the area based Basic Payment Scheme in 2015. While these direct payments are decoupled from production in an administrative sense, it is widely accepted that such decoupled payments continue to exert an influence on production. There are several mechanisms through which decoupled payments can potentially influence current production decisions. In particular, decoupled payments may alter farmers' risk preferences due to insurance and wealth effects (Hennessy 1998), ease credit constraints by increasing total wealth (Goodwin and Mishra 2006; Bhaskar and Beghin 2009) and change the allocation of land, labour and other inputs (Ahearn *et al*. 2006; Kirwan *et al*. 2012; Peckham & Kropp 2012). In addition, there is evidence that decoupled direct payments keep farms that would otherwise exit the market in business and thus inflate aggregate production (Chau & De Gorter 2005; De Gorter *et al*. 2008). Furthermore, farmers may use decoupled payments to increase production as a result of expectations that future payments will be reassessed and based on current production levels (Coble *et al*. 2008; Ciaian *et al*. 2015). Another reason for supposing Pillar I direct payments are not fully decoupled from production are cross compliance obligations that must be satisfied in order to ensure full payment. Cross compliance obligations require farmers to maintain land in good agricultural condition, which implicitly assumes that at least some production will continue.

This study employs an econometric technique (Instrumental Variables Fixed Effect) to estimate the impact of decoupled Pillar I direct payments on farm production in Northern Ireland. The analysis is based on Farm Business Survey panel data (*i.e.* the same farms over multiple time periods) over the period 2008 to 2016, with three forms of agricultural production:

i) milk output for dairy farms;
ii) suckler cow numbers for beef farms; and
iii) ewe numbers for sheep farms.

Details on the empirical model and dataset are provided in the Appendix.

Following estimation, the econometric results are used to parameterise the production stimulating impact of direct payments within a sectoral economic model (the FAPRI-UK partial equilibrium model). The FAPRI-UK model is then used to run scenarios on changes to Pillar I direct payments and thereby provide estimates of the market level effects of such changes to direct payments.

2. Existing Literature

A number of empirical studies have tested the theoretical findings about the production impact of decoupled payments. Most of this literature has investigated the production effects in the US, with a particular focus on crop production (Adams *et al.* 2001; Goodwin & Mishra 2006; O'Donoghue & Whitaker 2010; Weber & Key 2012). A number of studies have found that although decoupled payments have a statistically significant distorting impact on acreage, the magnitude is small minimal (Adams *et al.* (2001), Weber and Key (2012), Goodwin and Mishra (2006), Key and Roberts (2009), and Serra *et al.* (2011)). On the other hand, O'Donoghue and Whitaker (2010) empirically established that decoupled payments change individual acreage decisions significantly, ranging from about 9 to 16% changes. Within the EU context, only a small number of studies have examined the impact of decoupled payments on farm production. Using Ireland as a case study, Howley *et al.* (2012) examined if decoupled payments affect farmers' behaviour. They suggested using output from a partial equilibrium model that decoupled payments maintain a significant effect on agricultural activity, with farmers using this new form of support to partly subsidise unprofitable farm production. Rizov *et al.* (2013) and Kazukauskas *et al.* (2014) found that decoupled payments positively impact productivity.

Some additional studies have considered the impact of agricultural support on market participants along the supply chain. For instance, a number of studies have examined the effect of direct payments on land rents (Allen Klaiber *et al.* (2017), O'Neill and Hanrahan (2016), Michalek and Ciaian (2014), Ciaian and Kancs (2012), Van Herck *et al.* (2013) and Patton *et al.* (2008)). These studies indicate that between 10% and 80% of decoupled payments are leaked out of the farming sector by inflating the land rental or sales prices.

The main contribution of this study to the existing policy debate and literature is in providing new empirical evidence of the production impact of decoupled payments.

Moreover, most econometric studies that have examined the impact of decoupled payments on production have focused on crop production. In contrast, this study provides empirical evidence on livestock production.

3. Econometric Results

The estimated impact of decoupled payments on production, as well as the other explanatory variables, are provided in Table 1. The reported decoupled payment, revenue and cost terms are expressed in log terms and hence, the coefficients can be interpreted as elasticities. Based on economic rationale we focus on the specification in which the revenue and cost variables are weighted over a period of three years (specification number 4 in the Appendix) within this summary of results. Alternative specifications (including single year revenue and costs variables) are provided in the Appendix. It is interesting to note that the results indicate that farmers are more responsive to sustained changes in market revenue over a number of years (average over three year variables), compared to single year fluctuations (single year variables).

Table 1: Estimated Coefficients

	Milk Output	Beef Cows	Ewes
Decoupled payments	0.267***	0.127*	0.262***
Revenue *(3 year avg.)*	1.118***	0.191**	0.189***
Costs *(3 year avg.)*	-0.381***	-0.048	-0.02
Other government payments	0.012	-0.019	-0.015
Asset value	0.102	0.176*	0.052
Age	-3.742***	-2.644	1.1
Age squared	0.488***	0.278	0.015
Farm size	0.310***	0.349**	0.087
Off-farm employment	0.028	-0.014	-0.04
GSCE	0.001	0.165**	0.022
A-level	0.031	0.287**	0.185**
Higher education		0.659***	
Rent ratio	0.424***	-0.016	-0.046
Family labour ratio	-0.223*	-0.790***	-0.574**
Observations	462	471	460
Number of farms	66	62	58

