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Article

Three decades of organic wheat improvement: Assessing the impact and returns on investment

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Abstract

A changing regulatory environment and growing awareness are driving the need for crop improvement in organic agriculture. Contrary to conventional breeding, evidence on the economic effects of research and development in organic breeding is lacking. This study assesses adoption, economic impact, and rates of return to organic crop improvement research. The economic surplus method is used to quantify the impact of the Wiwa winter wheat variety. The standard model is enhanced by considering the economic benefits of improvements in crop nutrient and processing quality as well as resilience gains. Results show substantial economic returns of 18.6 per cent for the period from 1988 to 2019. The reduced downside risk of the organic cultivar is a key distinguishing factor in the analysis as organic breeding aims at providing farmers with resilient cultivars. Further investment in organic breeding appears as a promising element in the strategy for resilient and sustainable food systems.

Keywords: Economic surplus model, Impact assessment, Downside risk, Resilience

JEL code: Q16

1. Introduction

A transition of farm systems towards agroecology relies on varieties adapted to crop management without synthetic inputs. Over the past decades, there has been a growing interest in organic crop improvement, but investments in organic seed and plant breeding remain limited. This results in a general lack of organic seed and organically bred cultivars (Döring *et al.* 2012). The new organic regulation in the European Union foresees the phasing out of derogations for the use of conventional untreated seed in organic agriculture by 2035 (European Parliament 2018). While not regulating breeding as such, it recommends the use of cultivars that are well suited for organic agriculture (European Parliament 2018). The regulation thus implies that the organic seed shortage needs to be addressed, not only through increased organic seed multiplication but also through further breeding for organic agriculture, where all breeding stages take place under organic conditions.

Modern agriculture is mainly based on varieties bred for high performance under external input systems. These generally do not perform so well under other conditions

(Bharadwaj 2016). Innovative breeding solutions are needed to face the challenges of climate change and the pollution of ecosystems. While some wheat breeding goals, such as yield increase, climate change adaptation, or baking quality, are the same for conventional and organic agriculture, there are specific breeding goals that have a higher priority in organic agriculture, such as robustness and flexibility, beneficial interactions with soil organisms, or disease tolerance (Lammerts van Bueren *et al.* 2018). In some instances, breeding goals for conventional and organic agriculture are competing. An example of this is the introduction of semi-dwarf genes for yield increase in high-input wheat cultivation that resulted in short-strawed cultivars with less weed suppression ability and reduced nutrient uptake efficiency (Lammerts van Bueren *et al.* 2011).

A growing interest in organic breeding raises the question of what societal benefits it can deliver. A large number of empirical studies exist that have analysed the returns to crop improvement research in conventional agriculture (some recent examples include Brennan and Malabayabas 2011; Alene *et al.* 2013; Robinson and Srinivasan 2013; Walker *et al.* 2015). However, there is a lack of evidence for impact at scale and returns to investment in organic cultivars. This study, therefore, aims to quantify adoption, economic impact, and rates of return to organic crop improvement research, focusing on wheat as an important staple crop. More specifically, we study the cultivar development of 'Getreidezüchtung Peter Kunz (GZPK)', a non-profit plant breeding association with more than 30 years of experience in organic plant breeding. Their goal is the breeding and research of adapted varieties for sustainable agriculture as well as the maintenance, expansion, and sustainable use of crop diversity. GZPK is headquartered in Feldbach, Switzerland, and operates further sites in Germany and Italy (GZPK 2020; GZPK pers. comm.). We narrowed the scope of this study to the winter wheat variety Wiwa due to its successful adoption in Switzerland and parts of Germany. Returns to breeding conventional wheat varieties have been estimated to range from 39 (Morocco) to 41 per cent (Mexico) and 84–105 per cent (Nepal) by various studies (e.g. Azzam *et al.* 1997; Marasas *et al.* 2003; Thakur *et al.* 2007). The novelty of the present research is based on the consideration of the social benefits of organic wheat breeding, using an enhanced version of the economic surplus model. Estimated impacts relate not only to individual breeding businesses, but to the entire economy. Besides yield differences, quality and resilience gains are also considered in the analysis. The enhanced specifications are systematically compared with the standard specifications, which are usually found in the literature.

In the next section, the model background and description, as well as the data and scenarios, are explained. Subsequently, adoption, benefit-cost ratios (BCRs), and rates of return, just like some sensitivity tests, are presented. The last section provides some discussion of the results and the conclusions.

