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Christian Jörgensen

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- just like any other crop?

AgriFood Economics Centre

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Foreword

Developing sustainable global food production and ensuring food security will require both adaptation of current production systems and the innovation of new products and technologies. New crop varieties have the potential to simultaneously increase yields and reduce the adverse environmental impacts of the agricultural sector. The utilization of New Genomic Techniques (NGT) offers a means to develop crops with specific attributes to a comparable low cost. The potential benefits of NGT are considerable, yet the future benefits of NGT deployment is dependent on several factors, such as the characteristics of the new crops developed and consumer attitudes toward them. This report discusses the potential cost and benefits of regulating NGT crops as if NGTs are treated as traditional breeding techniques and not genetically modified organisms (GMOs) in the legislation. Two NGT potato varieties are used as a case study to exemplify the societal costs and benefits.

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Summary

Food production is continuously facing the challenge of satisfying an increasing demand. The global population is projected to increase by 1.5 billion by 2050. The population is not only growing larger but also becoming wealthier. The latter implies that, on average, people will demand food that requires more resources. Land for agriculture is also becoming scarcer, and farming conditions are worsening due to weather events. Agriculture is a significant contributor to climate gas emissions, water pollution, and deforestation. Therefore, enhancing productivity in agriculture is imperative to match supply with demand and minimize its environmental footprint.

Innovations in agriculture and food production in the past century were largely successful in securing enough food for an increasing population with higher demands in their food choices. Better irrigation, more potent fertilizers, and pesticides were important in making agriculture more resilient and increasing harvests. Another key area of innovation has been plant breeding. Throughout the 20th century, groundbreaking methods for plant breeding emerged, leading to higher yields and increased farm productivity.

Still, despite key improvements in agriculture, many people suffer from malnutrition and hunger. Although innovations alone in agriculture and along the food chain are not sufficient to secure food supply, they are a prerequisite. Recently, new genome editing techniques (NGTs) have emerged, increasing the opportunities for creating plants that increase yields, reduce the use of inputs like pesticides, and make crops more nutritious. A very small number of NGT plants have been commercialized outside the EU, but many are being developed across a wide variety of plants and for different traits both inside and outside the EU.

NGTs provide the opportunity to breed plants at a comparable low cost with valuable traits for both consumers and society. However, the future use of NGTs depends on how they are regulated and the attitudes

towards NGT food by consumers. Currently, NGTs are regulated as genetically modified organisms (GMOs) in the EU. This regulation effectively places a moratorium on the cultivation of NGTs and therefore NGT plants, while the regulation of NGTs in non-EU countries tends to be less restrictive.

Regulating NGT plants as traditional bred plants would facilitate market access and increase the prospects of cultivating NGT plants in the EU. There have recently been calls for the deregulation of NGTs, and the Commission proposed a measure to ease market access for NGTs as recently as July 2023. This study aims to illustrate the economic effects that result from treating NGTs as traditional breeding techniques and not as GMOs in the regulation. The study takes into account benefits and costs for consumers, firms, and citizens who are consumers. The study relies on a literature survey and a cost-benefit analysis of two different NGT potatoes.

According to scientific consensus, NGTs are more precise than other breeding technologies. The use of NGTs per se does not introduce additional risks in plant breeding. Treating NGTs as traditional breeding technologies would therefore expand the opportunity to create a wider variety of traits, all while no additional risks have been identified. The cost-benefit analysis for ware potatoes and starch potatoes suggests that the gains may, in the long run, amount to EUR 500 million at the EU level.

NGTs can be an important instrument to achieve the goals stated in the Farm to Fork Strategy. However, market success and benefits are conditional on consumer acceptance. Consumer studies suggest that consumers are currently hesitant toward NGTs. These studies, however, are based on hypothetical scenarios and cover only a small sample of the EU population. Revealed and stated preferences may also differ substantially, as suggested by actual consumer behavior in the US. Consumers also tend to be more positive towards NGT food than GMO food, and consumer acceptance may increase over time with more knowledge.

Treating NGTs as traditional breeding techniques does not require mandatory labeling of NGT food, unlike if they were treated as GMOs. This may impede consumer choice and result in a loss for consumers. However, it is possible for agents to uphold voluntary labeling, though there is a risk that such schemes may become misleading. Regardless of whether labeling is mandatory or voluntary, it may still be misleading, as it is not always feasible to analytically trace the use of NGTs in food and feed.