*** p<1%, ** p<5%, * p<10% (Shading denotes significance at least at 10% level)

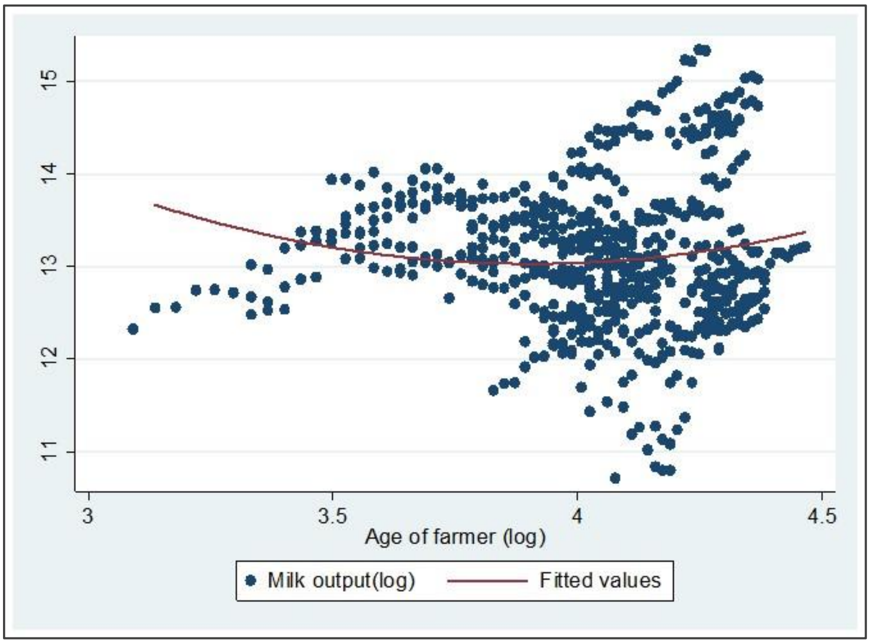
Milk output

Within the milk output equation, the estimated decoupled payment and revenue coefficients have positive signs and are statistically significant, indicating that both variables have a stimulating impact on milk output. In particular, the results indicate that a 10% increase in decoupled payments is associated with an increase in milk output of approximately 2.7%, while a 10% increase in revenue has an 11% impact on output. In line with expectations, the responsiveness of milk output to a change in the level of decoupled payments is less compared to an equivalent change in market revenue. The impact of decoupled payments on milk output is 24% compared to market revenue.

With regards to the other variables within the milk output equation:

- The coefficient for the cost variable was found to be significant and negative, indicating that milk output reduces with higher farm costs. However, the results suggest that farmers are more responsive to changes in output revenue than input costs (a 10% increase in input costs is associated with a decrease in milk output of approximately 4%).
- The coefficient of the variable representing other government subsidies payments (including mainly agri-environment and Less Favoured Areas payments) is not significant. This may reflect the fact that these payments represent a relatively small proportion of farm business income and therefore do not have a significant influence on milk output.
- The impact of age is complex. While the basic age variable was found to be negative, its quadratic form was found to be positive. This suggests that up to a certain threshold age has a negative impact on milk production, but beyond this point older farmers, who are more experienced, have all other things equal higher levels of production. It is however important to note the threshold point. As shown in Figure 1, the turning point is 46 years old. This suggests that the positive impact of experience on milk output dominates as the average age of dairy farmers in the Farm Business Survey is 57 years old.
- The variable farm size was found to be positive and significant, indicating as expected that that milk output increases with farm size.
- The share of area rented in net area farmed variable (Rent Ratio) was found to be positive and significant. It is likely that farmers who rent land do so due to a pressing need to accommodate more livestock.
- The family labour ratio (share of family labour with respect to total labour) was found to reduce milk output. This implies that dairy farmers that are more market oriented (lower proportion of family labour) use more paid labour so as to increase and or maintain milk output.

Figure 1: Age variable within milk output equation.



Turning point:
46 years

Avg. age of
dairy farmer
(2008 – 2016):
57 years

Beef cows

Within the beef cow equation, the coefficient for decoupled payments is positive and significant and implies that an increase in decoupled payments of 10% is associated with an increase in the number of beef cows of 1.3%. The revenue variable is also significant, yielding an elasticity of 0.19 (an increase in revenue of 10% leads to an increase in beef cow numbers of 1.9%). This indicates that the impact of decoupled payments on the number of beef cows is about 66% compared to the impact of market revenue. The cost and other government subsidies payments variables were found to be insignificant.

Turning to the other control variables:

- The asset value variable is positively significant. This suggests that wealthier farmers are less constrained by credit and can thereby expand beef production.
- The variable farm size was found to be statistically significant and positive, indicating that an increase in farm size has a positive impact on the number of beef cows.
- The results for the beef cow equation also show that higher levels of human capital, as measured by education attainment variables, are associated with higher levels of production. This may reflect better resource management as a result of education status.
- Similar to milk production, the variable family labour ratio has a negative impact on beef cows.

Ewes

The empirical results suggest a statistical relationship between decoupled payments and the number of ewes produced. The coefficients imply that a 10% increase in decoupled payments is associated with an increase in the number of ewes of 2.6%. Sheep revenue also has a statistically significant impact on sheep production. However, unlike the results for the dairy and beef sectors, the estimated elasticity is greater for decoupled payments compared to revenue. One possible explanation is that sheep farmers are generally less economically viable and may use decoupled payments to continue in production.

