Loss-Making Marginal Spending on Crop Variable Inputs

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Abstract

AIM: Crop variable inputs (CVI's) are critical to successful crops. So we here ask: "What are the marginal returns to crop variable inputs?" And explore whether observed CVI levels maximise economic returns to farmers. We compare results to national aggregates in India.

DATA: Analysed Farm Business Survey 2004-2012, where crop gross margins and input spending are available, for conventional winter wheat and oilseed in England and Wales.

RESULTS: Marginal spending on variable inputs (e.g. seed, fertiliser, crop protection) returns in economic product significantly less than GBP£1 per marginal pound spent. Therefore, expenditure allocation on those inputs could be quite far from economic optima. However marginal physical products (yields) are positive, but small, and significantly different from zero. These conclusions hold across a wide range of alternative economic models and subsets of the data. The same conclusions are observed, in estimations for Indian grain production, and for maize in China where lower national rates of fertiliser application appear optimal.

DISCUSSION: Unknowns, including yield, quality and price, make it difficult to optimise *ex ante* input levels. Tied advice could reduce the efficiency in the farm sector - owing to possible perverse incentives. And the preferences of farmers, may be to avoid risk, or to maximise yields. Farmers may also be biased - relative to full information and perfect competition. All of which might distort prices from the neoclassical equilibria with perfect information and perfect competition. Thus, one could ask "How useful are the prices seen in practice, for allocation in the context of the farmer behaviour reported here?"

Keywords Marginal Products, Marginal Profit, (Efficiency Ratios, Factor Coefficients, Factor Elasticities), Farm Variable Inputs, Fertiliser Use, Agricultural Productivity, Farm Enterprise Management, Farm Firms, Wheat, Oilseed Rape, England and Wales

JEL code

Q12	Micro Analysis of Farm Firms, Farm Households, and Farm Input Markets
Q120	Agricultural Management, Agricultural Productivity, Farm Enterprise, Farm Firms, Farm Input Markets, Fertiliser Use, Wheat, Oilseed Rape

INTRODUCTION:

Crop production depends on variable inputs - for example as seeds, nitrogen and fungicides. The levels of these inputs are varied by farmers in proportion to the level of production. And these incur costs (if only in terms of the costs of physical resources in the economy, where for example there are large subsidies), which are termed the "Variable Costs of Production" (Barnard and Nix 1979). The level of profitability and bountiful nature of crop production critically depends on their levels (Van Alfen 2014; Lawes and Gilbert 1879; Cato, cited in Campbell 2000).

For example, in the 2012 harvest year, in production of conventional winter wheat in England, variable costs (VC) accounted for 41 per cent of crop economic output (CEO). The resulting Gross Margin (GM=CEO-VC) was 59 per cent of crop economic output. Which, after deducting a further 51 per cent of crop economic output for fixed costs (which are incurred irrespective of levels of production), clearly leaves farm net profit in wheat production extremely sensitive to levels of variable costs (in this year being 8.3 per cent of CEO, Lang 2014).

In standard teaching farmers are assumed to increase the quantity of an input until the Marginal Value of the Product is equal to the Marginal Cost (MVP=MC) (Barnard and Nix 1979; Olson 2004; IFIA 2007; Defra 2010).

However in practice, the economic literature (e.g. Sheriff 2005), and effects on water bodies (Carpenter *et al* 1998), suggest that fertiliser applications can be excessive, relative to ecological and financial optima. This implies that, from a policy perspective, current spending, on fertilisers and other variable inputs, may not be optimal (either in terms of farm economic optimisation or in terms of social costs).

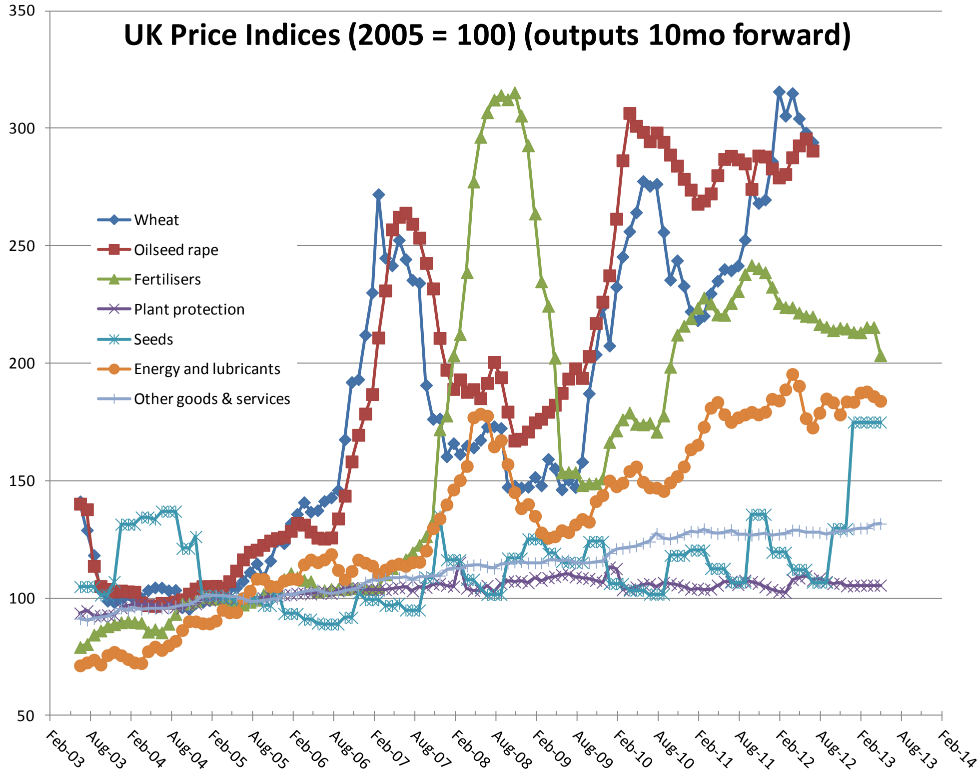
To achieve the objectives of the Water Framework Directive of the European Union (EU), a decrease in diffuse pollution is required. So the "Socially Optimal N-Rate", determined by the European Nitrogen Assessment, was estimated to be at least 50 kgN/ha less than the "Privately Optimal N-Rate" for cereals in Northern Europe (Brink and van Grinsven 2011) - which could incur a 20 percent yield penalty (Brink and van Grinsven 2011). Hence it will be interesting to know the current profitability of variable inputs - so as to explore the possible effects, on farm incomes and physical production, of reduced input levels. (So we ask if MVP=MC).