1 Introduction

Agriculture is the foundation for the global food supply and it faces the challenge of satisfying an increasing food demand parallel with a growing world appetite for biofuels and plant fibers such as cotton. Many farmers are simultaneously encountering worsened conditions for agriculture due to climate change, land degradation and less available freshwater. Recent extreme weather events such as droughts and floods have also suppressed supply and been a cause of higher food prices (GRFC, 2023). Technology improvements in agriculture are therefore crucial to lower the environmental impact of food production, increase productivity, lower food prices, and so prevent and ease disruptions to the food supply.

Global food supply largely managed to keep pace with the growing demand from a larger and wealthier population over the past century, although severe poverty and conflicts keep almost 10 % of the global population affected by hunger.[1] Food production almost quadrupled and one crucial component of yields keeping up with demand was the introduction of new plant varieties obtained through enhanced plant breeding techniques. However, the increasing use of agricultural inputs such as land, fresh water, pesticides, and fertilizers degraded land and water, released large amounts of climate gases, and spared less land for natural habitats, thus reducing biodiversity. About half of all habitable land is now dedicated to food production and around 70 % of the global freshwater withdrawals are used in agriculture (FAO, 2022). It has been estimated that hectare yields on existing agricultural lands must increase by about 60 % compared with 2010 to meet the projected growth

[1] See FAO, IFAD, UNICEF, WFP and WHO (2022) for the state of global malnutrition and hunger.

in demand by 2050.[2] Otherwise more land must be used for agriculture, increasing the risk of deforestation and reducing the opportunity to use land for other purposes.

Plant breeding and other technological improvements in irrigation and tillage are key to achieving a sustainable increase in food production. Techniques for genome editing have significantly multiplied just in the last two decades, opening up new opportunities for plant breeding. Current and further enhancements in genome editing can be a vital technology leap to feed an increasing population by enabling greater productivity and more resilient production.

The prospect of cultivating NGT plants affects both consumers and producers. Although potential regulatory uncertainty persists regarding NGTs, NGT plants and food and feed therefrom are currently considered to fall under the scope of the EU regulation of genetically modified organisms (GMOs) implemented in the early 2000s (European Commission, 2023). The legislation implies a de facto moratorium on the cultivation of NGT plants in the EU, as no GMO plants have been authorized for cultivation since the legislation was enforced.[3] The regulation therefore provides a strong disincentive for the use and development of NGTs and there is a perception of overregulation and calls to revise the legislation by scholars, industry, the agricultural community and public authorities, as well as political entities such as the European Commission and the European Council.[4]

In 2019, the Council of the European Union asked the Commission to provide a study of NGTs under Union law and propose, if appropriate, a legislative framework adapted for NGTs. The request from the Council in 2019 stated:

[2] See World Resources Institute (2019), where results stem from modelling crop yields, land use and demand.
[3] The only cultivated GMO, and the only GMO that is authorized to be cultivated in the EU, is the maize MON 810, which was approved in 1998 prior to the current legislative framework.
[4] NGOs and retailers on the other hand tend to support maintaining the status quo (European Commission, 2023).

"The ruling brought legal clarity as to the status of new mutagenesis techniques, but also raised practical questions which have consequences for the national competent authorities, the Union's industry, in the plant breeding sector, research and beyond. Those questions concern, inter alia, how to ensure compliance with Directive 2001/18/EC when products obtained by means of new mutagenesis techniques cannot be distinguished, using current methods, from products resulting from natural mutation, and how to ensure, in such a situation, the equal treatment between imported products and products produced within the Union."[5]

Thus, questions remain about how to regulate NGT products in practice, as they cannot always be distinguished from products derived from natural mutations. According to the Council, it therefore remains unclear how the current legislation will affect the Union's industry, plant breeding, and others.