Only a limited number of the other explanatory variables were found to be significant:

- Higher human capital through education is associated with increased ewe production (in this case only the A-Level variable is significant).
- The estimated coefficient associated with family labour ratio was negative and significant, again suggesting that production reduces with the share of family labour employed total labour.

4. Simulations using the FAPRI-UK Model

The econometric results presented in the previous section raises question marks regarding the production stimulating assumption of decoupled payments used in policy models such as the FAPRI-UK model. In line with the literature noted earlier, it is assumed within the FAPRI-UK modelling system that decoupled payments exert an influence on production, even though they are not linked to production in an administrative sense. Specifically, within the FAPRI-UK model, it has traditionally been assumed that the production impact of a £1 increase in decoupled payments is 30% that of a £1 increase in price. This assumption is in keeping with the treatment of decoupled payments within the FAPRI US model, where there has been a longer history of decoupled payments and hence, more empirical evidence is available. However, this empirical evidence is primarily based on the crop sector.

Within this study alternative production stimulating assumptions are incorporated within the FAPRI-UK model based on the econometric estimates in the previous section. In particular, it is assumed for the beef sector that the production impact of a £1 increase in decoupled payments is 66% that of a £1 increase in price. The same assumption is used for the sheep sector. This contrasts with the empirical results, which showed that the estimated impacts of decoupled payments in the sheep sector is greater than that for revenue. However, as previously noted the magnitude of the revenue term may be affected by the limited profitability in the sheep sector and hence, the estimated term from the beef sector is used instead. Finally, in line with the empirical results a 24% production stimulating assumption is employed for the dairy sector.

In order to determine the implications of these alternative assumptions the FAPRI-UK model is simulated based on policy scenarios involving the reduction of Pillar I decoupled payments. In particular, two scenarios are undertaken: (a) 50% reduction in Pillar I support and (b) full elimination. These reduction in Pillar I payment scenarios are simulating using both the traditional assumption for the production stimulating impact of decoupled payments (30% decoupling assumption) and the assumptions derived from the econometric estimates. These scenarios are hypothetical but are designed to capture the possibility of Pillar I payments being scaled back in the future. Note, the analysis does not consider the potential production impact of potential new schemes that would replace Pillar I payments.

The results are complementary to the FAPRI-UK report containing detailed results on reductions in Pillar I direct payments in the context of different post-Brexit trade arrangements (Patton *et al.*, 2019). The analysis is undertaken using the UK government's planned tariff schedule in the event of the UK leaving the EU without a deal[1] as the counterfactual; *i.e.* the projected percentage changes refer to the difference between combined changes in direct payments and new tariff schedule against changes in new tariff schedule alone. This comparison is used to isolate the impact of changes in direct payments in the context of the new tariff schedule. The percentage changes in the tables and text refer to the end of the projection period (2027).

The estimated impacts of reductions in Pillar I decoupled payments using alternative production stimulating assumptions on the beef, sheep and dairy sectors are shown in Table 2. Results are provided at both the UK and NI levels and refer to percentage changes at the end of projection period (2027).

Table 2: Impact of Reduction/Elimination of Pillar I Direct Payments Shocks Using Alternative Production Stimulating Assumptions

a) Beef Sector

	30% Stimulating Assumption		66% Stimulating Assumption	
	50% red.	100% red.	50% red.	100% red.
UK				
Beef cows	-2.9%	-5.0%	-5.4%	-10.1%
Dairy cows	-0.3%	-0.6%	-0.3%	-0.5%
Total Cattle	-1.5%	-2.6%	-2.6%	-4.9%
Production	-1.3%	-2.4%	-2.3%	-4.4%
Domestic use	-0.1%	-0.2%	-0.4%	-0.6%
Exports	0.0%	0.0%	0.0%	0.0%
Imports	2.3%	4.3%	3.5%	7.4%
Cattle price	0.1%	0.2%	0.2%	0.5%
Northern Ireland				
Beef cows	-4.1%	-8.1%	-9.0%	-17.9%
Dairy cows	-0.4%	-0.8%	-0.3%	-0.7%
Total Cattle	-2.2%	-4.3%	-4.5%	-9.0%
Production	-2.1%	-4.2%	-4.3%	-8.7%

[1] The change in trade arrangements entails the application of new tariffs to imports from the EU and the rest of the world; and the application of default MFN tariffs to UK exports to the EU (see FAPRI report for details).

b) Sheep Sector

	30% Stimulating Assumption		66% Stimulating Assumption	
	50% red.	100% red.	50% red.	100% red.
UK				
Ewes	-0.9%	-1.6%	-1.6%	-3.1%
Total Sheep	-0.8%	-1.5%	-1.8%	-3.1%
Production	-1.2%	-1.8%	-4.4%	-5.4%
Domestic use	-0.9%	-1.3%	-3.2%	-3.9%
Exports	-0.3%	-0.4%	-0.9%	-1.2%
Imports	0.4%	0.7%	1.7%	2.1%
Sheepmeat price	2.3%	3.4%	8.9%	10.9%
Northern Ireland				
Ewes	-2.1%	-4.4%	-5.0%	-10.1%
Total Sheep	-2.1%	-4.3%	-5.2%	-10.1%
Production	-2.6%	-4.7%	-8.4%	-13.1%

