Modeling and Analysis

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Can biofuel policies reduce uncertainty and increase agricultural yields through stimulating investments?

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Abstract: As history shows, the yield gap (the difference between actual and achievable yields) will not necessarily close automatically. Investments in agricultural technologies may be key. Price volatility is fundamental to investment. Price volatility has increased in agriculture in the past decade, leading to higher risks for potential investments. Some of these increased risks may be offset by the certainty offered by credible policies. The US experience indicates that ethanol policy may contribute to yield increases. Analysis suggests that corn use by ethanol plants in the USA may explain a significant part of the observed yield increase. A theoretical framework, centered on downside price-stabilization effects, is offered here, supported by some US, EU, and Hungarian empirical evidence. The research presented explores whether new ethanol plants resulting from effective biofuel policies could serve as a market mechanism to stimulate investments in farming technologies, triggering increased productivity. A survey of local stakeholders of an ethanol plant in Hungary, the only large-scale biofuel investment triggered in Europe by the EU's flagship bioenergy policy (the Renewable Energy Directive) suggests that relevant investments may have been stimulated. Over half of the respondent farmers said that the presence of the ethanol plant had stimulated investments in productivity. It is proposed that ethanol or biofuel policies may be effective in closing the yield gap, in effect resulting in additional biomass production and advancing the bioeconomy. With effective cross-sectoral policies, more biomass for food, feed, bio-based materials and / or bioenergy purposes can be produced. © 2019 The Authors. *Biofuels, Bioproducts, and Biorefining* published by Society of Chemical Industry and John Wiley & Sons, Ltd.

Keywords: biofuel; ethanol; bioenergy policy; yield gap; investment risk; price volatility; price stabilization; agriculture

Introduction

In many parts of the world the potential for crop yield increases, double cropping, and utilization of abandoned or underutilized land is large and mostly unexplored – see, e.g., Global Yield Gap Atlas.[1] Illustrating the scope of yield increases globally, one paper estimates that, with the right incentives, 50% more maize, 40% more rice, 20% more soybeans, and 60% more wheat could be produced globally if the top 95% of croplands produced at their current climatic potential – that is without additional land use.[2] There is a substantial potential for achieving higher productivity using available agricultural technologies. In addition to increased food security, higher productivity is relevant for the context of indirect land use change (ILUC) impacts, and one of the primary responses

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to avoid or mitigate ILUC is the stimulation of crop-yield increase.[3–6]

The concept of closing the yield gap (the difference between actual yields in a region and agro-climatically achievable yields using standard technology in the same region) is well known. However, progression of the concept seems to have suffered from insufficient cross-sectoral political interest. Although they are very important, this paper does not cover other adverse market conditions such as overproduction, low prices, inadequate subsidies, let alone food waste. These factors may play significant roles but fall outside the scope of the paper.

Most studies attempt to quantify potential yield and contrast it with realized yields, i.e. assessing and estimating the yield gap – see, e.g., van Ittersum *et al.*[7] Management and technological factors appear to be at the center of assessments of the causes of yield gaps – see, e.g., Edreira *et al.*[8] However, compared to the abundance of papers discussing the underlying causes of yield gaps – see e.g. van Ittersum and Cassman[9] – considerably less research has been conducted on how to close the yield gap and how to mobilize the potential extra biomass. Some papers acknowledge the role of management technologies and farming systems in closing the yield gap[10] but few focus on the policy aspects. In this paper the aim is to investigate the potential role of policies. It is hypothesized that policies may have an important role in increasing yields by stimulating investments, hence resulting in the provision of additional biomass. In this sense policies are not restricted to agricultural policies; in fact, cross-sectoral policies are considered here. Cross-sectoral policies are defined here as policies targeting one sector and having significant spill-over effects in another sector and the size of the effect is as significant as if the affected sector was the targeted sector.

It is not inevitable that yield gaps will be closed over time. Neumann *et al.* acknowledge the difficulty of closing the yield gap and that factors explaining crop production efficiencies are related to complex social, economic, and political processes.[11] They point out that, taking this complexity into account, the extent to which the calculated yield gaps can and will be closed is debatable.

There is little evidence that yields increase automatically. Ray *et al.* identify a variety of countries across the world, in Africa, Europe, Asia, and America, where yields of four key global crops (maize, rice, wheat, and soybean) are not growing, and instead are decreasing.[12] As an illustration, take the country from the case study: Hungary. Average corn yields are much lower in Hungary than those in Austria, a neighboring country with similar biophysical conditions. Average corn yields over the past three decades
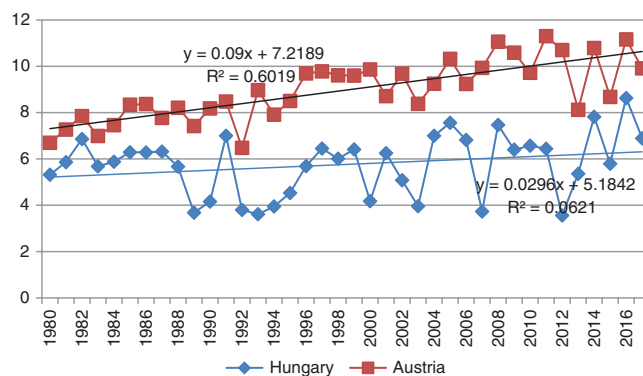

Figure 1. Corn yields in Hungary and Austria.

have averaged around 6 tons ha⁻¹ in Hungary, although they are above 10 tons ha⁻¹ in Austria, and the difference has grown wider.[13] Crucially, corn yields in Hungary have not produced a robust trend towards increased yields in the past 35 years (Fig. 1).