Swedish farmers, at peak of post-war technical change in farming in the context of strong policies to boost production, were estimated to achieve marginal products of 3.5-to-2.1$ per marginal $1 of fertiliser expenditure (Heady and Dillon 1961). Given public desire to reduce pollution (which may mean lower profitability of inputs is seen as desirable) it seems likely that the marginal returns will have declined substantially in the decades since then.

Thus, in current Chinese maize cultivation, it was estimated that farmers could increase profits, and save $50/hectare in variable cost for nitrogen, at the level of recommendations for national aggregate fertiliser rates, by applying an average of 67kg/ha (30%) less nitrogen than average farmer practice (224 kgN/ha maize, Xu *et al* 2014) - based on 408 trials over 2010-2012, in the prime maize growing region of eastern seaboard states.

And, globally, it is estimated that current world cereal production could be achieved, with approximately 50 per cent less nitrogen (Mueller *et al* 2014), if application rates were optimised across the world. Under which scenarios, Mueller *et al* (2014) estimates for England nitrogen applications would decrease by 27% - from an assumed (and perhaps questionable, in light of BSFP 2014) average across all grains in the year 2000 of 127kgN/ha. Similarly, in a sample of farmer maize crops in Indonesia, the optimum fertiliser application was measured to be 12kgN/ha (7.5%) less than farmer practice - however, given the variability experienced, this could have been due to random error (Pampolino *et al* 2012). Still, in many countries fertiliser applications are still suboptimal[1]. For example, in maize tested at 7 sites and 31 farmers over 2010-2011 in the Philippines, optimised fertiliser applications may return as much as $6 per $1 farmers invest in fertilisers (Pampolino *et al* 2012).

Figure 1. Recent trends in UK agricultural prices.



Source: Defra, APIMonthly 2014

Prices of agricultural products, as well as prices of inputs, fluctuate widely (Figure 1). This means that it is mostly very difficult for farmers to optimise inputs and outputs *ex ante* (before the outcome), because forward production, prices and quality, are all uncertain. What performance, in terms of optimising spending in the two main crops (conventional wheat and oilseed rape) over 9 years, do farmers achieve on aggregate?

The returns achieved by farmers, from spending on variable inputs, will also provide an indication of their preferences (for the environment, utility, risk and optimism). Which are also of great importance to policy makers. Who might seek, for example under the Water Framework Directive of the EU, to reduce the costs of potentially excessive applications - that are not incurred by the farmers responsible. That is to say the Pigouvian "negative

[1] This is accounted for in Mueller *et al* (2014).

externalities" of crop production (which occur when a cost is bourne by 3rd parties who do not bring that cost into existence). Which are accounted for in the "Socially Optimal N-Rate" (Brink and Van Grinsven 2011).

And if farmer behaviour does not conform to the neoclassical/standard model, we might question the usefulness of the resulting market prices. As incentives and to inform resource allocation.

Hence, in light of possible over-application of variable inputs (from the economists' perspective, and relative to "global optimisation" (Mueller 2014) or to "social optima" (Sutton *et al* 2011)) suggested in the literature, for wheat and oilseed production in England and Wales, we measure the marginal returns from spending on variable inputs. Are farmers maximising yields? Does MVP=MC?

DATA:

Data were drawn from the Farm Business Survey (Defra 2014), which is a stratified, random unbalanced, panel survey. Of farm businesses, that have substantial agricultural output (more than EUR€25,000 in 'Standard Output') and generally have a labour input of between 0.5 and 3 full-time-equivalents in England and Wales. The analysis uses derived variables and measures of: Gross Margins (GM's), yields, and variable costs - of conventional winter wheat and conventional winter oilseed rape over the harvest years 2004 to 2012 (Table 1).

Winter Wheat: Mean total area of crop sown was 83.7 hectares (all of which were conventional crops) and mean grain yield per farm business was 8.64 tonnes per hectare for (Table 2.) - not one crop on any one farm in one year had zero economic output (and so no crops were arbitrarily excluded). *Winter Oilseed Rape*: Mean total area of 51.0 hectares and mean average yield 3.46 tonnes per hectare for (Table 3.) per farm business - of which only 1 crop in one year on one farm had zero economic output (which, for Log_CropEO_ha, 0.5 GBP was arbitrarily added to the output per hectare).

Given an average size of these farms (while acknowledging wide variation) of 201 hectares, and utilised agricultural area of 194 hectares, this sample is very representative of the typical cropping patterns in English grain production, where cereals farms had in 2012 a mean area of 200 hectares with 75 hectares of wheat (Lang 2014).

All financial values were deflated to 2012 using standard GDP deflators from UK HM Treasury.

Table 1. The FBS sample for gross margins 2004-2012.