c) Dairy Sector

	30% Stimulating Assumption		24% Stimulating Assumption	
	50% red.	100% red.	50% red.	100% red.
UK				
Cow's milk production	-0.3%	-0.6%	-0.3%	-0.5%
Manufacturing use	-0.6%	-1.2%	-0.5%	-1.0%
Prices				
Producer milk price	0.0%	0.0%	0.0%	0.0%
Cheese price	0.0%	0.0%	0.0%	0.0%
Butter price	0.0%	0.1%	0.0%	0.0%
WMP price	0.0%	0.0%	0.0%	0.0%
SMP price	0.0%	0.0%	0.0%	0.0%
Cheese				
Production	-0.6%	-1.2%	-0.5%	-1.0%
Domestic use	0.0%	0.0%	0.0%	0.0%
Exports	-0.4%	-0.8%	-0.3%	-0.7%
Imports	0.3%	0.7%	0.3%	0.6%
Butter				
Production	-0.4%	-0.7%	-0.3%	-0.6%
Domestic use	0.0%	0.0%	0.0%	0.0%
Exports	0.0%	0.0%	0.0%	0.0%
Imports	0.6%	1.1%	0.5%	0.9%
Northern Ireland				
Milk production	-0.4%	-0.9%	-0.3%	-0.7%
Dairy cows	-0.4%	-0.9%	-0.3%	-0.7%
Milk price	0.0%	0.0%	0.0%	0.0%

The reduction/elimination of direct payments has a downward impact on livestock numbers in the beef, sheep and dairy sectors. Following the full elimination of Pillar I decoupled payments it is projected that Northern Irish beef cow numbers fall by 18% using the 66% decoupled payment production stimulating assumption, compared to 8% under the 30% production stimulating assumption. The projected decline in ewe numbers is also more marked under the alternative production stimulating assumption. Northern Irish ewe numbers fall by 10% in response to the full elimination of decoupled payments using the alternative production stimulating assumption, compared to 4% using the traditional assumption. Note the decline in ewe numbers is partially offset by an increase in price. The responsiveness of ewe numbers to a reduction in direct payments would be more significant if the increase in price was less significant.

In contrast to the beef and sheep sectors, there is little difference in the projected declines in milk production following the elimination of decoupled payments using both the alternative and traditional production stimulating assumptions. This reflects the fact that the derived production stimulating assumption based on empirical estimation is comparable to the traditional FAPRI assumption. The modest negative impact of reducing decoupled

Pillar I payments on milk production is due to the relatively small proportion of farm income represented by Pillar I direct payments in the dairy sector compared to other pasture based farm types.

It is important to stress that the full removal of Pillar I direct payments (and even the 50% reduction scenario) entails a significant departure from existing policy upon which the models have been calibrated. The coefficients within the supply functions capture the production responses of changes in returns (market receipts and direct payments) observed during the historic period. This includes changes in Pillar I direct payments that occurred due to modulation and exchange rate fluctuations. The coefficients for supply responses are reasonably robust for changes in direct payments within these bounds. However, there is uncertainty regarding the linearity of production responses following substantial changes in direct payments, such as those considered in this study. The substantial nature of the changes in direct payments considered in this analysis could lead to structural changes not captured by the modelling system.

5. Conclusions

This study quantifies the impact of Pillar I payments (decoupled payments) on farm production, with a particular emphasis on livestock production in Northern Ireland. Although Pillar I payments are decoupled from production in an administrative sense, it is widely accepted that such payments continue to exert an influence on production due to a variety of mechanisms, including influence on risk preferences, credit constraints, allocation of labour, expectations about future preferences and cross compliance obligations.

To estimate empirically the impact of decoupled payments on farm production in Northern Ireland, we employed the Instrumental Variables Fixed Effects procedure using Farm Business Survey panel data for the period 2008-2016. Our results suggest that that even though decoupled payments are delinked from production, they continue to exert an influence on production. According to our elasticity estimates, the production effect of decoupled payments impact is significant in each of the sectors studied. Relative to market revenue, decoupled payments have a larger impact on production in the beef and sheep sectors, compared to the dairy sector. This is likely to reflect the importance of such payments to supporting farm income in these sectors.

The results have important implications for the implementation of future reforms of agricultural subsidies in the EU and UK. Pillar I decoupled payments are likely to be squeezed in the future, particularly in the UK post-Brexit with either more money being transferred to Pillar II payments (i.e. Less Favoured Areas and more explicit Agri-environmental payments) or a reduction in the overall agricultural budget. The finding that decoupled payments have a significant impact on production, suggests that such reductions will lead to a decline in agricultural production. However, it is important to bear in mind that the estimated elasticities in this analysis capture marginal changes in the level of direct payments and hence care needs to be taken in making inferences regarding substantial changes in these payments such as the full elimination of direct payments.