Fischer argues that yield gap closing arises when the adoption by farmers of known innovations is faster than new ones that are invented.[14] The author believes a key follow-up question is what drives farmers to adopt innovations, and what are the right environments to stimulate such adoptions as early and as comprehensively as possible?

In contrast to agronomic yields, considerations of profit and risk are at the center of the discussion. Van Dijk *et al.* argue that agronomic assessments of the yield gap tend to focus on the bio-physical and physiological determinants of crop production but do not account for socio-economic constraints such as prevailing market conditions, infrastructure, risk attitude, and institutions.[10] The question necessarily arises of how and when do policies – specifically ethanol (or bioethanol) and biofuel policies – impact crop yields? This paper aims to examine the factors that drive investment decisions in technologies that can influence yields.

Theoretical framework of underlying mechanisms

The recent agricultural situation has been characterized by relatively high price volatility. Agricultural commodity markets have been affected by a rise in volatility since 2006.[15] The first decade of the 21st century in agriculture globally was characterized by a higher price volatility compared to the two decades before that. The Food and Agricultural Organization of the United Nations (FAO)

observes that volatility in agricultural markets seems to have increased (Fig. 2).[16] Implied volatility represents the market's expectation of how much the price of a commodity might move in the future; and FAO suggests that the first decade of the 21st century may be characterized by extreme movements in an historical context.

Price volatility indicates how much and how quickly a value changes over time, with the concept being rooted in variability and uncertainty. Price variability describes the pace and degree of overall price movement but unpredictability due to increased movement introduces uncertainty. Volatility provides a measure of price uncertainty in markets. In this paper volatility is approached from an investment perspective, so it is deemed appropriate that it is interpreted in the long term (on an annual basis or longer) coinciding with the natural cycles of arable farming and related investment decisions. Accordingly, volatility is defined as the variation (amplitude and frequency) of commodity price changes around their mean value on an annual basis or longer.[17] Short-term movements (on a monthly or shorter basis) are considered less relevant for the topic of the paper.

Explaining corn price variation, Mcphail et al. find that, in contrast to speculation, which is important in the short run (over one month time periods), crude oil price shocks were the most important factors followed by global demand in the long run (12 months and beyond), and ethanol demand was a minor factor in the short term and became minimal beyond a year.[18] Looking at the period between 1986 and 2011, Nazlioglu et al. indicate that a shock to oil price volatility was transmitted to agricultural markets only from 2006.[19] While there
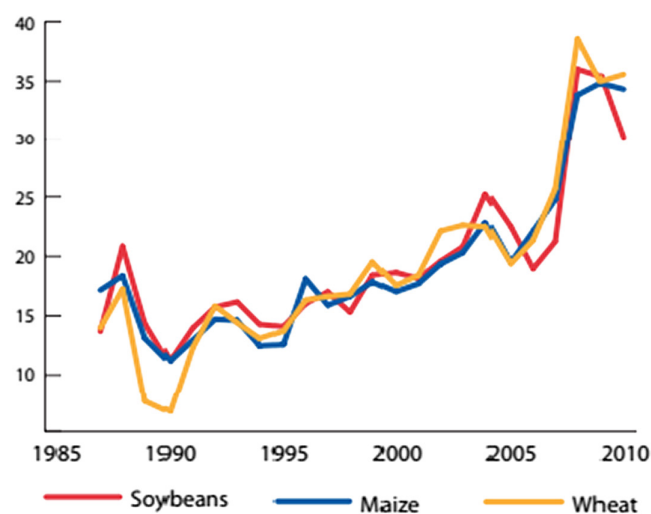
was no risk transmission between oil and agricultural commodity markets from the 1990s until 2006, oil market volatility spilled into the agricultural markets from 2006 onwards, and the dynamics of volatility transmission changed significantly. The authors conclude that, after 2006, risk transmission emerged as another dimension of the dynamic interrelationships between energy and agricultural markets. Furthermore, Baldi et al. found that volatility spillover from financial markets to agricultural commodity markets increased significantly after the 2008 financial crises.[20] Similarly, Nazlioglu et al. found no volatility spillover between oil and agricultural commodity markets before the so-called food price crisis around 2006 but, on the other hand, they found that oil volatility transmitted to the wheat, corn, and soybean markets after the crisis.[19] Looking at the last half-century Huchet-Bourdon found that the period between 2000 and 2010 saw higher levels of agricultural volatility than in the 1990s but not higher than in the 1970s when oil prices also increased substantially.[17] Furthermore, that author found that, when focusing on the years between 2006 and 2010, the volatility seems higher than in the 1970s for cereals.

The FAO cereal price index shows that compared to the period from the mid 1980s to mid 2000s, when prices were relatively stable in real terms, the past decade saw two spikes (2007–2008 and 2010–2012) followed by a decline and a surge again (Fig. 3).[21]

When the risks of investment in farming technology or management practices are high, not investing may be the most rational decision. A yield gap may exist because the low returns on investment from increased production make it economically suboptimal to raise production to the maximum technically attainable.[22] From an investor's perspective, as price uncertainty increases, the level of expected returns necessary to justify an investment decision increases proportionally.