2. Material and methods

2.1 Conceptual background

The impact of Wiwa breeding was quantified based on an economic surplus model (Alston *et al.* 1995; Masters *et al.* 1996). The method is grounded in welfare economics and has been widely applied to determine the returns of crop improvement research (e.g. Lantican *et al.* 2005; Alene *et al.* 2009; Robinson and Srinivasan 2013). It allows estimation of the total social welfare effect generated by the dissemination of a new variety, specifying economic gains for producers and consumers. An rconomic surplus is defined as the monetary gain obtained by producers and consumers from selling and buying at the market price. The area between the supply curve and the demand curve up to the point where they intersect (market equilibrium) describes this surplus. According to the model, adopting an improved variety triggers a downward and right shift of the supply curve, which creates economic benefit (Alston *et al.* 1995). This is represented by an increase in the area between the supply and demand curves. While the model is theoretically well-grounded, it is based on certain assumptions, such as the shape of supply and demand curves, the market equilibrium, and the nature of the supply shift (Schreinemachers *et al.* 2017). According to Alston *et al.* (1995), the assumption of a parallel shift of the supply curve due to a new variety is very important, while the assumed functional forms of the demand and supply curves do not strongly affect results.

To estimate the welfare effect of crop improvement, it is necessary to design the supply curve in the absence of the new technology, which results in the counterfactual for the ex-post impact assessment (Marasas *et al.* 2003). The supply curve without the dissemination of the improved variety is unobserved in this context, but previously dominant varieties generally serve as counterfactuals (Schreinemachers *et al.* 2017). Traditionally, the supply shift and the resulting welfare effect have been modelled as a function of increased crop yields or reduced production costs from improved varieties (Masters *et al.* 1996). In addition to these effects, the present application also considers the economic benefits of crop quality and resilience improvements. This is key to capturing some of the central breeding goals related to organic crop improvement. Nutrient and processing quality were selected as quality criteria. These are rewarded by the Swiss organic certification body through premium payments. Resilience was incorporated in the analysis due to increasing concerns about climate change impacts. Resilient wheat farms will find it easier to anticipate and adapt to changing conditions. In economic terms, resilience is defined as downside risk, which accounts for years where negative deviations from average revenues occur.

The estimated welfare gains are put into relation with the breeding costs to determine the return on investment. For the entire analysis of Wiwa returns, calculations begin in 1988, the year in which varietal development was initiated, and are split into four steps: (i) breeding (including pre-breeding), which lasted from 1988 to 2001, (ii) registration from 2001 to 2005, (iii) introduction to the market in 2005 and 2006, and (iv) maintenance breeding and adoption starting in 2006. As maintenance breeding is still taking place and data were available until 2019, the impact estimations run until that year. Furthermore, to consider that welfare benefits will continue to accrue, key data for selected model variables were forecast until 2030 based on trend analysis. For the national area under organic winter wheat and the national organic winter wheat yields, future growth was linearly extrapolated from data of the past 5 years (2015–9). For adoption trends, a logistic adoption curve was estimated, as explained in Section 2.2. While Switzerland's overall organic winter wheat area is likely to continue its rapid growth over the next 10 years, the upper limit on the area under Wiwa has been set only 20 per cent above current adoption levels, in absolute terms. In relative terms, this translates to a decreasing share over the next 10 years, which is deemed reasonable as experts pointed out likely resistance breaks and organic-bred wheat varieties with good potential in current trials (Agroscope 2020; Bioland-HG, pers. comm, 12 March 2020; GZPK 2020; LTZ, pers. comm., 8 April 2020). All data and calculations for the assessment of Wiwa breeding return are available from the supplementary material.

2.2 Model specifications

Data on the area cultivated with Wiwa is not available. Following previous studies (e.g. Schreinemachers *et al.* 2017; Sequeros *et al.* 2019), seed sale figures were used to infer the area under the improved variety, as defined in equation (1). From the introduction into the market in 2006 until 2019, yearly adoption of Wiwa A_t was estimated from observed data on the quantity of Wiwa seed S_t (in tons) sold in the Swiss market in each year t:

$$A_t = (S_t * 10^6) r^{-1} p^{-1}, \tag{1}$$

where r is the seed rate (seed needed for one ha in grams) and p is the seed replacement rate, which is the proportion of farmers buying new seed as opposed to using farm-saved seed (ranging between zero and unity). Both parameters are assumed constant over the calculation period. The recommendation for the seed rate remained unchanged between 2006 and 2019 (GZPK 2020; GZPK pers. comm.). As further explained in Section 2.3, the seed replacement rate is extremely high amongst Swiss farmers growing organic wheat (close to 100 per cent), so most used seed is bought at the beginning of the cropping cycle (GZPK 2020; GZPK pers. comm.).

As data equation (1) is calculated with actual data, available until 2019, a variety-specific adoption profile needed to be estimated for future projections from 2020 until 2030 by assuming a logistic curve for Wiwa uptake. This is in line with similar studies (e.g. Maredia *et al.* 2000; Bantilan *et al.* 2005; Robinson and Srinivasan 2013; Sequeros *et al.* 2019) and the theory of innovation diffusion (Rogers 2010). It postulates that uptake of innovations is initially slow and then accelerates until it reaches a plateau:

$$A_{t+19} = U/[1+e^{-(a+b_{t+19}}], \tag{2}$$

where A_{t+19} is the total projected area planted with the crop variety in each future period $t+19$ (starting 19 years after the introduction, where our actual data ends), U is the upper adoption limit, as explained at the end of Section 2.1, a is the intercept, and b is the slope coefficient measuring the rate of variety uptake. The adoption values computed with actual data in equation (1) and forecast with equation (2) are shown in Fig. 2 in Section 3.1.