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Appendix

A1. Empirical model and data

A1.1 Empirical model

The main objective of the study is to examine the impact of decoupled payments on farm production. Based on the premise that decoupled payments affect farm production both directly (by altering the payments received and farm behaviour) and indirectly (by influencing input and output prices), the specification of the model is as follows:

$$Prod_{it} = \beta_0 + \beta_1 DP_{it} + \beta_2 MR_{it-1} + \beta_3 C_{it-1} + \beta_4 X_{it} + \delta_i + \psi_t + \varepsilon_{it} \quad , \qquad (1)$$

where the $Prod_{it}$ represents the production outcomes of interest (milk output, number of suckler cows and number of ewes) for farm i in year t; β_j is the estimated parameter coefficients; DP_{it} is the amount of decoupled payments received by farm i in year t; MR_{it} and C_{it} represent the one year lagged form of market revenue and costs for farm i in year t respectively[2]; $\boldsymbol{X}_{it}$ denotes a set of other farm specific variables; δ_i and ψ_t are the farm and year fixed effects, respectively, and ε_{it} is the idiosyncratic error term. The farm fixed effect controls for any unobserved farm characteristics, such as landscapes with different agro-climatic conditions, that do not change over time and that may affect farm production outcomes. The inclusion of the year fixed effect, ψ_t, in equation (1) is to control for shocks common to all the farms, for example changes in market signals to all farms and price volatility (Kazukauskas *et al.* 2013; Takayama *et al.* 2019).

Identifying a causal relationship between decoupled payments and farm-level production decisions is complicated by the existence of a number of confounding factors (Weber and Key, 2012). It is possible that there are un-observed farm-, system-, and time-specific factors that impact on production that are also related to the level of decoupled payments a farmer receives, subjecting the model to the potential endogeneity issue. In order to remove the unobserved effect, we estimate a farm fixed effect model thereby removing all time invariant component of omitted variable bias in equation (1). To identify the causal effect of payments on farmland and farm numbers, we instrument for the receipt of decoupled payments using appropriate instruments.

Instruments for DP_{it} are obtained using the following reduced from equation:

$$DP_{it} = \pi_0 + \pi_1 z_1 + \pi_2 z_2 + \boldsymbol{\pi X} + \upsilon_{it}, \qquad (2)$$

where π_k is the estimated parameter coefficients; $\boldsymbol{X}$ is the vector of all the explanatory variables; z_k are our instruments. Following Miao *et al.* (2015), we use one-year and two-year lags of DP_{it} for the milk output model; one year lags of DP_{it} for the suckler cow model and one year lags of DP_{it} for the sheep output model. The selection of these instruments are on the basis that they are exogenous and are strongly correlated with the endogenous regressor, in this case DP_{it}, and uncorrelated with the error term, ε_{it}, in equation (1).

[2] Similar to O'Donoghue and Whitaker (2010), we measured market revenue and cost variables using lagged values to avoid endogeneity biases from entering our results. This is valid because at the beginning of the current year, the values of the previous years are all known and can be considered as exogenous.

We show in the empirical results section that our instruments are strong predictors of the receipt of decoupled payments. We also perform a diagnostic test that shed light on the extent to which possible correlation with the error term might affect our results.

We estimate three production equations based on equation (1). The first relates to decoupled payments for milk output for dairy farms, while the second outcome variable relates to number of suckler cows for beef farms. The third equation relates to number of ewes for sheep farms[3]. In order to ameliorate the influence of outliers and to be able to interpret coefficient as elasticities, we employ the natural logarithms to transform the production outcomes variables, DP_{it}, and the decoupled payments variable, DP_{it}.

A1.2 Data

The dataset used in this study is based on the Northern Ireland Farm Business Survey (FBS)[4]. Annually, the Department of Agriculture, Environment and Rural Affairs (DAERA) conducts a nationally representative survey of farm businesses in NI. For the purpose of this study, we focus on the panel of farms for the periods from 2008 to 2016. In sum, there are 2,938 observations relating to 342 different farms, with approximately 53% of farms being present for all 8 years understudied. In order to ensure consistency in the data set we perform some data cleaning. We exclude farms indicating zero net area farmed with inexplicably high subsidies. Following the data cleaning process, we have panel of 1,805 observations.

Our analysis focuses on the impact of decoupled payments on Northern Irish livestock production decisions, which include dairy, beef and sheep production. For dairy farm type, the dependent variable is milk output, defined as quantity of milk produced per farm, while for beef and sheep farm types, the dependent variables are number of beef cows and ewes respectively. In other to control for output and input prices, we employed market revenue per hectare and variable cost per hectare respectively. In addition to decoupled payments, farmers also receive other forms of payments such as the agri-environmental payments, disadvantaged area payments and general subsidies which are included in the model. Due to the excess number of zeroes, these amounts were aggregated in the variable Other Government Subsidies defined on a per hectare basis.

We also include other farm level variables that potentially influence farm production. Given that production may increase with the share of family labour due to productivity differences between family and hired labour, we include the share of family labour with respect to the total labour (Allen Klaiber *et al.* 2017; Guastella *et al.* 2018). To proxy for wealth, we included value of asset in the model. As wealth increases, production may increase because more funds are available; although this may be unlikely when wealth levels are low. The variables measured in monetary units were corrected for inflation using the appropriate annual price indices published by the UK Office for National Statistics (ONS).

Farmers who are engaged in off-farm employment may have less time and resources to commit to agriculture and so may produce less, *ceteris paribus* (Holden & Ghebru 2005).

[3] A farm is classified as dairy farm if a minimum of two-thirds of farm standard output is from grazing livestock and dairy cows. Similar classification applies for beef and sheep farms.

[4] The Northern Ireland FBS is conducted as part of the EU Farm Accountancy Data Network (FADN).