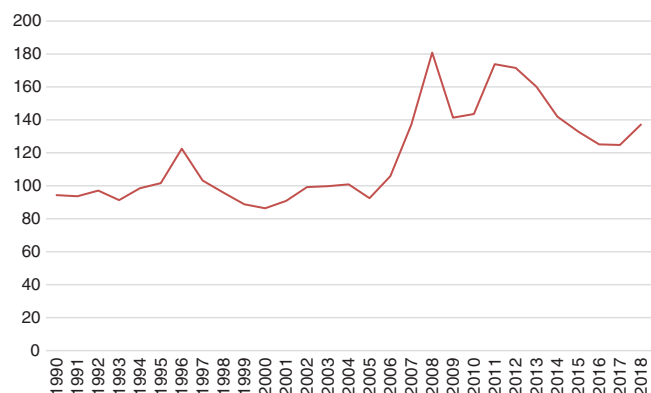Figure 2. Implied price volatility of selected staple foods (in %).

Figure 3. Annual real cereals price index (2002–2004 = 100).

The relatively low recent profitability of farming, especially in the EU, suggests that there is a need for modernization and rationalization in the agricultural sector. However, as Hüttel *et al*. note, observed investment rates were frequently lower than expected, resulting in a lagged catching up of productivity and a slow structural change.[23] Viewed from a financial perspective, volatility and / or uncertainty would be expected to confine firms' investments. Furthermore, from the perspective of a real options approach,[24] the interaction of irreversibility, uncertainty, and flexibility might also result in investment reluctance or low investment rates. If future investment returns are uncertain, therefore, an investor can increase profits by deferring an investment, i.e. in the case of irreversible decisions. In other words, waiting has a value in an uncertain world. The 'joint occurrence of irreversibility, uncertainty and the opportunity to wait causes a kind of inertia, i.e. there is a large range of marginal returns on investment in which inaction appears to be optimal.'[23]

Price volatility is key to investment decisions. As discussed before, price volatility in agriculture has increased in the past decade compared to the previous two decades, leading to higher risks for potential investments. Price volatility becomes problematic when it is high and cannot be anticipated. Studying the sector-level allocation impact of relative price volatility, Cavallo *et al*. found that price volatility provides incentives for entrepreneurs to adopt more 'malleable' but less productive production technologies.[25] In this way investors are better able to accommodate abrupt and frequent changes in relative prices more easily, albeit at the cost of opting for less productive technologies. In other words, investments in farming may lead to lower yield increases than would be the case in a low-volatility environment.

Theoretically, rational farmers' decisions on investments are based on price expectations. Crucially, current prices are a poor indicator. Farmers typically invest based not on today's relations between input costs and revenue from their harvests but on what they perceive that relationship will be the following year (for short-term investments like better seeds) or in 5 years or in 10 years (for medium- and longer term investments like precision agriculture). Profitability in the upcoming business climate is what determines rational investment decisions. It needs to be noted that, in practice, farm policies or subsidies may work against these rational considerations.

In a volatile price environment, high prices today are often not so much a signal of future high prices but a warning of a price correction. Here the maxim of commodity prices that 'the cure for high prices is high prices and the cure for low

prices is low prices' is particular apt. In a world of volatility, average prices may remain the same, which means that a high price in one year increases the statistical likelihood of an abnormally low price in the succeeding year. This reasoning seems to be confirmed by Huchet-Bourdon, whose paper finds that the high agricultural price events of the past 50 years have typically followed a similar pattern – 'a price hike in one year followed by a sharp drop in the following year.'[17]

Some of the increased risks stemming from the volatile price environment may be offset by the certainty offered by credible policies. Policy may be key to 1-, 5- and 10-year price expectations. Policies may compensate for the damaging effect of volatility by offering some certainty in the upcoming time period. Dale *et al*. note that if a policy generates confidence around more stable prices, then that stability can support local agricultural production opportunities even if prices change.[26]

Policies may have a price-stabilization effect because they may act as an insurance mechanism against downside price risks. This downside protection effect, whereby the volatility of prices is shifted from uncertainty about the entire range of prices towards uncertainty only about upside events, may reduce the risk that farmers face when investing, hence the decision may in the end be more pro-investment. Among other things, policies may lead to expanding the base of agricultural production and to more diversified sales market options (whereby increasing the profitability of sales by, e.g., setting up a new biofuel market), either of which contributes to lower associated risks for investments, leading to yield increase. In conclusion, policies may have a dampening effect on external drivers of volatility and act as enablers of a more certain business environment.

Uncertainty and risk are inherent in agriculture. It may also be argued that farmers in general are risk averse, and farming, especially smallholding, is often considered a way of life in addition to a profit-maximizing business. Aimin finds that farmers' decisions under risk can hinder the adoption of new agricultural technology.[27] There are signs that small-scale farmers in developing countries tend to exhibit a high degree of risk aversion.[28] If this held true for farmers in general, price-volatility-induced risk would further discourage investments in farming – see also Mcphail *et al*.[18] and Adjemian *et al*.[29]

Investments in management technology and farming systems are essential to close the yield gap. Arguably, yields are partly a function of policy, not just economic and agronomic variables. In turn, investment decisions may be impacted by policies. To the best of my knowledge, no scientific paper has focused on the role of cross-sectoral

policies potentially contributing to yield increases through investments.