In 2021 the European Commission published a roadmap for a legal framework for NGTs and their use in food and feed. Its aim was to enable innovation in plant breeding while maintaining a high level of protection for human and animal health, as well as the environment.[6] A deregulation of NGTs may in turn help fulfill goals such as providing affordable and nutritious food in a sustainable manner, as set out in the "Farm to Fork Strategy" which is an integral part of the European Green Deal (European Commission, 2020). The European Commission provided the study in 2021 (SWD(2021) 92) and as recently as 5 July 2023 presented a proposal for a legislative framework that, according to the Commission, should be adapted to make NGTs subject to the appropriate level of regulatory oversight (European Commission, 2023). If implemented, it will lift the de facto moratorium for many NGT plants by treating them as traditional bred plants and not GM plants in the legislation. Before the proposal, or a version of it, becomes law though, it must be approved by both the Council and the European Parliament.

[5] See https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019D1904&from=EN.
[6] See Legislation for plants produced by certain new genomic techniques (europa.eu).

The purpose of this study is to assess the potential economic benefits and costs if NGTs are regulated as traditional bred plants and not GMO plants in the EU. The study therefore illuminates the economic impact of deregulating NGT plants and food therefrom in the EU. The study assesses the economic impact on innovation, production, and consumers. The study also addresses issues such as food security and environmental concerns. Finally, we provide a case study with a cost-benefit analysis of a legislative change that would treat two NGT potatoes differently if they were to fall under the legislation of plants from traditional breeding technologies.

The study is restricted to plants for food production and hence does not consider the use of NGTs for other purposes, such as fiber production, the breeding of micro-organisms, animal breeding or gene therapy in humans. Besides a cost-benefit analysis for two NGT potatoes, the study utilizes a literature review as its primary methodology.

We begin by giving a background to various breeding technologies and how NGTs relate to them. Then, we address NGT plants that are commercialized and in development and their traits. Next, we describe the current EU legislative framework that regulates NGTs as GMOs, followed by a costs and benefits analysis of treating NGT plants as conventional plants. Thereafter we discuss the findings of the case studies. The paper ends with a concluding discussion.

1.1 NGTs, GMOs and traditional breeding techniques

Humans have practiced plant breeding since the beginning of agriculture about 10,000 years ago (von Bothmer et al., 2015). The first traditional breeding techniques involved domestication of wild plants. Mass selection was practiced, where seeds from selected plants were mixed and stocked and then sown. Later, around 1900, seeds from individual plants were collected and sown in what is known as pure-line selection. The selection process tends to create genetic erosion, i.e. when the gene pool diminishes, and this bottleneck for plant breeding leads to various techniques to induce mutations and artificially increase genetic variation (Sikora et al., 2011). Induced mutations with the help of irradiation to create mutants with desirable traits were introduced in the 1920s (von Bothmer et al., 2015). This method was complemented by chemical mutagens in the 1940s that were easier to work with and less destructive on the genome, i.e. all the genetic information of organisms, than irradiation (Sikora et al., 2011).

In the 1980s genetic engineering was applied in plant breeding (von Bothmer et al., 2015). It transformed plant breeding, as it made it possible to transfer genes between organisms, creating what has become known as GMOs. The genetic modification of marketed GM plants is transgenic, i.e. a gene transfer between not sexually compatible species, in contrast to cisgenic or intragenic, where genes are transferred within species. The technique involves identifying the genetic information that gives the organism its desirable traits. After identifying the genetic information, the process of generating GM plants involves the steps of isolating the genetic trait of interest, inserting the trait into a genome of another species and, finally, growing the GM plant and determining whether it can replicate. In 1994, the FLAVR-SAVR tomato was the first GM plant to be brought to market.

The latest and third phase of plant breeding, according to von Bothmer et al. (2015), is referred to genome editing and has evolved during the 21st century. The technology is based on the progress of mapping and understanding the genome. Improved computational power has accelerated the identification of genes underlying important agronomic traits relevant to food production and quality (Ricroch, 2020). With various tools (techniques) such as the so-called gene scissor CRISP/CAS9, genes can be moved between organisms or genetic alteration can be made within the same individual. NGTs in our study are defined based on the European Commission's impact assessment that states that NGTs are "techniques that are capable of altering the genetic material of an organism and that have emerged or have been developed since 2001,…"[7], that is, they are a genome editing technique as defined above. The definition

[7] See page 2 European Commission (2021).

draws a dividing line between GMOs and NGTs according to when the technology was developed.