For this reason, we include a binary indicator to proxy for farms with off-farm activity. Finally, to account for farm-owned factor inputs, we include rental ratio constructed by dividing the area rented by the total area farmed. Age may have two opposing impacts on farm production. On the one hand, farmers that are older may not wish to farm as actively as younger farmer and hence may produce less (O'Neill & Hanrahan 2012). On other hand, experience may have positive impact on production. To account for these effects, we included the age of the head of household in quadratic form (age and age^2) in the model as a proxy for farmer experience. Farm size defined as the net area famed is included to control for possible effect of size of farm in the model. We also control for differences in education status of farm households by including the level of education attained. Lastly, we include dummy variables for each Less Favoured Areas (LFAs) to account for regional variability that is not captured by the other regressors, specifically differences in soil and land quality. The summary statistics of the data used in the model are presented in Table A1.

Table A1. Data Description and summary statistics (2008 – 2016)

Variable	Description	Mean	Std. Dev.	Min.	Max.
Dependent variables					
Milk output	Output of milk ('000 litres)	676.29	665.49	44.96	5015.94
Beef cows	Number of beef cows	43.854	23.497	20.00	182.00
Ewe	Number of ewe	252.53	206.32	20.00	990.00
Main independent variable					
Decoupled payments	Decoupled payments ('000 £) per farm	22.95	17.85	0.43	169.04
Control variables					
Market revenue	Market revenue per hectare (£/ha)	1305.27	717.44	131.00	2995.57
Dairy revenue	Dairy revenue per hectare (£/ha)	2048.32	1169.10	637.98	2995.57
Beef revenue	Beef revenue per hectare (£/ha)	252.65	166.97	13.57	939.47
Sheep revenue	Sheep revenue per hectare (£/ha)	141.52	124.20	20.12	744.92
Costs	Cost of variable inputs per hectare (£/ha)	1184.65	836.24	55.60	4907.57
Other government payment	Other government payments per hectare (£/ha)	49.78	45.62	0.00	418.96
Age	Age of farmer (years)	57.73	12.67	21.00	88.00
Farm size	Net area farmed (ha)	93.95	94.20	5.50	850.40
Education : GSCE	= 1 if farmer has GSCE certificate	0.48	0.50	0.00	1.00
A-level	=1 if farmer has A-level certificate	0 .17	0.37	0.00	1.00
Higher education	=1 if farmer has higher education	0.04	0.18	0.00	1.00
Off-farm employment	=1 if farmer has off-farm employment	0 .35	0 .47	0.00	1.00
Asset value	Value of asset ('000£)	1347.10	850.87	46.66	8835.20
Family labour ratio	Share of family labour in total labour	0 .92	0 .12	0 .01	1.00
Rent ratio	Share of area rented in net area farmed	0 .24	0.24	0	1

A2. Empirical results

A2.1 First stage results

The estimates of the first stage of the Instrumental Variables Fixed Effect (IVFE) procedure are reported in Table A2, confirming the statistical relevance of our instruments on decoupled payments. The results show that, in all the equations, the one year and two year lagged decoupled payments per farm are statistically significant in explaining the variation of decoupled payments. The Cragg-Donald Wald F test for joint significance of all the instruments formally tests and provides empirical evidence of the relevance of the instrumental variables. Moreover, the joint significance test statistic, are substantially higher than the Staiger and Stock (1997) rule-of-thumb criterion that the F-value be at least 10 and we can conclude that the instruments are valid.

Table A2: IV First stage of estimation results: log Decoupled Payments

Variable	Milk output equation		Beef cows equation		Ewes equation	
Instruments	Coeff. (SE)	P value	Coeff. (SE)	P value	Coeff. (SE)	P value
One year lagged ln Decoupled Payments	0.595*** (0.078)	0.000	0.638*** (0.145)	0.000	0.646*** (0.096)	0.000
Two year lagged ln Decoupled Payments	0.148* (0.089)	0.098				
CD Wald F Statistics	103.140		224.660		215.904	
Sargan p value	0.645		0.000		0.000	

*Note: All the explanatory variables in equation (2) are included; The asterisks ***, ** and * indicate statistical significance at 1, 5 and 10% respectively; Sargan overidentification p>0.1 implies that we fail to reject the null hypothesis that the instruments are valid, not applicable with number of beef cows and number of ewe equation as the equations are exactly identified.*

A2.2 The impact of decoupled payments on milk output

In Table A3, we present the estimates of the impact of decoupled payments on milk output. We ran the regression using different specifications by allowing revenue to enter the model in different forms. Model [1] includes market revenue for all outputs while model [2] includes revenue from dairy output only (dairy cows plus milk output). Model [3] includes the three-year weighted average of market revenue and weighted average of overhead costs, whereas model [4] reports the estimation that includes the three-year weighted average of dairy revenue and weighted average of overhead costs.