Linear transformation creates an equation, where parameters a and b can be estimated using the standard linear regression based on the existing observations for A_t and assuming a realistic value for U (Schreinemachers *et al.* 2017):

$$\ln\left[A_{t+19}/\left(U - A_{t+19}\right)\right] = a + b_{t+19}. \tag{3}$$

According to the economic surplus model, adoption of the new variety induces a shift in the supply, known as 'K-shift' (Alston *et al.* 1995). This shift can be determined using data on the benefits of the new variety and the estimations from equations (1) and (2). It represents technological change due to output improvements or due to a reduction of production costs once the innovation diffuses amongst farmers. If the new technology simply enhances yield or reduces yield variability, then the producer sells more of the good in the market. If it also enhances quality, then more premium goods are sold in the market. K_t defines the benefit and cost changes in year t due to technological change. Following Alston *et al.* (1995), the supply shift was derived as

$$K_t = A_t\left[\left(\Delta Y/Y_t\right)/\varepsilon + \left(\Delta C/Y_t P_t\right)\right], \tag{4}$$

where ΔY represents the gain attributable to the new variety, which is assumed constant over the calculation period, Y_t is the average national reference value in year t, ε is the price elasticity of supply for the crop, ΔC is the difference in cost between the new variety and the previously dominant varieties, and P_t is the selling price of the crop in each period. In Section 2.5, the scenario-specific calculations of the 'K-shift' are explained.

Positive changes in K_t should boost total supply due to higher profits and a corresponding expansion of the planted area by farmers. This growth is presumed to put downward pressure on the market price, depending on the shape of the demand curve. The market mechanism is illustrated in Fig. 1 in Section 2.5. As defined in Alston *et al.* (1995), Z_t describes the price effect as follows:

$$Z_t = K_t\varepsilon/\left(\eta + \varepsilon\right), \tag{5}$$

where η is the price elasticity of demand.

Ultimately, the total welfare effect is computed by combining the supply shift K_t and the price effect Z_t. The economic surplus ΔTS (in CHF) comprises producer and consumer

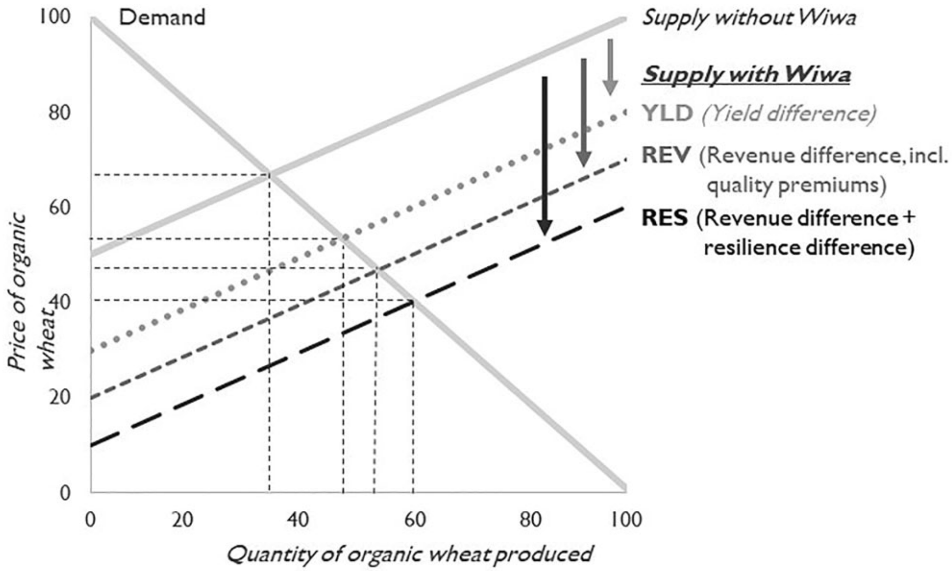

Figure 1. Conceptual frame of 'K-shift' in three different scenarios (general organic wheat price and quantity for scenario YLD, price and quantity of high quality organic wheat included for scenarios REV, and RES).

gains (Alston *et al.* 1995; Robinson and Srinivasan 2013). It is calculated as follows:

$$\Delta TS_t = P_t Q_t (1 - s) K_t (1 - 0.5 Z_t \eta), \tag{6}$$

where Q_t represents the sold output (in tons) and s is the proportion of output reused in the next cropping season.