	Conventional Winter Wheat	Conventional Winter Oilseed Rape
Crops (of one arable conventional crop species on one farm in one year)	6,314	3,090
Farms	1,595	846
Years (2004/5-2012/13)	up to 9	up to 9
Farms with >= 4 years observations	751	360

Table 2. Descriptive statistics for the winter wheat.

Wheat variable	Mean	Median	Minimum	Maximum	Standard deviation	Standard error of mean	Skewness	Kurtosis
ha_Prod (t/ha)	8.642	8.736	0	15.37	1.871	0.0236	-0.385	0.339
Area (ha)	83.79	47.64	0.5	2009	120.1	1.511	5.004	42.87
ha_GM (£GBP/ha)	706.3	669.1	-396.7	2352	314.1	3.952	0.509	0.346
ha_CropEO	1024	989.5	129.7	2365	318.9	4.014	0.383	-0.104
ln_haCropEO	6.879	6.897	4.865	7.769	0.333	0.00419	-0.648	1.261
log_haCropEO	2.988	2.995	2.113	3.374	0.145	0.00182	-0.648	1.261
ha_Ferts	152.7	138.4	0	656	73.07	0.92	1.078	2.169
ha_Protects	149.1	146.3	0	743	50.64	0.637	0.752	5.914
ha_Seeds	56.45	53.42	0	394	22.71	0.286	1.736	13.21
ha_OtherCropC	25.76	11.02	0	448.3	40.98	0.516	2.995	11.82
btw_Fert_ha	152.7	150.4	0	656	50.84	0.64	0.48	3.227
btw_Protect_ha	149.1	147.6	0	387.8	39.13	0.492	0.0783	1.772
btw_Seed_ha	56.45	54.83	0	318.1	15.75	0.198	1.521	15.12
btw_Othr_ha	25.76	13.85	0	220.1	33.61	0.423	2.415	6.563
wi_Fert_ha	0	-2.552	-245.1	340.5	52.48	0.66	0.903	2.606
wi_Spray_ha	0	0	-201.4	516.1	32.14	0.405	1.526	21.63
wi_Seed_ha	0	0	-81.05	296.8	16.36	0.206	1.553	20.88
wi_Othr_ha	0	-0.0597	-199.4	368	23.44	0.295	2.173	27.04
WeightAll	32.78	29.31	0	253.4	20.93	0.263	1.842	7.379

Source: Farm Business Survey (Defra 2014)
Notes: Production is in tonnes per hectare sown, others in £GBP/hectare (or logarithms - where specified). n=6,314. Ha_[input] are per hectare figures for all variation, btw_ are between farms variation in mean farm spending, wi_ are individual farms deviations from individual farm means.

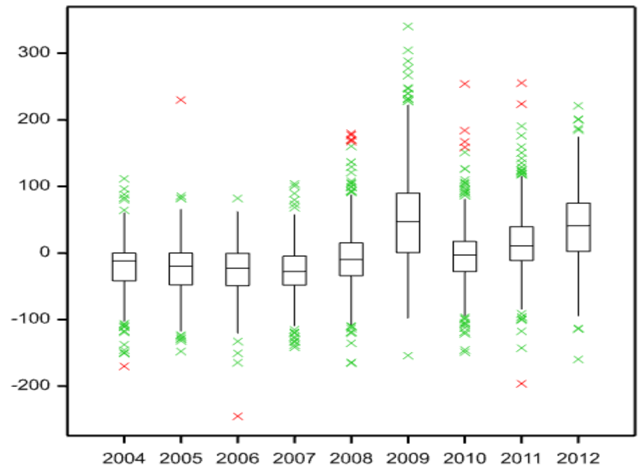
Table 3. Descriptive statistics for the winter oilseed rape.

Oilseedrape variable	Mean	Median	Minimum	Maximum	Standard deviation	Standard error of mean	Skewness	Kurtosis
Area (ha sown)	50.99	33.32	1.31	525.9	55.53	1	3.2	14.56
Production (t)	180.1	113.8	0	3394	212.7	3.827	4.02	29.8
ha_Prod (t/ha)	3.457	3.516	0	9.942	0.835	0.015	-0.215	1.841
CropEO	53120	31380	0	921878	68295	1229	4.123	26.74
ha_GM	626.8	571.5	-1220	2019	363.4	6.537	0.577	0.414
ha_CropEO	1007	943.6	0	2293	400.7	7.209	0.543	-0.174
Log10_CropEO_ha	2.966	2.975	-0.301	3.36	0.195	0.0035	-2.03	25.97
ha_Ferts	168.9	153	0	738.4	73.58	1.324	1.131	2.387
ha_Protects	145.5	138.1	0	479.4	55.35	0.996	0.824	1.592
ha_Seeds	46.16	44.06	0	735.7	26.43	0.476	7.822	166.4
ha_OtherCropC	21.04	12.67	0	537.5	27.93	0.502	4.218	45.17
btw_Ferts_ha	168.9	163.3	0	738.4	50.57	0.91	1.079	7.049
btw_Sprays_ha	145.5	140.7	0	479.4	42.23	0.76	0.784	2.326
btw_Seeds_ha	46.16	44.77	0	735.7	20.28	0.365	13.19	432.7
btw_OtherCC_ha	21.04	15.5	0	233.2	21.71	0.391	2.338	9.487
wi_Ferts_ha	0	-1.237	-174.6	271.6	53.45	0.961	0.754	1.534
wi_Sprays_ha	0	0	-212.9	218.5	35.78	0.644	0.23	2.482
wi_Seeds_ha	0	0	-89.12	270.7	16.96	0.305	3.496	47.15
wi_OtherCC_ha	0	-0.0148	-175.5	350.8	17.57	0.316	2.763	64.77
WeightAll	33.16	30.16	0	212.8	19.5	0.351	2.031	8.52

Source: Farm Business Survey (Defra 2014)
Notes: Production is in tonnes per hectare sown (t/ha), Area is in hectares (ha), others in £GBP/hectare (or logarithms - where specified). n=3,090. Ha_[input] are per hectare figures for all variation, btw_ are between farms variation in mean farm spending, wi_ are individual farms deviations from individual farm means.