An effective biofuel policy will result in investments in biofuel facilities. These biofuel facilities may have local and global effects in the feedstock markets.[30,31] In response to these effects the farming sector is expected to adjust. Kline *et al.* argue for exploiting the synergies between bioenergy and agriculture by applying sustainability policies.[3] It is therefore hypothesized that robust bioenergy policies – including ethanol policies – which trigger investments and have real effects on the market, will initiate a response in the agricultural sector. The nature of the response in the farming sector needs to be researched. It is reasonable to assume that the market stimulus from the biofuel sector would trigger a positive response in farming. This response may take the form of investments. Fig. 4 outlines a theoretical framework of cross-sectoral policies that aim to mitigate the investment deferral effect of increased price volatility by providing some market certainty and therefore lowered risk.

Two key underlying questions are: (i) How investments in farming are stimulated? (ii) Is there a role for sectoral policies to stimulate the closing of the yield gap? Bioenergy and ethanol policies are examples of such sectoral policies. The corn yield increase in the USA in parallel with the introduction of its biofuel policy and the sugar beet yield increase in EU in response to the sugar policy reform (discussed later) indicate that there may be a link between sectoral policies and yield increase. The former may have stimulated investments in cropping technology, the latter largely triggered structural changes. The EU biofuel policy (mostly framed by the Renewable Energy Directive – RED) mobilized very limited investments in biofuel plants, and in fact, since the adoption of RED in 2009, there has only been one successful large-scale investment in biofuels in Europe. Thus, as a consequence, it cannot be considered an effective biofuel policy and is not discussed here.
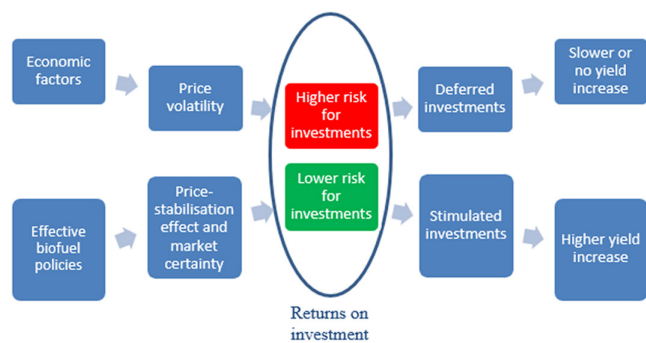
Historical developments in yields and cross sectoral policies

Corn (maize) is a major crop in the USA. Yields have been increasing in the past two decades (in fact much longer), although the rate of growth has varied. Arguably, weather conditions have a big impact on yields across years; therefore, when assessing the trend, it is better to use averages of some years rather that looking at a series of single datapoints. Figure 5 shows the corn yields in the USA in the past two decades calculated by a 5-year moving average (to neutralize the impact of weather).[32] An increasing trend is best described by a polynomial curve (order 6, $R^2 = 0.9896$), and there appears to be a 'hill' in the period in the first decade in the 2000s followed by a drop in the early years of the second decade.

The US Energy Policy Act of 2005 created the Renewable Fuel Standard (RFS), a centerpiece of the US regulation of biofuels, requiring a minimum volume of biofuels to be used in the transportation fuel supply in the USA each year. The RFS proved to be an effective policy measure as ethanol production and use more than tripled in 5 years. Likewise, corn used to produce ethanol (and the co-product animal feed, DDGS) increased from 34 mt in 2004 to 127 in 2010.[33]
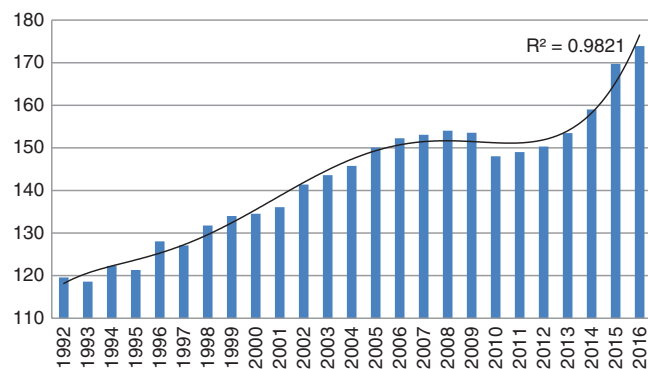

Figure 5. Corn yield in the US (5-year moving average).

Figure 4. Theoretical framework of investment risk mitigation by cross-sectoral policies.
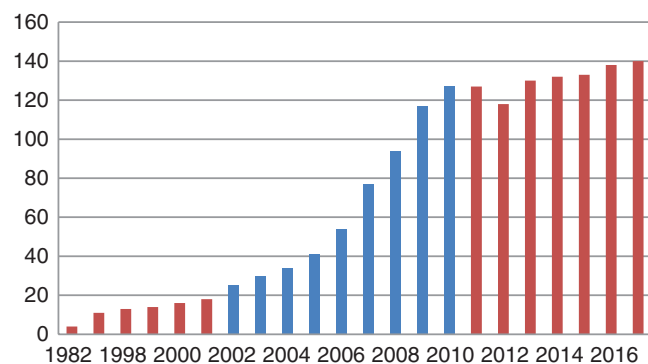

Figure 6. Corn used for ethanol and DDGS production (mt).