Just as traditional breeding methods consist of many different diverse techniques, so do NGTs. One common denominator though is that they are target-specific, as they can create specific mutations and edits at chosen sequences in the genome (JRC,2021). The outcomes of using NGTs are therefore considered to be more predictable than other breeding techniques, although unwanted additional mutations, off-targets effects, are still possible.[8] NGTs *per se* have also been concluded not to carry new risks compared to plants obtained from conventional breeding techniques.[9] Like GMOs, NGTs can be transgenic, but those NGTs are treated as GMOs in the effort to update the legislation. Thus, some NGTs are defined as GMOs while others are not. In summary, NGTs are new mutagenesis techniques that have wide potential to change the genome, with an outcome that is considered more precise and predictable compared to other breeding techniques.

1.2 NGT plants commercialized and in pre-commercial stage

NGT plants are being developed by both private and public/academic entities. According to the European Commission (2021), public/academic entities tend to dominate research and development to a greater extent, while private firms dominate commercial and pre-commercial applications. There are at least two marketed NGT plants in at least one country globally, a soybean variety with a healthier fatty acid profile and a tomato fortified with an acid commonly sold as a dietary supplement (European Commission, 2021). Although only a few NGT plants are commercialized, many are in a pre-commercial stage. The lack of approval and commercialization partly reflects the fact that techniques such as CISPR/Cas9 have only been in use for a short period of time.

The network of European Sustainable Agriculture Through Genome Editing (EU-SAGE) provides an online database of NGT plants described in peer-reviewed scientific publications. In total, 719 NGT plants

[8] See for instance JRC (2021) and Sprink et al. (2022).
[9] See for instance EFSA (2022), EASAC (2020) and the Royal Society (2021).

were published and included in the database as per October 8, 2023. They involved 67 different plants and were categorized under eight different traits (see Table 1). Research institutes in 55 countries worldwide were associated with the development of the NGT plants.[10] Chinese research institutes were involved in the developing more than half of the NGT plants. Almost 13 % of the plants (93 NGT plants) were developed by researchers affiliated with institutes in EU countries. Most of them were developed by researchers located in France and Germany, 31 and 24 respectively, while the other 38 NGT plants are spread across 11 other EU countries.[11] CRISPR/Cas9 is by far the predominant technique used in both the EU and other parts of the world. As much as 94 % of NGT plants are developed by CRISPR/Cas9 in the EU, while the corresponding figure at the global level is as high as 90 %.

Most NGT plants are developed for the use of food or feed, but some have also been developed to produce wood, tobacco, and textiles. Table 1 shows the distribution of NGT plants for food production according to traits and plants in the database constructed by EU-SAGE.

The three most common traits in the EU (and worldwide), constituting more than three quarters of the traits, are stress tolerance, food/feed quality and plant yield and growth. Stress tolerance includes both abiotic stresses such as high salinity, drought and heat, and biotic stresses encompassing plants' exposure to bacteria, fungi, and parasites. Stress tolerance thus encompasses yield growth. Food/feed quality includes, among other things, health improving traits such as the removal of allergens. Almost 20 % of the traits are for industrial utilization. Finally, the traits of herbicide tolerance, which is a major trait in cultivated GMO plants, and increased storage performance of plants are found in about 10 % of the NGT plants.[12]

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[10] The database is found at https://www.eu-sage.eu/ .
[11] Italy (12), Belgium (10), Netherlands (8), Spain (7), Czech Republic (6), Sweden (5), Hungary (4), Poland (2), Denmark (2), Portugal (1) and Greece (1).
[12] In 2019, 43 % of all biotech crops cultivated on 81.5 million hectares had the single trait herbicide tolerant, while 45 % were grown with stacked traits which often included herbicide tolerance (ISAAA, 2019).

Table 1: Distribution of NGT plants developed for potential use for food production according to traits and plants

Developed in	EU	World
Traits related to:	Stress tolerance (30) Food/feed quality (26) Plant yield and growth (20) Industrial utilization (11) Herbicide tolerance (3) Storage performance (3)	Food/feed quality (209) Stress tolerance (197) Plant yield and growth (173) Industrial utilization (87) Herbicide tolerance (56) Storage performance (17)
Plants (top 7 among edible plants)	Tomato (25) Rice (13) Potato (10) Barley (9) Maize (7) Canola (6) Wheat (5)	Rice (258) Tomato (110) Maize (54) Soybean (46) Wheat (44) Canola (35) Potato (32)

Notes: Downloaded from the database at European Sustainable Agriculture Through Genome Editing (EU-SAGE). Stress tolerance includes both biotic and abiotic stress, and the trait color/flavour is included in food/feed quality.