There do not appear to be systematic bias, or consistent trends, in relative prices of crops input and outputs (Figure 1.) Equally there does not appear to be systematic bias, or consistent trend, in relative spending on inputs. For example, Figure 2. shows the distribution, of farm deviations from individual farm mean spending in winter wheat on fertilisers, across the time series.

Figure 2. Distribution of farm deviations from individual farm mean spending in winter wheat on fertilisers*, by years.



* £GBP per hectare

METHOD:

Panel data can be analysed, using the methodology of Mundlak (1961), to obtain coefficients for the effects that are of interest, in a way that is "free of management bias" and also to control for other sources of unobserved heterogeneity. In other words, free of the bias from permanent factors specific to an individual farm - like soils, aspect and location, education, skill and so forth. And also from those factors specific to each year.

This is done by incorporating "fixed effects" for each farm and for each year (dummy variables), and then by analysing the "within farms" variation (which is defined below). We use the fixed effects estimation because there is the need to control for omitted variables and because it is expected that some of the variables not considered (and therefore in the error term) might be correlated with the independent variables (e.g. management, and other variables that might affect the use of inputs, subsidies, and so forth) (Brooks 2014; Angrist and Pischke 2009; Chavas *et al* 2010).

Hence, for the linear case, the within farm variation (in spending on crop-variable-inputs), with fixed effects for firms and years, is given as:

$$\text{Output}_{ti} = a + b_1{*}\mathbf{Ferts} + b_2{*}\mathbf{Sprays} + b_3{*}\mathbf{Seed} + b_4{*}\mathbf{Othr} + c_t{*}\text{Year}_t + c_i{*}\text{Farm}_i + e_{it}$$

Where the dependant variable is Output per hectare (in year t, on farm i). Being either Crop Gross Margin (GM) (£ per hectare), or Crop Yield (Yld) (kilograms per hectare). Which were regressed on farm deviations, from the mean spending rate of each individual farm - for fertilisers (Ferts); all crop protection (Sprays); seeds (Seed); and other crop minor variable costs (such as baling twine or packaging, but which do not include heating and drying costs or fuel, because spending on fuel for machinery is not allocated to crops in the FBS) (Othr).

Spending variables in the above are expressed as "individual-farm-deviations" from the "individual-farm-mean", in £ per hectare. That is to say "within farm variation" in spending per hectare - eg a series of [$Fert_{ti}$ minus Mean_$Fert_i$]. Year and Farm effects ($Year_t$ and $Farm_i$), are dummy variables for each respective degree of freedom (t-1 and i-1) (to average out variation between years, and between farms). And e_{it} is the residual variation (Farms*Years).

These $b_{1\text{-}4}$ are thus the linear effects (coefficients) (because they are the return to changes in spending on these inputs at the margin, and are thus the tangents to the aggregate production function) - for GM or Yld - of "an additional one £GBP per hectare spent on that particular Crop Variable Input" - beyond the individual farm mean, averaged across years and farms. So, these coefficients are for "marginal profit" (Gross Margin), or "marginal physical product" (Yield), per "marginal cost". (That is the return from a unit increase beyond "individual farm mean" levels of input-spending).

While this is a production function (in the sense that we calculate effects of production factors on output), for unobserved factors of production[2] (the omitted variables), it depends on terms that are specific to each individual farm. And the specific effects derived and discussed here are marginal effects.

It should be noted that other specifications were also tested. Namely: translog, quadratic, and within years between farms with proxies[3] for known variation in farm characteristics (so, in that case, residual variation was farm). And all-inputs-variation (that is between-farms variation in farm-mean spending) were similarly modelled.

The regressions are assumed to be independent of scale effects, because the factors of interest are costs which "vary in direct proportion to the scale of the enterprise" (by definition) (Barnard and Nix 1979) - termed "Variable Costs". And here are expressed per unit area (hectares) of sown land. This is the dimension that is used, and understood, by farmers. And is also the correct dimension in which to analyse the effect of changing the *rates* of spending on these variable costs.

Hence we do not, here, investigate the substitutability of land, labour, machinery and fertilisers (Clark *et al* 2013). Which analyses are more on fixed factors that, over the short term, are not subject to farmer intervention and do not vary. So their coefficients are seen in the fixed effects for each farm.

Trend components are not assessed or tested here.

Regressions were estimated with and without (population) weights (Defra 2014) (which increased standard errors by around 2% for the coefficients that are of interest).

[2] which are taken into account by the fixed effects, for each farm and for each year

[3] proxies for farm effects (educ/ lfa/ robusttype/ StdLabourSize/ Country/ FBSregion/ DiversificationSizeBand/ Tenure/ HasLivestock-yn/ Spouse/ UAA/ woodland/ Log10-LandExpenses)

RESULTS:

Marginal coefficients for GM, of spending an extra unit on Ferts/Sprays/Seed/Other beyond the individual_farm_means, are all loss making (that is: the marginal GM is negative because marginal costs exceed marginal returns) and significant (Tables 4 & 6). Robust to other specifications (Table 5). Marginal coefficients for physical production (yield) are small, but positive, and significantly different from zero (Tables 4 & 6).

Table 4. Standard analysis for conventional winter wheat*.