2.3 Data for estimating economic impact

Adoption rates. No data on Wiwa adoption is available, but comprehensive information for exact estimation could be collected. To obtain the adoption rate (A_t), it was the first necessary to calculate the potential area planted with the Wiwa variety, using seed production and seeding rate information. Seed production (S) data were taken from the Swiss Seed Producers Association Swisssem (pers. comm., 24 February 2020). It increased from 11 tons in 2006 to 629 tons in 2019. For the seeding rate (r), the value of 190,000 g/ha, the optimum sowing date provided by UFA Samen (2020), was chosen. We estimated the seed replacement rate (p) based on expert opinion (GZPK 2020; GZPK pers. comm.). Semi-structured interviews were conducted with experts in wheat research, breeding, propagation, and distribution of the Wiwa variety. These experts were recruited by e-mail, and all interviews were conducted one-to-one, mainly by telephone. Organisations from which key experts were recruited are listed in Table 1. Per organisation approximately 2–3 experts were interviewed.

According to the experts, self-propagation of organic winter wheat seed is hardly practised in Switzerland due to the high risk of plant diseases. This is in line with our calculations, as the seed production quantity corresponds to the cultivated winter wheat area, based on a seeding rate of 1 ton per 5 hectares[1]. As a result, we consider a seed replacement rate of 99 per cent as exact. Per this rate, the proportion of the harvest retained from Wiwa production to produce seed (s) is tiny, at 0.1 per cent.

The total area planted of organic winter wheat in Switzerland from 2006 to 2019 was taken from the Swiss Federal Statistical Office (BFS, pers. comm., 10 June 2020). In this

Table 1. Expert opinions.

Organisation	Expertise	Roles
Agroscope (Swiss Federal Centre for Agricultural Research)	Wiwa, Titlis, and Runal trial data	Breeding and variety trials
Agristat (Swiss Farmers' Association)	Swiss crop statistics	Advocacy and advisory services
BFS (Swiss Federal Statistical Office)	Swiss crop statistics	Administration
Bundessortenamt (German Federal Plant Variety Office)	German crop statistics	Administration
ÖBBW (Organic Advice Baden-Württemberg)	Trial data from Germany	Advisory services
Bioland-Handelsgesellschaft (Bioland Trading Baden-Württemberg)	Organic seed multiplication and distribution	Marketing
GZPK (Cereal breeding company Peter Kunz)	Wiwa breeding stages and investments	Breeding and variety trials
LTZ Augustenberg (Centre for agricultural technology Augustenberg)	Trial data from Germany	Advisory services and variety trials

period it increased from 2,321 to 6,001 ha. Ultimately, adoption rates for 2006–19 were calculated by dividing the estimated Wiwa area by the total organic winter wheat area.

Time series data of Swiss organic winter wheat crop yields (YLD_t) were estimated based on individual yield reports submitted by farmers to the Agristat system of the Swiss Farmers' Association (Agristat, pers. comm., 3 March 2020).

Wheat prices. National average wholesale prices (P_t) for organic winter wheat (Franco mill grinding wheat *Knospe*[2]) for the years 2013–9 were taken from the Swiss Federal Office for Agriculture (BLW 2020). As the data for the years before 2013 were not available from official sources, the price data from 2006 to 2012 is based on reference prices obtained from Bio Suisse (pers. comm., 2 July 2020). We calculated the average price difference for 2013–9 of the BLW and the Bio Suisse data. As the Bio Suisse reference prices are always lower than the actual prices, we added the average price difference of 105.90 CHF/t to the reference prices in order to determine the approximate prices for the years 2006–2.

The supply elasticity (ε) in the economic surplus model was set to 0.35 following Ricci *et al.* (2019), findings on wheat supply elasticity in Italy. This is within the range specified by Masters *et al.* (1996), indicating that supply elasticity estimates should lie between 0.2 and 1.2. The demand elasticity (η) was set to –0.7 following Abdulai (2002), who examined cereal demand in Switzerland. Sensitivity analysis was performed for both parameters to test the robustness of study results in response to elasticity changes.

Crop characteristics. As mentioned in Section 2.1, a key challenge when estimating crop improvement returns is identifying a suitable counterfactual. To this end, we relied on data for two previously dominant winter wheat varieties, called Runal and Titlis. These are conventional cultivars that have been widely used in the organic wheat production system in Switzerland. We selected these two varieties based on expert interviews (Agroscope 2020; GZPK 2020; GZPK, pers. comm.) and 'Swisssem' seed production data. Runal and Titlis were introduced to the market about 10 years before the introduction of Wiwa. As done in similar studies (e.g. Alene *et al.* 2009; Sequeros *et al.* 2019), we assumed that, in the absence of Wiwa development, it is likely that farmers would have continued to use the

Table 2. Key crop characteristics.

Parameters	Units	Wiwa Ø 2006–9	Wiwa Semideviation	Ø Runal/Titlis Ø 2006–19	Ø Runal/Titlis Semideviation
Average physical yield	t/ha	4.55		4.49	
Average sales revenues	CHF/ha	5289.70		5219.01	
Processing quality premium (HLM)	CHF/ha	18.30		4.69	
Nutrient quality premium (protein)	CHF/ha	41.42		31.48	
Total sales revenues	CHF/ha	5349.42	588.97	5255.18	642.40

Note: Own calculations based on data provided by Agroscope (2020); semi-deviation only calculated for total sales revenues.

dominant varieties that they were already familiar with and that corresponded to seed regulations in the organic sector. Therefore, the selected cultivars are considered to provide a valid counterfactual for our analysis.