The bioethanol boom in the US was concentrated roughly over 8 years (between 2002 and 2010, marked in blue in Fig. 6), with production taking off in 2005 and in essence plateauing in 2010, when production approached the 56.7 billion liter mandate and met with corn ethanol in the RFS. Consumption of corn for ethanol production largely leveled off after 2010 (Fig. 6).

Looking at the two charts (Figs 5 and 6), the correlation between corn yields and ethanol production is evident. Correlation between corn yield and corn use by biorefineries in the USA is strong and significant ($r = 0.825$, $P = 0.00$). How can one determine if higher yields are linked to additional demand for feedstock as an outcome of biofuel policy (ethanol production)? Correlation is not causation, and the limited number of datapoints does not offer conclusive evidence, yet analysis of data certainly does not reject the hypothesis that RFS indirectly contributed to crop yield increase.

Since the biofuel market has provided a significant demand for corn – in fact more than a third of corn produced is now processed by biorefineries in the USA (ethanol, DDGS and other products) in recent years – it is reasonable to assume that there may have been an impact on yields. The ethanol (and adjacent co-markets such as animal feed DDGS) market grew from less than the volume of export in 2002 (25 versus 40 million tons, respectively) to more than twice the size of export in 2010 (125 versus 50 mt).[33] That suggests the US corn market experienced a boom due to the RFS. In fact, it is unreasonable to assume that arguably one of the largest market developments in US crop market in the past two decades left farming unimpacted.

Further analysis indicates that the initial growth in corn use by biorefineries may have had a relatively substantial impact on yields (Fig. 7). A power trendline appears to explain the relationship between corn yield and biorefinery use of corn ($R^2 = 0.83$).
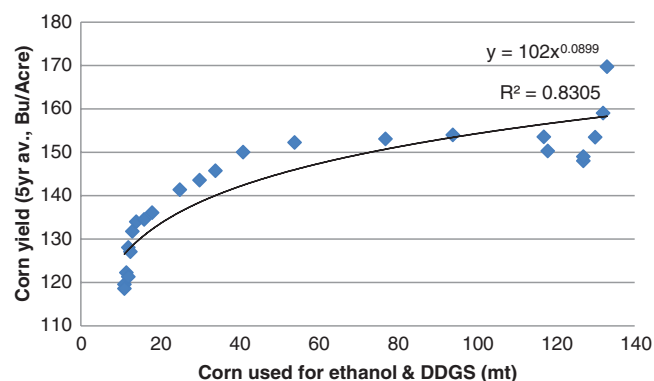
Data suggest that the initial effect had a greater impact. The effect on crop yield seems to be fading and the cause may be that investments ceased to increase after an initial period. There is limited data available on investments in farming technology, but data show that US farm production expenditure on (i) farm improvements and construction, (ii) tractors and self-propelled farm machinery, and (iii) other farm machinery, expressed as a proportion of total expenditure, spiked from 2002 onwards for three consecutive years (Table 1). This period seems to match the initial bioethanol boom (2002 to 2010). As investments have a lasting impact on production and yields, the stimulation due to RFS may explain a large part of the yield increase in corn production. This speculation is underpinned by the significant correlation ($r = 0.55$, $P = 0.006$) between two variables: (i) corn used for ethanol and DDGS production (Mt) and (ii) farm investment expenditure (percentage of total). A power trendline appears to explain a large part of the relationship between the level of farm investments and biorefinery use of corn ($R^2 = 0.49$, $y = 6.9802x^{0.0898}$).

The US experience indicates that a stable and credible government policy can play a role in stimulating crop yield growth. Such a policy environment has been identified as a crucial factor needed for the successful development of (new) bioenergy chains.[34]

What are the possible mechanisms through which an energy policy may be an effective tool in boosting crop yields? In the more volatile recent environment, sectoral policies, including the RFS, may have alleviated some of the uncertainty in future markets, thereby providing some stimulus to farmers to invest, resulting in higher crop yields.

The stimulating role of a local biorefinery

The largest investment (from a feedstock-use perspective) in Europe since the RED was adopted in 2009 took place in Dunaföldvár, Hungary. It is therefore appropriate to select this region as the target for further investigation. A survey in Hungary was carried out to establish a relationship between biofuel policy and investments in farming technology. The aim was to shed some light on the nexus of a presence of an ethanol plant or biorefinery, an investment stimulated by EU bioenergy policy and investments in farming technology.

A simple methodology was applied: a survey was carried out among farmers in the region with a long-term business relationship with the plant. Computer-assisted telephone interviewing data collection was carried out in July 2016, with the participation of the TÁRKI Social Research

Figure 7. Corn yield and corn used for ethanol (1992–2015).

Table 1. Farm investment expenditure (1993–2015).