Deviations included		**Regression**		
	Model	**gm_wi_1**	**eo_1**	**yld_wi_1**
Regression constant		816 (199) <.001	1,009 (189) <.001	11,892 (1,186) <.001
	Dep. Variable	Marginal profit (£)	Marginal product (£)	Marginal yield (kg)
w/i farms	Fertilisers	-0.8905 (0.0642) <.001	0.1548 (0.061) 0.011	1.193 (0.383) 0.002
w/i farms	Crop protects	-0.5641 (0.0871) <.001	0.4068 (0.0827) <.001	3.401 (0.52) <.001
w/i farms	Seed	-1.023 (0.168) <.001	-0.088 (0.16) 0.581	0.14 (1) 0.891
w/i farms	Other	-0.446 (0.108) <.001	0.503 (0.103) <.001	2.944 (0.645) <.001
	Years	yes p<.001	yes p<.001	yes p<.001
	Farms	yes	yes	Yes
	Proxies	no	no	No
	reg df	1608	1608	1608
	N	6314	6314	6314
	pseudo r²	60.0	65.0	59.9
	s.e.o.	199	189	1,186

* Effects are in £GBP/hectare with Gross Margin (GM) and marginal economic product (EO), or kg Wheat Harvested per hectare sown that is to say the "marginal physical product" (Yld) as the dependent variables, per pound sterling of marginal spending. Fixed effects are included for Years and Farms (both Wald p<.001). Standard Errors (s.e.'s) are in parentheses.

Table 5: Alternative specifications for winter wheat (with marginal products estimated at central values)

Deviations included		Regression			
	Model	logEO_1	log_log (MEP)	wts_wi_1	4yr_wts_wi_1
Regression constant		3.0039 (0.0834) <.001	3.0843 (0.0897) <.001	811.7 (98.4) <.001	816.4 (98.6) <.001
	Dep. Variable	Marginal product	Marginal product	Marginal profit	Marginal profit
w/i or all	Fertilisers	0.0915 (0.0276) <.001	0.0337 (0.0202) 0.001	-0.9037 (0.0644) <.001	-0.9127 (0.0688) <.001
w/i or all	Protects	0.1917 (0.0374) <.001	0.0095 (0.0187) 0.52	-0.4944 (0.0908) <.001	-0.5584 (0.0975) <.001
w/i or all	Seed	-0.0241 (0.0723) 0.739	0.1652 (0.0997) 0.002	-0.972 (0.177) <.001	-1.259 (0.193) <.001
w/i or all	Other	0.2406 (0.0465) <.001	0.0484 (0.0288) 0.001	-0.403 (0.108) <.001	-0.449 (0.115) <.001
	Years	yes p<.001	yes p<.001	yes p<.001	yes p<.001
	Farms	Yes	yes	Yes	yes
	Proxies	No	no	No	no
	reg df	1608	1608	1578	750
	n	6314	6314	6163	4732
pseudo r²		66.7	66.5	60.3	61.2
	s.e.o.	0.0834	0.0837	1141	142

* Effects are in £GBP/hectare, regressing Log10 of Economic Output (LogEO), Marginal Economic Product (MEP) of translog for LogEO (central estim), standard regression of GM weighted with population weights (wts), and standard regression of GM using only farms with 4 or more data points (4yr). Fixed effects are included for Years and Farms (both Wald p<.001). Standard Errors (s.e.'s) are in parentheses.

Table 6. Standard regressions for conventional winter oilseed rape.

Deviations included		Regression	
	Model	WOSR-gm_wi_1	WOSR-Yld_wi_1
Regression constant		779 (224) <.001	3659 (647) <.001
	Dep. Variable:	Marginal profit (£)	Marginal yield (kg)
w/i farms	Fertilisers	-0.689 (0.105) <.001	0.849 (0.303) 0.005
w/i farms	Crop protects	-0.222 (0.132) 0.092	2.986 (0.382) <.001
w/i farms	Seed	-1.574 (0.246) <.001	-1.174 (0.713) 0.1
w/i farms	Other	-0.237 (0.23) 0.303	2.6 (0.665) <.001
	Years	yes p<.001	yes p<.001
	Farms	Yes	yes
	Proxies	No	no
	reg df	859	859
	N	3090	3089
	pseudo r²	62.1	39.9
	s.e.o.	224	647

* Effects are in £GBP/hectare with - Gross Margin (GM) -, or in kg Grain Harvested per hectare sown - marginal physical product (Yld) - as the dependent variables. Fixed effects are included for Years and Farms (both Wald p<.001). Standard Errors (s.e.'s) are in parentheses.

Table 7. Within farm variation in spending on conventional winter wheat - effects within years between farms (so residual variation is farm).

GM is dependent variable	**Within farm deviations in variable inputs spending only**								
Variable \ Year	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**
Constant	845 (116) <.001	890 (111) <.001	1082 (117) <.001	517.4 (73.4) <.001	551.8 (91) <.001	858 (123) <.001	437 (71.7) <.001	304.6 (61.4) <.001	667.7 (59.4) <.001
Fertilisers	-0.512 (0.252) 0.042	-0.635 (0.243) 0.009	-0.328 (0.274) 0.232	-0.941 (0.112) <.001	-0.856 (0.206) <.001	-1.107 (0.352) 0.002	-0.504 (0.206) 0.015	-0.552 (0.169) 0.001	-0.383 (0.171) 0.025
Crop protection	-0.691 (0.322) 0.032	-0.212 (0.353) 0.548	-0.57 (0.423) 0.178	-0.476 (0.222) 0.033	-0.334 (0.297) 0.262	-0.647 (0.437) 0.14	-0.42 (0.264) 0.112	-0.604 (0.217) 0.005	-0.467 (0.203) 0.022
Seeds	0.559 (0.717) 0.435	-2.02 (0.711) 0.005	0.21 (0.734) 0.775	-1.015 (0.362) 0.005	-1.004 (0.585) 0.087	-1.141 (0.809) 0.159	-0.658 (0.516) 0.203	-0.413 (0.43) 0.338	-0.6 (0.427) 0.16
Other crop variable costs	-0.334 (0.512) 0.514	-0.612 (0.427) 0.152	-0.527 (0.515) 0.307	-0.742 (0.271) 0.006	-0.666 (0.289) 0.021	0.794 (0.552) 0.151	-0.32 (0.352) 0.364	0.062 (0.283) 0.827	-0.145 (0.29) 0.616
UtilisedAgArea	-0.012 (0.109) 0.91	-0.2109 (0.097) 0.03	-0.12 (0.103) 0.245	0.0236 (0.0633) 0.71	0.096 (0.0864) 0.267	-0.024 (0.101) 0.812	-0.0449 (0.0663) 0.498	0.0191 (0.0583) 0.743	0.0026 (0.0652) 0.968
Proxies†	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	717	697	694	674	732	675	675	702	747
pseudo r^2	6.0	14.3	10.0	20.1	19.2	6.9	6.2	10.7	10.3
s.e.o.	299	270	277	178	234	288	169	142	140