To assess differences in yield, quality, and risk between Wiwa and the two previously dominant varieties, we relied on trial data from the Swiss agricultural research centre Agroscope (see Table 2). The Research Group 'Varieties and Production Techniques' has been carrying wheat trials under organic conditions for over 20 years (Agroscope 2020). Wiwa was introduced to the market in 2006, so our analysis required times series data starting in that year and ranging until 2019.

Based on Bio Suisse payments for organic wheat, the three economically most relevant features tested in the field trials were included in our analysis. In addition to the grain yield, these are hectolitre mass (HLM) and the percentage of protein content in the grains. The protein content is a nutrient quality criterion, and a high percentage is rewarded in monetary terms. The same applies to HLM, which is a processing quality criterion. The premiums and discounts were based on the 2019 Bio Suisse purchasing conditions for bread cereals (see Bio Suisse 2019). Trial data thus allowed a monetary valuation of the quality differences.

In addition to yield and quality differences, the risk profiles of the crops at hand were considered a critical factor in the analysis. Organic breeding aims at providing farmers with resilient cultivars. Stable financial returns are an important consideration in cultivar choice for farmers. In this regard, rather than overall fluctuations, it is important to capture below-average performance. Negative deviations from the expected yield are most problematic for farmers. Therefore, it was decided to measure the downside risk of Wiwa as compared to that of Runal and Titlis. Downside risk has been specified as semi-deviation (Nawrocki 1999).

2.4 Breeding investments

As shown in Table 3, we calculated the investment cost of (1) breeding, (2) registering, (3) disseminating, and (4) maintaining the Wiwa variety by the Peter Kunz Breeding Company (GZPK) based on the actual costs incurred for the different steps in the process of breeding winter wheat. We set the starting year for calculating the investment costs at 1988 when the breeding process of the Wiwa variety began. As the maintenance breeding is still ongoing, we predicted the same values for continuing maintenance breeding in 2020–30.

We distributed the total costs amongst the successfully registered and marketed varieties, including seven other varieties besides Wiwa. These varieties overlap time-wise with Wiwa in at least one of the four breeding steps. The allocation of costs to the eight varieties was based on the sum of seeds sold from 2004 to 2019 (Swisssem, pers. comm., 24 February 2020) and was calculated separately for each breeding step. Due to Wiwa's dominance in seed sales, this variety accounted for between 80 and 96 per cent of total costs.

Table 3. Breeding costs of the Wiwa winter wheat variety.

	Time period	Wiwa breeding costs in 1,000 CHF, real 2015
Breeding	1988–2001	470.4
Registration	2001–5	10.2
Dissemination	2005–6	13.5
Maintenance breeding	2006–19	52.9
Total breeding costs	1988–2019	547.0

Note: Based on GZPK (pers. comm., April 2020)

Since the Wiwa variety is successfully cultivated in Switzerland and to an even greater extent in Germany, we have allocated only 40 per cent of the total costs to Switzerland. The adjustment factor calculation of 0.4 is based on seed production data and the assumption that approx. One ton of seed is needed for five hectares of land. As German data was only available from 2010 to 2018, the average of these years was used to allocate the share for both countries. We have taken the Swiss data from Swisssem and included a seed replacement rate of 99 per cent into the calculation (see Section 2.3). To calculate the area under Wiwa cultivation in Germany, data from the federal plant variety office on the quantity of certified seed was used (Bundessortenamt, pers. comm., 24 March 2020). However, there is some uncertainty associated with these data, as the seed may come from both domestic and foreign production. The seed replacement rate p for Germany is also subject to uncertainty, as it is based on the judgment of a few experts only (Bioland-HG, pers. comm, 12 March 2020; Saatgut-Treuhandverwaltungs GmbH, pers. comm., 8 April 2020). According to the best information we could obtain, we have assumed a value of 50 per cent for p.

The costs and benefits were deflated (BFS 2020) and converted to net present values by compounding historical values and discounting future values at a real discount rate of 5 per cent per year, as used in comparable studies (e.g. Alene *et al.* 2009; Schreinemachers *et al.* 2017).

2.5 Scenario development

This study tests three main scenarios, which closely build on each other. Key-informant interviews clearly highlighted the importance of yield, quality, and risk differences in the Wiwa case. In addition to yield, quality, and risk are key parameters for assessing economic performance, as high-quality levels are financially rewarded, and high risk implies potentially high monetary losses. Experts pointed out no differences in production costs when comparing Wiwa to the Runal and Titlis varieties (GZPK 2020; GZPK, pers. comm.). This is also confirmed by trial data (Agroscope pes. comm.). Therefore, the baseline scenario models the 'K-shift' primarily as a function of physical yield gain, reflecting the approach frequently found in other studies (e.g. Alene *et al.* 2009). The subsequent scenarios introduce aspects of quality improvement and risk reduction. From the original supply shift formula in equation (4), three scenario-specific formulae for K_t have been developed, illustrated in Fig. 1.