	1993	1994	1995	1996	1997	1998	1999	2000
Farm improvements and construction	5650	5400	5200	5900	6100	6450	7100	8400
Tractors and self-propelled farm machinery	4440	4610	4750	5000	5400	6000	5400	5400
Other farm machinery	3610	3360	3100	3350	3410	3550	3500	3600
Total	29393	26740	26100	28500	29820	32000	32000	34800
% of total expenditure	8,8	8,4	7,7	8,2	8,1	8,7	8,7	9,1
	2001	2002	2003	2004	2005	2006	2007	2008
Farm improvements and construction	7800	8000	11800	12600	12700	12700	14100	15800
Tractors and self-propelled farm machinery	6100	6200	7000	8700	8500	7300	8600	11400
Other farm machinery	3800	3700	3900	4300	4100	3800	4400	5900
Total	35400	35800	45400	51200	50600	47600	54200	66200
% of total expenditure	9	9,3	11,3	12,1	11,3	10,1	9,6	10,7
	2009	2010	2011	2012	2013	2014	2015	
Farm improvements and construction	14100	12600	14300	15600	16600	18200	16100	
Tractors and self-propelled farm machinery	9300	10900	12500	17000	17100	16900	11900	
Other farm machinery	4700	5000	6400	8000	8800	9000	6100	
Total	56200	57000	66400	81200	85000	88200	68200	
% of total expenditure	9,7	9,9	10,4	11,2	11,6	11,2	9,4	

Source: [33].

Institute coordinated by the Center for Economic and Regional Studies of the Hungarian Academy of Sciences.[35] The respondent farmers ($N=270$) mostly run large farms, with the average size of arable land cultivated being close to 500 ha, above the national average. Note that since the arable land cultivated by the respondent farmers accounts for 2.1% of Hungary's farming area, the findings may have significance beyond the study area.

The survey results showed that investment and development activities to improve competitiveness were rather common among farmer respondents. The purchasing of machinery and equipment was the most frequently mentioned investment (87%), followed by improving plant protection practices (83%), changing the method of crop rotation (67%), and creating the conditions for precision farming (i.e. differentiated nutrient management and plant protection) (59%). Creating the conditions for, and developing, irrigation was the least frequently mentioned (14%) form of investment they carried out in the last 5 years. All of these investments have the potential to increase yields.

These survey results appear to reinforce the hypothesis both in terms of price volatility reduction and risk mitigation potential of biorefineries.

First, 61.5% of the respondents agreed with the statement that the ethanol plant's corn purchases represent predictable and stable demand which, on the whole, 'mitigates price volatility' (12.2% of respondents disagreed with the statement). This finding indicates that a majority of surveyed farmers believed that an ethanol plant can reduce agricultural price volatility.

Second, the ethanol plant seemed to have become a stabilizing factor in the corn market in Hungary. The respondent farmers thought that the market entry of a significant industrial buyer had reduced their risks. Accordingly, a large majority (61%) of the farmers agreed, while only 15.9% said that they fully or partially disagreed with the statement that 'the operation of the ethanol plant reduced the risks to farmers by stabilizing the corn market.'

Third, the survey finds that the bioethanol plant contributed to lowering farmers' business risk. In the farmers' opinion, the predictable demand for maize from the plant plays an important role in this, while also exerting a price-stabilizing effect. Over half of the respondent farmers (53%) agreed that 'the presence and operation of the ethanol plant had stimulated the implementation of their investments and upgrades.' In other words, about every second investment in farming technology would have had a lower chance of materializing in the absence of the local bioethanol plant. Follow-up interviews with the farmers confirmed that being able to rely on predictable demand from the plant meant that they implemented their investments and upgrades either earlier or on a larger scale than they had planned. In other words, the

survey found that the presence of a local ethanol plant stimulated investments in farming, which enhanced the competitiveness of local agriculture in the long term.

The finding presented suggests that an effective biofuel policy, whereby biorefineries are established, leads to investments in agriculture by reducing price volatility and, as a consequence, lowering risk. As a result, additional investments in farming technologies may be stimulated, potentially leading to increased yields. A robust, effective biofuel policy may therefore be an effective element in agricultural development.

Conclusion and discussion

Recent price volatility in agriculture may have a negative impact on the level of investment in farming technologies. In a volatile price environment, a high price today does not predict continued high prices. Volatility increases risk. Higher risk requires higher expected returns to justify an investment. A credible ethanol, biofuel, or bioenergy policy may reduce downside price uncertainty for investments in farming. Investments in farming can increase biomass yields and efficiency of production.

How and when do policies – specifically bioenergy or ethanol policies – impact yields? Cases involving US and Hungarian ethanol were examined and found to be consistent with a hypothesis that if policies provide credible rules and more stable demand, crop yields increase. The survey result suggests that an effective biofuel policy lowers risks, stimulates investments, and can improve productivity.

Some evidence is offered that farmers see the beneficial impacts of biorefineries with regard to price volatility, market stability, and lowered risks. The survey result in Hungary suggests that farmers attribute a price-stabilization effect to an ethanol plant, a recent outcome of a biofuel policy. As a result of the potential price-stabilization effect it appears that farmers are more likely to invest in agricultural technology. The finding indicates that an effective bioenergy policy might provide a key market mechanism in stimulating the production of additional biomass. The resulting additional biomass may be used for food, feed, bio-based materials, or bioenergy purposes, advancing the bioeconomy.[36]

Modeling future impacts of an extreme biofuels scenario, Enciso *et al.* found that abolishing all biofuel policies would not have a significant impact on price volatility of crops.[37] Their model appears to be incomplete, as the potential mitigation mechanism described in the current paper provides additional factors for consideration. If the theoretical framework presented holds true and is supported by further research, it suggests that biofuel policies may mitigate risk and price volatility.