Effects are in £GBP/hectare, with Gross Margin (GM) as the dependent variable. †Proxies were included (for: Farmer-Educucation/ Less-Favoured-Areas/ Robust-Types/ Standard-Labour-Size/ Country/ FBS-Region/ Diversification-Size-Band/ Tenure/ Has-Livestock-yn/Has-Spouse-yn/ Woodland/ Log10-Land-Expenses) Standard Errors (s.e.'s) are in parentheses.

Table 8a. Exploration of peas or beans in preceding year (2005-2012), and all milling wheat (2009-2012), marginal effects on wheat profit and physical product.

Deviations included		Regression			
	Model	gm_wi_PrvYrPulse	yld_wi_PrvYrPulse	gm_wi_MillingWheat	yld_wi_MillingWheat
Regression constant		-31 (206) 0.882	6883 (1170) <.001	866 (112) <.001	10018 (592) <.001
Dep. Variable		Marginal profit (£/ha)	Marginal yield (kg/ha)	Marginal profit (£/ha)	Marginal yield (kg/ha)
w/i farms	Fertilisers	-0.9096 (0.0736) <.001	1.119 (0.419) 0.008	-0.779 (0.103) <.001	2.073 (0.547) <.001
w/i farms	Protects	-0.584 (0.102) <.001	3.286 (0.581) <.001	-0.724 (0.155) <.001	1.709 (0.82) 0.037
w/i farms	Seed	-0.941 (0.196) <.001	0.17 (1.11) 0.88	-0.742 (0.289) 0.01	1.81 (1.53) 0.236
w/i farms	Other	-0.454 (0.124) <.001	3.08 (0.708) <.001	-0.311 (0.204) 0.128	4.62 (1.08) <.001
Peas/beans (t-1)		11.2 (11.2) 0.317	102.6 (63.5) 0.106	-	-
All milling wheat		-	-	64.1 (36.3) 0.078	96 (193) 0.617
	Years	yes p<.001	yes p<.001	yes p<.001	yes p<.01
	Farms	Yes	yes	Yes	Yes
	reg df	1303	1303	1029	1029
	n	4948	4948	2782	2782
	pseudo r^2	61.4	60.4	56.7	54.9
	s.e.o.	205	1167	222	1179

* As previously annotated. Respectively with dummy variable for presence of peas or bean crops on farm in preceding crop year (PrvYrPulse) , or for "Does not grow milling wheat (NABIM group 1)" (MillingWheat), relative to "No milling wheat grown". Fixed effects were included for Years and Farms (both Wald p<.001). Standard Errors (s.e.'s) are in parentheses.

Table 8b. Regressions of data subsets: all with peas or beans in preceding year (2005-2012), and only all milling wheat (2009-2012), marginal effects on wheat profit and physical product.

Deviations included		**ONLY WITH PULSE IN PRECEDING YEAR***		**ONLY MILLING WHEAT†**	
	Model	**gm_wi_PrvYrPulse**	**yld_wi_PrvYrPulse**	**gm_wi_MillingWheat**	**yld_wi_MillingWheat**
Regression constant		533 (185) 0.004	11575 (1051) <.001	397 (155) 0.013	6426 (759) <.001
Dep. Variable		Marginal profit (£/ha)	Marginal yield (kg/ha)	Marginal profit (£/ha)	Marginal yield (kg/ha)
w/i farms	Fertilisers	-0.954 (0.149) <.001	0.438 (0.848) 0.606	-1.083 (0.443) 0.018	1.64 (2.17) 0.453
w/i farms	Protects	-0.693 (0.218) 0.001	4.77 (1.24) <.001	0.033 (0.967) 0.973	4.81 (4.74) 0.314
w/i farms	Seed	-0.672 (0.408) 0.1	0.24 (2.33) 0.917	-0.18 (1.64) 0.915	11.59 (8.05) 0.155
w/i farms	Other	-0.206 (0.276) 0.456	6.16 (1.57) <.001	0.147 (0.957) 0.878	9.9 (4.69) 0.039
Peas/beans (t-1)		yes	Yes	-	-
All milling wheat		-	-	Yes	Yes
	Years	yes p<.001	yes p<.01	yes p<.001	yes (p is variable)
	Farms	yes	Yes	Yes	Yes
	reg df	558	558	88	88
	n	1476	1476	145	145
	pseudo r^2	66.3	65.3	61.2	61.2
	s.e.o.	183	1041	214	1047

As previously annotated. * These use only "individual farm deviations within this sample". † These use deviations from "all time individual farm means" (not just "deviations within this sample")

When the sample is "only wheat - on a farm with peas or beans in preceding year", marginal losses were much the same (differences are less than 2x the s.e.), although slightly larger - being a loss on marginal fertiliser spending of GBP£ -0.95 compared to a loss of GBP£ -0.91 for the all wheat crops sample (Tables 8a and 8b). And yields appear to be maximised, from marginal spending on fertilisers and seeds (but, for crop protection and other, marginal physical products are positive and significantly different from zero, although still relatively small) (Table 8b). The same is seen when terms are included, in overall wheat regressions, for PrecedingYear-PeasBeans, or for MillingOnly (Table 8a). And, when the sample is only "Milling Wheat" (which likely receives much more attention of agronomists, and higher rates of inputs) all coefficients, except other, indicate yield maximisation (being not significantly different from zero) (Table 8b).