In the first scenario (YLD), enhanced supply is characterised by a yield gain (in *t*/ha) only

$$K_{t\mathrm{YLD}} = A_t\left[\left(\Delta\mathrm{YLD}/\mathrm{YLD}_t\right)/\varepsilon\right], \tag{7}$$

where ΔYLD represents the increase in physical yield from the Wiwa variety (using agronomic data from 2006 to 2019). YLD_t is the average national reference yield for winter wheat in year t (from 2006 to 2019). The price elasticity of supply for the crop is given by ε (see section 2.2), with $\mathrm{A_t}$ assuring scaling following the Wiwa adoption rate.

In a second scenario (REV), the 'K-shift' is defined by a change in sales revenues

$$K_{t\mathrm{REV}} = A_t\left[(\Delta\mathrm{REV})/(\mathrm{REV}_t)/\varepsilon\right], \tag{8}$$

where ΔREV represents the mean revenue change due to the introduction of Wiwa, which includes average yield gain (ΔYLD) valued at average organic winter wheat prices plus the average gains in Bio Suisse price premium payments described in Table 1 (Processing quality premium and nutrient quality premium, both based on a 2006–19 average). REV_t is the national organic winter wheat reference revenue in each year t (from 2006 up to 2019). It is based on YLD_t parameters valued at yearly organic winter wheat prices P_t plus annual differences in quality premium payments. Wiwa and Runal/Titlis processing and nutrient quality were prized for each year using the Bio Suisse payment scheme as reference. With this, the difference in the premium payment could be computed for each year. To reflect the fact that the share of Wiwa and thus the composition of the overall organic winter wheat variety portfolio is changing over time, the annual gain in premium payments was adjusted for the Wiwa adoption rate in year t.

The third scenario (RES) involves an extended version of the economic surplus model. In this scenario, the 'K-shift' is characterised not only by a revenue gain but also by a reduction in downside risk. We consider that less negative divergence from the expected average yield translated into higher economic resilience of the organic wheat enterprise of the farm. The risk parameters are calculated for those years with revenues below the average revenue by subtracting the actual revenue from the average value. The resulting differences are then squared. The square root of the mean squared differences represents the semi-deviation or downside risk, a reduction of which corresponds to a gain in resilience

$$K_{t\mathrm{RES}} = A_t\left[((\Delta\mathrm{REV})/(\mathrm{REV}_t) + (\Delta\mathrm{SED})/(\mathrm{REV}_t))/\varepsilon\right], \tag{9}$$

where an extra term is added to equation (8), with ΔSED representing the difference in semi-deviation of sales revenues when comparing the new variety to the counterfactual. For each year, this value, reflecting the crop's comparative resilience, is put in relation to the overall revenues REV_t.

3. Results

3.1 Adoption profile

Adoption of the Wiwa variety started in 2006. There has been a substantial increase in the area under organic winter wheat in Switzerland, from 2,321 ha in 2006 to 6,001 ha in 2019. At the same time, the overall winter wheat area in Switzerland slightly decreased from 78,180 ha in 2006 to 72,741 ha in 2019 (BFS, pers. comm., 10 June 2020). For our projection, we assumed that this trend continues so that the organic winter wheat area reaches 11,879 ha in the final year of the forecast, which is 2030. The adoption calculations for Wiwa, as defined in equation (1) in Section 2.2, resulted in an initial coverage of 58 ha, which grows to 3,344 ha in 2019, representing a 56 per cent share. This is in line with expert opinions. We then assumed a declining share of Wiwa in the years after 2019. As explained in Section 2.1, this assumption is based on likely resistance breaks and promising new organic wheat varieties. Future use of the variety was estimated based on the adoption model defined in equations (2) and (3) in Section 2.2. It yielded an area of 3,981 ha for the year 2030, representing a share of 34 per cent, as shown in Fig. 2.

3.2 Returns to investment

The three scenarios explained in Section 2.5, were evaluated for the Wiwa variety in terms of BCRs and the internal rate of return (IRR). While BCRs compare the aggregate net present value of the economic surplus to the aggregate net present value of the investment and maintenance costs, the IRR measures the profitability of the breeding project.

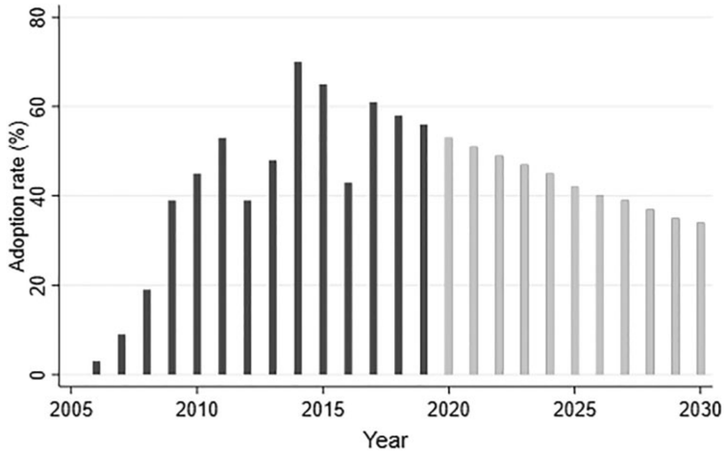

Figure 2. Adoption profile of the Wiwa winter wheat, 2006–30 (forecast values from 2020 onwards).