The ability to be shock-absorbing may be an important element of effective cross-sectoral policies. Price volatility may be high due to various external factors beyond the control of farmers. High volatility leads to increased uncertainty, and uncertainty is antithetical to investments contributing to yield increase. A key aspect of a biofuel policy with a cross-sectoral impact would be to mitigate, in the long run, the shocks stemming from price volatility by providing secure markets to farmers to justify investments in technology. The theoretical framework and analysis of data provided may offer an alternative to claims that bioenergy policies, by mandating extra demand for crops, make price volatility worse.[38–40] In fact, the negative impact of price volatility may be dampened in the long run by effective and credible cross-sectoral biofuel policies.

Although it does not concern the price-stabilization effect, nor is it clear to what degree investments played a part in the outcome, another policy is mentioned below providing further indication that policies may affect crop yields. Sugar beet production in the EU underwent a substantial change in response to a reform of EU policy. An evaluation of the effectiveness of the policy found that the 2006 EU sugar policy reform led to a general improvement in sugar yields per hectare because underperforming farms abandoned production more than better ones.[41] In fact, in the few years before the reform in the EU-15, sugar production per hectare was increasing by 2.6% a year on average, whereas after the reform the yield increase jumped to an annual average of 7.4%. In other words, due to favorable policy changes, yield growth tripled in a relatively short period of time. It is unclear how much of the total increase was attributable to a shift in production to more efficient farms or to other factors, although it seems the former is of higher relevance.

Another potentially interesting case to investigate could be Brazil, where sugarcane production yields increased, seemingly coinciding with Brazil's ethanol policy, while other parts of the world, such as India, the second largest producer globally after Brazil, lacked such development. Other corn or sugarcane cases, including Guatemala, could be considered for further research for assessing the relationship between cross-sectoral policies and feedstock yields.

Future research is warranted to study the impact of policy on price elasticity in farming. Farming responds to changes in demand, and the extent of the supply response is influenced by price elasticity. It might be hypothesized that biofuel demand represents a type of demand different

from typical commodity demand changes, hence farmers may respond qualitatively differently. The difference may be grounded in the investment stimulus. As a result, a qualitatively different price elasticity may apply when it comes to biofuel demand.

Investments also influence the environmental impact profile of farms. As for future research, it may be interesting to look into whether the investments in farming results in increased productivity of land or the application of more sustainable practices. In addition to advancing farming, sustainable intensification has been proposed as a way forward, bringing benefits to the climate and the environment. Whether yields increase or environmental impacts decrease may depend on the chosen type of investment. It would be interesting to research what elements of a cross-sectoral biofuel policy design effectively contribute to yield increase and, at the same time, improve sustainability.