In World Bank functions for Indian grain production, returns are estimated here to be small - with marginal production being of *circa* 0.45Rs of cereals/ per Rs of fertiliser spending (that is to say a loss of 0.55Rs/Rs at the margin) (author calculations based on averages for the breadbasket areas of "High Yield - Not Growing Production"). Similarly our figures for England and Wales suggest a marginal value of product of only GBP£0.1-to-0.3 per GBP£1 of marginal fertiliser spend.

DISCUSSION:

Why are marginal profits negative?

The evidence seems to suggest that farmers are maximising yields, relative to rates of input spending. Rather than applying more of the input until MC=MVP, as assumed in the standard models and teaching. That is to say MPP is close to zero, but positive.

Tied advice. Independent advice is only used by a minority of farmers in the UK (so many others use tied advice - which is often called "free" advice - the costs of which are actually bundled into the input prices). Thus independent advice "accounts for [only] around 40% of the arable area and consists of 244 advisors - [where the] farmer buys the advice at face value usually in a payment per hectare or per visit"[4]. In a large part, of the remaining portion (60%), of arable area in the UK, the company advising the farmer will mostly receive more revenue, by advising higher application rates - a potentially perverse incentive.

Prophylactic N-applications may sometimes be made to try to ensure the minimum protein content (13 per cent) to meet the standard for milling wheat (CAM-Grain pers. comm.).

The standard fertiliser recommendation (Defra 2010) - RB209 - for average wheat fertilisation is the amount of N required to achieve the 98th percentile of average maximum yield (Ymax) (versus N applied). This corresponds very closely to the 5 year average application rate on winter wheat in Britain (BSFP 2014; 185 kgN/hectare). Clearly, given random variation, this means that many applications will be well in excess of Ymax - especially if farmers are averse to yield losses (ie "risk averse"). The IFIA (2007) recommend applications at similar levels of the response curves.

Thus in many site-by-year combinations a nil response to N is seen. For example, 13 out of 30 (45%) site-by-year combinations, in trials at 15 sites over 2005-2007, gave no response to N (by author scans of Sylvester-Bradley *et al* 2008). In such "site*years" N-applications will, clearly, incur substantial losses. Such situations can arise, for example, where the crop follows a heavily fertilised crop of intensive potatoes, carrots, onions or other field-scale vegetables, or a nitrogen fixing crop (such as peas or beans). Or where a different nutrient is limiting yield - a point that may often be unknown to farmers.

Mistakes, such as applying a non-limiting nutrient, or applying a prophylactic spray for a blight that does not eventuate, will also incur large losses. And, if the response curve is fairly flat, will not gain much, when averaged across years.

Subsidies, to farmers in Europe, are of the order of EUR€230 per hectare, each year, under the EU Common Agricultural Policy. Input suppliers may gain some of this support (Lambert 2012), through economic processes (such as a decrease in the marginal utility of income, or a gain in the marginal utility of production, given the certainty of EU payments).

Reasons for (apparent) over-application of inputs are reviewed by Sheriff (2005). These include: i) The perceived relevance of recommendations to "my farm", to "my county", and to "this year" (be they official - such as in the UK RB209 - Defra 2010, or commercial such

[4] Chair of the Association of Independent Crop Consultants (AICC), Patrick Stephenson, http://landbridgeblog.blogspot.co.uk/2014/10/why-farmers-need-agronomists-but-which.html

as IFIA 2007), where farmers believe the recommendation is too conservative or pessimistic; ii) Substitutability of limiting factors (where a farmer might apply extra nutrients where yields are limited by rainfall, and the farmer is optimistic about rain); iii) opportunity costs (for example: time in autumn, the convenience of "with seed" applications of nutrients or pesticides, or application of standard mixes of fertiliser nutrients); and iv) uncertainty (especially in the context of large potential losses and small costs).

And in the same logic, to quote Rajsic and Weersink (2008), "the decision to apply more than average to take advantage of the good years is appropriate since the cost of over-application is low compared to the cost of under-application". However, it should be noted that, in the current study, in no single year were the marginal effects of within-farm-deviations profitable when averaged across farms within each year (Table 7). And optimism about expected returns (yield, quality and market) will have the same consequence (Rajsic, Weersink and Gandorfer 2008).

Nitrogen applications - when averaged across the whole of the production function - are quite profitable in Northern Europe. With profits from N-application being EUR€ 0.4 to EUR€ 2.7 per *average* kilogram of N applied (Brink and van Grinsven 2011), and GBP£2.46 per *average* kg of N applied seen here in England and Wales. These contrast strongly with the *marginal* profits, seen here, from the last (or tangent) GBP of spending. Where, at the *margin*, we observe losses on fertiliser spending of nearly GBP£ 0.7 to 0.95

What others have said & seen:

In Sweden in the 1950/60's farmers were incentivised with good returns (Heady and Dillon 1961). However, in China and Indonesia, today farmer practice is suggested to exceed economically optimal input rates (as discussed in the introduction). Similarly, in World Bank functions for the main grain producing areas in India, returns are very small. With marginal production losing say 0.55Rs/Rs spent on fertiliser (at the margin). Our figures are comparable, with a marginal value of product of only GBP£0.1-to-0.3 per GBP £1 of marginal fertiliser spend.