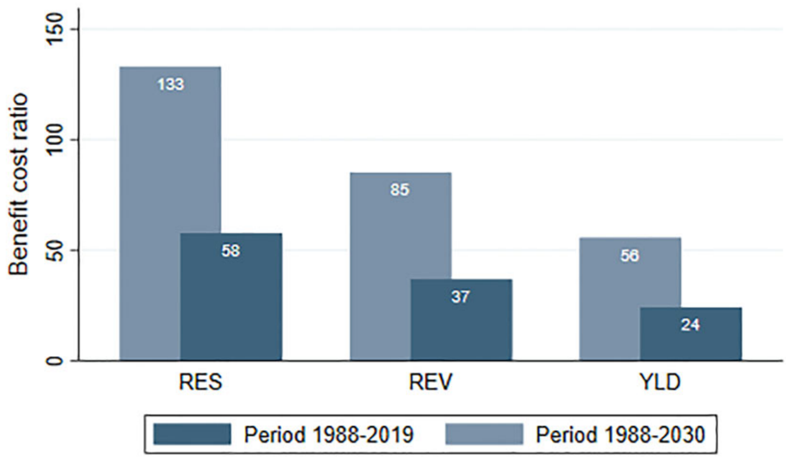

Figure 3. Benefits cost ratios for the three model scenarios by calculation period (YLD—yield difference; REV—revenue difference, incl. quality premiums; and RES—revenue difference + resilience difference).

It represents the discount rate that makes the net present value of all cash flows equal to zero.

Findings for the periods from 1988 to 2019 and from 1988 to 2030 are reported separately and are displayed accordingly in Fig. 3. The BCR for the simple yield gain scenario (YLD) ranges between 24 and 56. Once quality differences between Wiwa and Runal/Titlis are accounted for in the revenue gain scenario (REV), the ratio increases to 37 and 85, respectively. Ultimately, downside risk aspects were included in the resilience gain scenario (RES). Here, the BCR rises to 58 for the current period and 133 once future benefits are considered. The IRR starts at 13.5 and 15.5 per cent in the YLD scenario and reaches 16 and 17.7 per cent for the respective calculation periods in the REV scenario. In the RES scenario, the rate lies at 18.6 per cent for the period up to 2019 and at 20 per cent for the period up to 2030.

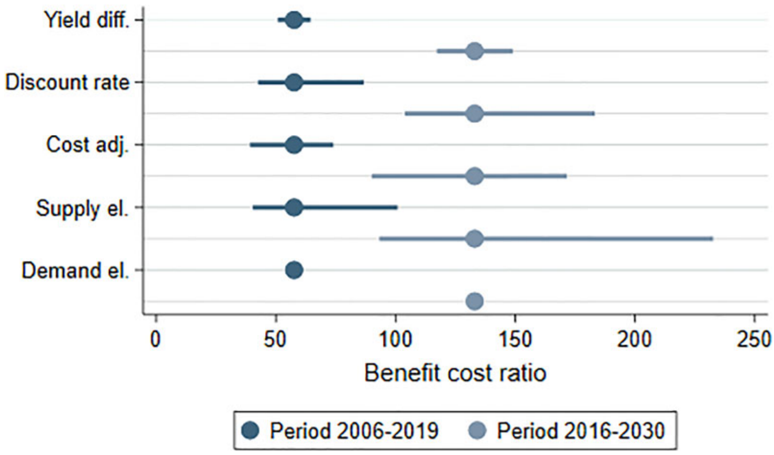

Figure 4. Sensitivity ranges for key model parameters by calculation period.

3.3 Sensitivity tests

Sensitivity tests were carried out for model parameters, which are considered key leverage points and subject to a degree of uncertainty. This includes the yield difference between Wiwa and the previously dominant varieties. Here, the yield premium was first reduced by 25 per cent and then increased by 25 per cent to test its influence on the results. As part of the sensitivity testing, the standard discount rate of 5 per cent was set at 3 and 8 per cent, respectively. To reflect the fact that more than half of the entire area cultivated by Wiwa is outside of Switzerland, investment costs were adjusted downwards using a multiplication factor of 0.4, as explained in Section 2.3. Here, we also test adjustment factors of 0.3 and 0.5. Finally, elasticities for supply and demand were included in the uncertainty analysis. The supply elasticity of 0.35, as specified in the literature, was alternatively set to 0.2 and 0.5. Demand elasticity was reduced to –0.3 and increased to –1.5 from the ordinary model coefficient of –0.7.