Based on the empirical results reported in Table A3, all estimated decoupled payments and revenue coefficients have positive signs and are statistically significant suggesting that both the decoupled payments and revenue have significant stimulating impacts on milk output. Particularly with respect to model [1], the results show that receipt of decoupled payments is associated with an increase of about 0.24% in milk output while market revenue is associated with higher increase of about 0.41%. Similarly, in model [2] the results suggest that the positive impact of dairy revenue on milk output is about 1.7 times that of decoupled payments. When the market revenue and overhead costs are weighted as reported in model [3], decoupled payments and market revenue still retain their signs and significance. The elasticities of decoupled payments is 0.234 while that of weighted market revenue is 1.289, suggesting that the responsiveness of milk output to market return is about 5.5 times that of decoupled payments. The relationship is also reported in model [4] as the results show that the elasticities of decoupled payments is 0.267 and that of weighted dairy revenue is 1.118, suggesting that the impact of dairy revenue on milk output is about 4 times that of decoupled payments. Overall, the results indicate that the impact of decoupled payments was significant but with lower elasticities compared to market revenue, suggesting that milk production decisions are more guided by market determinants rather than the receipt of decoupled payments by dairy farmers. Other studies that found modest impact of decoupled payments include Serra *et al.* (2011) and Weber & Key (2012). Not surprisingly, the coefficient for the cost variable was found to be significant and negative in models [3] and [4] suggesting that milk output reduces with farm overhead costs. However, the results suggest that farmers are more responsive to changes in output returns than input costs. The estimates of the other covariates are also reported in the Table 3. We observe uniformities in the signs of the coefficients of the control variables across models [1], [2], [3] and [4], albeit with different significant levels.

A2.3 The impact of decoupled payments on beef production (number of beef cows)

Similar to Table A3, we report four model specifications with different revenue and costs variables for the beef cow equation (Table A4). Model [1] includes market revenue for all outputs while model [2] include revenue from beef output only. Model [3] includes the three-year weighted average of market revenue and weighted average of overhead costs, whereas model [4] reports the estimation that includes the three-year weighted average of beef revenue and weighted average of overhead costs.

The coefficients of decoupled payments across all the models as reported in Table 4 are positive and significant which imply that an increase in decoupled payments of 1% is associated with an increase in the number of beef cows, ranging from 0.13% to 0.15%. Similarly, the results across all the models also show that the coefficients of market and beef revenue are positive and significantly impact number of beef cows produced except in model [3] where it was found insignificant. The impact of revenue ranges from 0.13% to 0.19%. Specifically, the results reported in model [1] shows that the impact of revenue on the number of beef cows is about 1.1 times higher than the impact of decoupled payments. In contrast, the results of model [2] show that the positive impact of beef revenue on the number of beef cows is 1.3 times higher than the impact of decoupled payments. When the market revenue and overhead costs are weighted (as reported in model [3]) only decoupled payments was found to be significant, while weighted market revenue was not significant. In model [4], the results show that the elasticities of decoupled payments is 0.13 and that of weighted beef revenue is 0.19, suggesting that the impact of beef revenue on number of beef cows is about 1.5 times that of decoupled payments. The finding that the elasticities of beef revenue are significantly higher than the elasticities of decoupled payments, suggests that the production decisions by beef farmers are more guided by market conditions than direct payments. The cost and other government subsidies payments variables were found to be insignificant. With regards to the other control variables, we observe uniformities in the signs of the coefficients across all the models, but at different significant levels.

A2.4 The impact of decoupled payment on sheep production (number of ewe)

Similar to the other sectors, we report in Table 5 four model specifications with different revenue and cost variables for the sheep sector. Model [1] includes market revenue for all outputs, while model [2] include revenue from sheep output only. Model [3] includes the three-year weighted average of market revenue and weighted average of overhead costs whereas model [4] reports the estimation that includes the three-year weighted average of sheep revenue and weighted average of overhead costs.

The empirical results across all the models suggest a statistical relationship between decoupled payments and the number of ewes produced. The coefficients imply that a 1% increase in decoupled payments is associated with an increase ranging from about 0.23% to 0.26% in the number of ewes. The coefficient of market revenue and its weighted term in model [1] and model [3] respectively are found to be insignificant. However, the results of model [2] and model [4] show that sheep revenue and its weighted term are positive and significantly influence number of ewes. Comparing the impact of decoupled payments and revenue on number of ewes, our results suggest that decoupled payments have a greater production stimulating impact than revenue in the sheep sector. For example in model [2], the impact of decoupled payments is approximately 2 times that of sheep revenue, while in model [1] the impact of market revenue is negative and insignificant. The results for the other explanatory variables are consistent in signs although with differing significance levels, lending credence to our estimates.

Table A3. The impact of decoupled payment on milk output, 2008-2016

Variable	Market revenue & Cost	Dairy revenue & Cost	Three year Market revenue (weighted average)	Three year Dairy revenue (weighted average)
	(1)	(2)	(3)	(4)
Ln Decoupled payments	0.239**	0.324***	0.234**	0.267***
	(0.106)	(0.100)	(0.102)	(0.099)
Ln Market revenue	0.411***			
	(0.059)			
Ln Dairy revenue		0.564***		
		(0.054)		
Ln Dairy revenue *(3 year avg.)*				1.118***
				(0.079)
Ln Market revenue *(3 year avg.)*			1.289***	
			(0.094)	
Ln Costs	0.081	-0.008		
	(0.060)	(0.055)		
Ln Costs *(3 year avg.)*			-0.411***	-0.381***
			(0.084)	(0.068)
Other government payment	0.000	0.000	0.012	0.012
	(0.000)	(0.000)	(0.009)	(0.008)
Ln Asset value	0.154**	0.113*	0.220**	0.102
	(0.062)	(0.059)	(0.093)	(0.085)
Ln Age	-0.128	-1.903	-1.978	-3.742***
	(2.011)	(1.889)	(1.450)	(1.331)
Ln Age squared	0.033	0.268	0.264	0.488***
	(0.264)	(0.248)	(0.186)	(0.171)
Ln Farm size	0.213**	0.183**	0.333***	0.310***
	(0.098)	(0.093)	(0.099)	(0.090)
Off-farm employment	0.015	-0.001	0.025	0.028