Weaknesses and Limitations:

Prices/De-trending: Input and output prices, while adjusted for UK inflation are not detrended here. That is we do not adjust results to reflect different prices of inputs and outputs in different years (except for the effects of general inflation). However, it is the marginal value of product - from marginal changes in spending - that we wish to measure. And it is this that farmers are expected to maximise. Thus, for example if fertiliser prices fell (relative to grain) and farmers increase nutrient rates to maximise returns - and we "corrected" for this using the indexes for prices of farm inputs and outputs - efficiency will appear to decline unrealistically (Langton 2011).

Confounding of quantity, quality and price of inputs: Results can be explained in terms of either or both of:

- "farmers got a worse bargain" (that is they bought a more expensive product but it was of no higher quality, and/or the relative prices of grain fell or did not compensate)
- "farmers put on more, or higher quality, inputs"

However, given the near perfect yield maximisation that we observed here, for expenditure on inputs recorded in England and Wales, it seems that farmers are optimising very well across these components of input spending.

Rotations: Farms will achieve more yield and spend less (on fertilisers at least) after a nitrogen-fixing crop (for example peas or beans), and may spend more and certainly achieve less yield with a wheat crop that follows wheat. So, the MPP (yield coefficients) would be expected to be negative. However, here, almost all of the MPP's are positive and small, or non-significant. And yield coefficients - for "All Wheat", "Just - Peas or Beans in Preceding Year", "Just Milling Wheat", or "All Oilseed Rape" - suggest that yields are being maximised (contradicting the hypothesis quoted just above). And the marginal losses, of "Just - Peas or Beans in Preceding Year", "Just Milling Wheat", or "All Oilseed Rape", were much the same as when rotations are ignored, although slightly larger (but differences were less than 2x s.e.).

Also, less than 15% of cereals area is accounted for each year by crops in total that: could be expected to be heavily fertilized (eg potatoes/onions) or that fix N (beans/peas). And observations here are normally averaged across several different preceding crops within each individual farm observation - because most farms will have several fields wheat following a number of different crops. Hence we do not consider that rotation effects could account for the observation that marginal profits (gross margins) are almost always negative, and significantly different from zero.

Further research:

Aggregate losses to the whole industry, from non-optimal input spending, could be estimated from the areas under the relevant response curves (production functions) - at actual and optimal levels of spending. However, fitting these response curves is left to future researchers, being beyond the scope of the current analysis.

Fitting of relationships with physical inputs is not possible here - as these are not collected at the crop level in this data - although available recently at the farm level for fertilisers in the FBS. This is, however, an avenue of research that is being actively pursued in strip trials around the UK (Sylvester-Bradley 2014). Which this study complements with data on financial and physical returns, from differences in spending rates, experienced in typical cropping in England and Wales.

CONCLUSIONS:

For conventional cropping, of winter wheat and oilseed rape across years, it appears when trying to achieve marginal profit, farmers sometimes spend excessively on variable inputs relative to the financial returns from those inputs. So *marginal spending* on variable inputs (of for example seed, fertiliser, crop protection) returns very little to farmers. On an average farm applications could actually be quite far from the economic optimum - where perhaps sometimes as much as 90 pence in the marginal pound does not return any income.

Caution is needed, clearly, because in some years sub-optimal inputs could incur substantial losses.

These conclusions hold valid across a wide range of economic models used to derive the results. Ranging from elementary regressions to sophisticated econometric fixed effects and translog functions. Regressions on subsets of the data, including results just for oilseed rape, indicate that different rotations are unlikely to account for the results, and that farmers are likely very skilled in maximising yields.

Ecological negative effects (or "social costs"), such as diffuse pollution and losses of habitats and species, are likely to be greater than would be expected if farming was economically optimal. Because input levels may be excessive, relative to economic optima. Although one must note that if prices in the main reflect factors and preferences other than those assumed here (possibly owing to violation of neoclassical assumptions, of "perfect competition" and that farmers have "perfect information"), relative to the local and global optima the conclusions will also be distorted. Or in other words "unrealistic".

Farmer Information / Available observables: Unknowns are faced by farmers, from variations of climate, biology, ecology and markets (which have as little as 10-20% skill 1-2 years forward - so only 10 or 20% of the variation in prices is predicted 1-2 years forward (author obs.)). Hence it is rather difficult for farmers to optimise input levels, because production, quality and price are unknown (when inputs must be applied). So they adopt best guesses, based on inchoate Bayesian optimisation, using crop appearance and experience of yields in other years, and other farms in their circle.

Also, in the face of very significant fixed costs, with risk and uncertainty it may be rational to maximise yields. While MVP > MC.

Tied advice: The frequency of tied advice (where advisors are paid through input sales) may reduce the efficiency of the farm sector. Owing to the possible perverse incentive, that the advisor might gain with greater applications.

Overall, it appears that levels of input spending are distorted relative to the neoclassical ideal (with perfect competition and perfect information), as posited in evolutionary economic theory (Nelson and Winter 2009).

Inflation of input prices could occur, in part, also from preferences of farmers, to avoid risk (prophylactic applications), or to maximise yields (seeing themselves as "feeding the people"). Biases related to their own self-image (for example, the received wisdom, that 80 percent of drivers think that they are "a better than average driver"), will also distort perceptions about advice. And consequently distort typical input rates, relative to those that the advisor or policy-maker may consider are optimal, or that should occur under neoclassical optima.

In light of above, one might question "How useful, good and adequate are the consequent prices and incentive structure?"

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