Acknowledgements

References

1. Global Yield Gap Atlas. (2018). Available: http://www.yieldgap.org/web/guest/yieldgaps.
2. Licker R, Johnston M, Foley JA, Barford C, Kucharik CJ, Monfreda C *et al*., Mind the gap: how do climate and agricultural management explain the 'yield gap' of croplands around the world? *Glob Ecol Biogeogr* **19**:769–782 (2010).
3. Kline KL, Msangi S, Dale VH, Woods J, Souza GM, Osseweijer P *et al*., Reconciling food security and bioenergy: priorities for action. *GCB Bioenergy* **9**:557–576 (2017).
4. Langeveld J, Dixon J, van Keulen H and Quist-Wessel F, (2013): Analyzing the effect of biofuel expansion on land use in major producing countries: evidence of increased multiple cropping. *Biofuel Bioprod Biorefin* **8**:49–58 (2014).
5. Kløverpris JH and Mueller S, Baseline time accounting: considering global land use dynamics when estimating the climate impact of indirect land use change caused by biofuels. *Int J Life Cycle Assess* **18**:319–330 (2013).
6. Szabó Z, Full carbon accounting: the case of ethanol. *Int Res J Environ Sci* **6**(10):32–41 (2017).
7. van Ittersum MK, Cassman KG, Grassini P, Wolf J, Tittonell P and Hochman Z, Yield gap analysis with local to global relevance – a review. *Field Crop Res* **143**:4–17 (2013).
8. Edreira JIR, Mourtzinis S, Conley SP, Roth AC, Ciampitti IA, Licht MA *et al*., Assessing causes of yield gaps in agricultural areas with diversity in climate and soils. *Agric For Meteorol* **247**:170–180 (2017).
9. van Ittersum MK and Cassman KG, Yield gap analysis – rationale, methods and applications – introduction to the special issue. *Field Crop Res* **143**:1–3 (2013).
10. van Dijk M, Tom Morley T, Jongeneel R, van Ittersum M, Reidsma P and Ruben R, Disentangling agronomic and economic yield gaps: an integrated framework and application. *Agr Syst* **154**:90–99 (2017).
11. Neumann K, Verburg P, Stehfest E and Müller C, The yield gap of global grain production: a spatial analysis. *Agric Sys* **103**(5):316–326 (2010).
12. Ray DK, Mueller ND, West PC and Foley JA, Yield trends are insufficient to double global crop production by 2050. *PLoS One* **8**(6):e66428 (2013).
13. Eurostat (2018). Crops products - annual data [apro_cpp_crop]. Eurostat database.
14. Fischer RA, Definitions and determination of crop yield, yield gaps, and of rates of change. *Field Crop Res* **182**:9–18 (2014).
15. Ganneval S, Spatial price transmission on agricultural commodity markets under different volatility regimes. *Econ Model* **52**:173–185 (2016).
16. FAO, Price volatility in agricultural markets. *Economic and Social Perspectives, Policy Brief* **12**:1–2 (2010).
17. Huchet-Bourdon, M. (2011). Agricultural Commodity Price Volatility: An Overview. OECD Food, Agriculture and Fisheries Papers, No. 52; OECD Publishing, Paris.
18. Mcphail L, Du X and Muhammad A, Disentangling corn Price volatility: the role of global demand, speculation, and energy. *J Agric Appl Econ* **44**:401–410 (2012).
19. Nazlioglu S, Erdem C and Soytas U, Volatility spillover between oil and agricultural commodity markets. *Energ Econ* **36**:658–665 (2013).
20. Baldi L, Peri M and Vandone D, Stock markets' bubbles burst and volatility spillovers in agricultural commodity markets. *Res Int Bus Financ* **38**:277–285 (2016).
21. FAO (2018): Cereal price index. Available at: http://www.fao.org/worldfoodsituation/foodpricesindex/en/
22. Godfray HCJ, Beddington JR, Crute JI, Haddad L, Lawrence D, Muir JF *et al*., Food security: the challenge of feeding 9 billion people. *Science* **327**:812–818 (2010).
23. Hüttel S, Mußhoff O and Odening M, Investment reluctance: irreversibility or imperfect capital markets? *Eur Rev Agric Econ* **37**(1):51–76 (2010) March.
24. Hüttel S, Musshoff, O and Odening M, (2007). Investment Reluctance: Irreversibility or Imperfect Capital Markets? Evidence from German Farm Panel Data. 2007 Annual Meeting, July 29–August 1, 2007, Portland, Oregon 9826, American Agricultural Economics Association.
25. Cavallo E, Galindo A, Izquierdo A and León JJ, The role of relative price volatility in the efficiency of investment allocation. *J Int Money Finance* **33**:1–18 (2013).
26. Dale V, Efroymson R, Kline K, Langholtz M, Leiby P, Oladosu G *et al*., Indicators for assessing socioeconomic sustainability of bioenergy systems: a short list of practical measures. *Ecol Indic* **26**:87–102 (2013).
27. Aimin H, Uncertainty, risk aversion and risk Management in Agriculture. *Agric Agric Sci Procedia* **1**:152–156 (2010).
28. Brick K and Martine Visser M, Risk preferences, technology adoption and insurance uptake: a framed experiment. *J Econ Behav Organ* **118**:383–396 (2015).
29. Adjemian, M. K., V. G. Bruno, M. A. Robe, and J. Wallen (2016). 'What Drives Volatility Expectations in Grain Markets?' Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. St. Louis, MO. Available: http://www.farmdoc.illinois.edu/nccc134.
30. Mumm R, Goldsmith P, Rausch K and Stein H, Land usage attributed to corn ethanol production in the United States: Sensitivity to technological advances in corn grain yield, ethanol conversion, and co-product utilization. *Biotechnol Biofuels* **7**:61 (2014).

31. Elliott J, Sharma B, Best N, Glotter M, Dunn J, Foster I *et al.*, A spatial modeling framework to evaluate domestic biofuel-induced potential land use changes and emissions. *Environ Sci Technol* **48**(4):2488–2496 (2014).

32. USDA (2018): United States Department of Agriculture, National Agricultural Statistics Service.

33. NCGA (2018): National Corn Growers Association: world of corn.

34. Langeveld JWA, Kalf R and Elbersen HW, Bioenergy production chain development in The Netherlands: key factors for success. *Biofuel Bioprod Biorefin* **4**:484–493 (2010). https://doi.org/10.1002/bbb.240.

35. Koós B, Király G, Hamar A and Németh K, Sustainable rural renaissance: The case of a biorefinery. Centre for economic and regional studies of the Hungarian Academy of Sciences, pp. 38 (2016).

36. Heijman W, Szabó Z and Veldhuizen E, The contribution of biorefineries to rural development: the case of employment in Hungary. *Stud Agric Econ* **121**:1–12 (2019).

37. Enciso SRA, Fellmann T, Dominguez IP and Santini F, Abolishing biofuel policies: possible impacts on agricultural price levels, price variability and global food security. *Food Policy* **61**:9–26 (2016).

38. McPhail L and Babcock B, Impact of US biofuel policy on US corn and gasoline price variability. *Energy* **37**(1):505–513 (2012).

39. Serra T and Zilberman D, Biofuel-related price transmission literature: A review. *Energ Econ* **37**:141–151 (2013).

40. De Gorter H, Drabik D and Just DR, *The Economics of Biofuel Policies: Impacts on Price Volatility in Grain and Oilseed Markets*. Palgrave Studies in Agricultural Economics and Food Policy, US, p. 282 (2015).

41. Agrosynergie (2011): Evaluation of Common Agricultural Policy measures applied to the sugar sector. Report by European Commission, DG Agriculture and Rural Development (2011).

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