	(0.034)	(0.033)	(0.031)	(0.032)
GSCE	0.021	0.020	0.001	0.001
	(0.042)	(0.040)	(0.031)	(0.029)
A-level	0.026	0.064	0.032	0.031
	(0.052)	(0.049)	(0.043)	(0.042)
Rent ratio	0.604***	0.640***	0.537***	0.424***
	(0.164)	(0.155)	(0.153)	(0.144)
Family labour ratio	-0.122	-0.149	-0.204*	-0.223*
	(0.114)	(0.108)	(0.123)	(0.121)
Observations	525	525	462	462
Number of farms	75	75	66	66

Robust Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A4. The Impact of Decoupled Payment on number of beef cows, 2008-2016

Variable	Market revenue & Cost	Beef revenue & Cost	Three year Market revenue (weighted average)	Three year Beef revenue (weighted average)
	(1)	(2)	(3)	(4)
Ln Decoupled payments	0.145**	0.134*	0.140*	0.127*
	(0.074)	(0.072)	(0.074)	(0.073)
Ln Market revenue	0.128**			
	(0.057)			
Ln Beef revenue		0.172***		
		(0.056)		
Ln Beef revenue *(3 year avg.)*				0.191**
				(0.086)
Ln Market revenue *(3 year avg.)*			0.097	
			(0.087)	
Ln costs	0.014	0.020		
	(0.057)	(0.057)		
Ln costs *(3 year avg.)*			-0.018	-0.048
			(0.091)	(0.092)
Ln. Other government payment	-0.024	-0.025	-0.021	-0.019
	(0.019)	(0.019)	(0.019)	(0.019)
Ln Asset value	0.171*	0.165*	0.181*	0.176*
	(0.094)	(0.093)	(0.101)	(0.099)
Ln Age	-1.951	-2.520	-2.384	-2.644
	(4.525)	(4.464)	(4.715)	(4.601)
Ln Age squared	0.193	0.260	0.249	0.278
	(0.592)	(0.584)	(0.615)	(0.600)
Ln Farm size	0.356**	0.416***	0.290**	0.349**
	(0.140)	(0.141)	(0.139)	(0.139)
Off-farm employment	-0.008	-0.009	-0.012	-0.014

	(0.031)	(0.031)	(0.032)	(0.033)
GSCE	0.152*	0.158*	0.159*	0.165**
	(0.081)	(0.082)	(0.083)	(0.084)
A-level	0.272**	0.278**	0.289***	0.287**
	(0.111)	(0.111)	(0.112)	(0.113)
Higher education	0.616***	0.645***	0.636***	0.659***
	(0.149)	(0.151)	(0.151)	(0.152)
Rent ratio	0.016	-0.006	0.023	-0.016
	(0.212)	(0.210)	(0.217)	(0.217)
Family labour ratio	-0.708***	-0.715***	-0.792***	-0.790***
	(0.226)	(0.224)	(0.233)	(0.230)
Observations	471	471	471	471
Number of farms	62	62	62	62

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A5. The Impact of Decoupled Payment on number of ewe, 2008-2016

Variable	Market revenue & Cost	Sheep revenue & Cost	Three year Market revenue average	Three year Sheep revenue average
	(1)	(2)	(3)	(4)
Ln Decoupled payments	0.242***	0.238***	0.232**	0.262***
	(0.090)	(0.087)	(0.094)	(0.091)
Ln Market revenue	-0.010			
	(0.051)			
Ln Sheep revenue		0.132***		
		(0.044)		
Ln Sheep revenue *(3 year avg.)*				0.189***
				(0.064)
Ln Market revenue *(3 year avg.)*			-0.044	
			(0.098)	
Ln costs	0.042	-0.022		
	(0.070)	(0.067)		
Ln costs *(3 year avg.)*			0.099	-0.020
			(0.106)	(0.094)
Ln. Other government payment	-0.017	-0.019	-0.016	-0.015
	(0.024)	(0.023)	(0.024)	(0.023)
Ln Asset value	0.101	0.066	0.170	0.052
	(0.083)	(0.081)	(0.115)	(0.082)
Ln Age	0.037	-0.127	-0.134	1.100
	(5.163)	(5.095)	(5.295)	(4.933)
Ln Age squared	0.141	0.169	0.164	0.015
	(0.677)	(0.668)	(0.695)	(0.647)
Ln Farm size	0.054	0.106	0.019	0.087
	(0.167)	(0.164)	(0.175)	(0.161)
Off-farm employment	-0.058*	-0.045	-0.063**	-0.040
	(0.031)	(0.033)	(0.031)	(0.034)

GSCE	0.021	0.009	0.021	0.022
	(0.068)	(0.064)	(0.068)	(0.066)
A-level	0.168**	0.161**	0.163**	0.185**
	(0.080)	(0.078)	(0.080)	(0.079)
Rent ratio	-0.039	-0.057	0.041	-0.046
	(0.346)	(0.342)	(0.376)	(0.346)
Family labour ratio	-0.635**	-0.565**	-0.622**	-0.574**
	(0.250)	(0.245)	(0.251)	(0.247)
Observations	460	459	460	460
Number of farms	58	58	58	58

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1