In this paper, we focus on the sensitivity results for the main RES scenario. Figure. 4 shows that the results for this scenario are somewhat sensitive to the specification of the discount rate, the cost adjustment factor, and the supply elasticity. In particular, a lower supply elasticity and a higher discount rate produce substantially higher BCRs. For the current period up to 2019, the ratio is diminished from 58 to approximately 40 when applying a higher supply elasticity, a lower discount rate, or a bigger cost share by changing the cost adjustment factor. The model appears relatively robust to changes in the yield difference. As these differences are based on highly detailed trial data, the 25 per cent downward and upward adjustments in the sensitivity testing are considered more than sufficient to capture possible on-farm deviations from the trial results. Finally, it should be noted that model outcomes are only minimally affected by changes in demand elasticity.

To sum up, the uncertainty analysis demonstrates that model outcomes are rather robust within certain ranges, with the highest uncertainty regarding the supply elasticity parameter (see Fig. 4). As expected, sensitivity to model specifications increases with extending the calculation period. Still, trends are confirmed for the analysis until 2030. Parameter choices are generally backed up by data or literature and are deemed reasonable.

4. Discussion and conclusion

Winter wheat is one of the most important arable crops in Switzerland. While there is a substantial investment in conventional wheat breeding, the situation in organic breeding is quite different. At the same time, however, the organic winter wheat area share has almost tripled in the last 15 years, reaching 8.25 per cent of the total wheat area (BFS, pers. comm., 10 June 2020). It is therefore important to better understand the role of crop improvement based on organic principles. This study contributes to closing the scientific gap on the economic benefits of organic wheat breeding by quantifying rates of return from a societal perspective. Considering that the organic sector is still a niche market and that R&D spending in the sector lags far behind conventional agriculture, the results show how investments in breeding the organic Wiwa wheat variety produce attractive returns.

It should be noted that this is contingent on a sizeable uptake of the variety, which has not been the case for other organic wheat varieties so far. Depending on the respective scenario, the IRR ranges between 13.5 and 18.6 per cent for the period up to 2019. Moreover, benefits from the investments significantly outweigh costs, being 58 times higher in the resilience scenario (and 133 times higher once future benefits are accounted for). Such positive returns are in line with the results of other studies that have quantified the rate of return to crop improvement research in wheat varieties (e.g. Azzam *et al.* 1997; Marasas *et al.* 2003; Thakur *et al.* 2007). In conventional breeding, studies generally produce higher estimates though. Concentrated know-how, economies of scale and geographical scope are all possible explanations for the gap in rates of return between organic wheat breeding and conventional wheat breeding.

The present study provides evidence that investments in organic crop improvement research can pay off, especially when quality and resilience gains are accounted for. For the Wiwa case, economic returns were estimated by valuing the grain yield, the nutrient quality (protein content), the processing quality (HLM), and the risk profiles of the varieties (semideviation). We consider the downside risk as a key distinguishing factor in the analysis, as a central goal of organic breeding lies in supplying farmers with robust and resilient cultivars. In the context of climate change, we expect that this breeding goal will even attain greater importance, not only in the context of organic farming. Therefore, some relevant spill-over effects from organic breeding to conventional farming are likely to happen in the future. Already, in the case of Wiwa, this is happening to a small extent. A significant challenge will be to address trade-offs that exist between yield, quality, and risk performance. While retailers focus mainly on quality parameters such as protein content, farmers, and policymakers are more interested in yield stability.

Overall, organic crop improvement is still in its infancy. Existing initiatives have fragmented and insecure funding (Wirz *et al.* 2017). Compared to the Wiwa study, it can therefore be expected that higher BCRs will be achieved in the future, but targeted investments into the organic crop improvement sector are required. Regarding this type of analysis, it is important to note the difference between a private business perspective and a welfare economics perspective. Considerable social gains do not imply the profitability of the breeding activities themselves but demonstrate the larger benefits of R&D investments. In fact, small breeding initiatives often struggle to cover their costs. The positive findings on the broader economic welfare of organic crop improvement provide a rationale for developing creative funding solutions and boosting the sector's public and private R&D spending. Value chain partnerships and pool funding are ways of distributing the financial burden amongst multiple actors who benefit and collectively secure the integrity of the future organic product supply (Messmer *et al.* 2019; Winter *et al.* 2021). At the same time, there is also a case for higher R&D funding of organic breeding through public initiatives. While organic breeding companies will benefit, it will most likely also increase competition as larger seed companies enter the organic breeding market. Ultimately, a growing market should lead to a greater diversity of varieties and potentially more choices for farmers. This will help to achieve more sustainable farming systems in line with policy goals.

Supplementary material

Supplementary data are available at *Q Open* online.

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End Notes

1 A total of 6,001 ha total area planted organic winter wheat CH 2019 (BFS, pers. comm.,10 June 2020); approximately 1 t seeds per 5 ha; 1,503 t total organic winter wheat seed sales CH 2019 (Swisssem 2020) ≙ 7,515 ha.
2 Organic label in Switzerland.

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