Rice is by far the most common plant to have generated NGT events globally which, according to Ricroch (2020), can be explained by the major investments in biotechnology made by China. The main agricultural crops wheat, potato, barley, and maize constitute a little over 30 % of NGT plants developed in the EU. Many NGT variants associated with research institutes in the EU are hence found in crops cultivated on a large share of EU farmland. Compared to the commercialized GMO plants (mainly soybean, maize, canola, and cotton), NGT plants include crops such as wheat, barley, and potato that are important for agriculture in the EU.

As well as a comparably small proportion of NGT plants being linked to EU research institutes, only a few field trials of NGT plants have been initiated in recent years in the EU. Field trials are a prerequisite for the commercialization of plants and only 40 field trials were conducted or in progress between January 2015 and June 2020 using transgenesis and/or NGT plants in the EU, compared to at least 50 annually between 2002 and 2015 (Ricroch, 2020). Field trials were only conducted in seven countries, and more than half were in two countries: Spain and Sweden (Ricroch, 2020).[13] Field trials of GM plants are regulated, and individuals must apply for a permit to conduct them. One reason for both the low frequency in the EU and the discrepancy across individual member states is that, under EU Directive 2015/412 amending Directive 200/18/EC, they can restrict and prohibit GMO field trials in their territory.

[13] Rochrich (2020) includes the UK as a member state, which we ignore.

2 The regulation of NGT plants and food, and its enforcement

In this section we discuss the task of developing a process-based regulatory framework that covers NGT plants. This is indeed difficult, as technological developments within the field are moving very fast. A process-based regulatory framework therefore makes it difficult to harmonize legislation across countries and trading blocs, and to keep it updated to cover additional NGTs.[14] We also provide a short overview of how the legislation is enforced in the EU, which reflects the ambiguities that persist. Finally, the section presents the extent to which EU regulation harmonizes with the regulation of NGTs in other countries.

2.1 The legislative package that covers NGT plants and NGT products, and its rationale

NGTs are treated as GMOs in the EU legislation (European Commission, 2021). Directive 2001/18/EC, which came into force in 2002, regulates the deliberate release of GMOs into the environment. According to the Directive, GMO plants must pass a stringent and extensive assessment of their impact on safety for the general population and the environment. The precautionary principle is invoked in the legislation, which according to the Commission:

"[…] may be invoked when a phenomenon, product or process may have a dangerous effect, identified by a scientific and objective evaluation, if this evaluation does not allow the risk to be determined with sufficient certainty".[15]

[14] See Sprink et al. (2022) for the challenges of regulating NGTs.
[15] See The precautionary principle | European Union regulations | European Encyclopedia of law (lawlegal.eu).

The EU regulation goes beyond the cultivation of GMO plants and there are three other main pieces of legislation that also regulate the use of GMOs for food and feed, namely:

- Regulation (EC) No 1829/2003 on genetically modified food and feed;
- Regulation (EC) No 1830/2003 concerning the traceability and labelling of GMOs and the traceability of food and feed from GMOs; and
- Regulation (EC) No 1946/2003 on transboundary movements of GMOs,

Which covers the import of GM plants and the use of GM plants for food and feed. Regulation (EC) No 1946/2003 does, however, have no effect as it only considers the non-existent exports of GMOs from the EU. Where ingredients in pre-packaged food/feed contain GMOs, the product must be labelled "Contains GMOs", and if non-pre-packaged products contain GMOs, this must be displayed on the product or in the connection with it. Mandatory traceability of GMOs makes labelling possible and facilitates monitoring and withdrawal of products from the market if necessary.[16] Products are, however, excluded from mandatory labelling if an ingredient contains less than 0.9 % GMO and if this presence is accidental or technically unavoidable.

As the legislation does not draw any distinction between whether the food and feed from GMOs is domestically produced or imported, the legislation affects producers in third countries that may consider exporting GMOs or food and feed therefrom to the EU. The legislation thus has a broad and deep impact on the market and concerns plant breeders, farmers, industry in the EU and abroad, as well as retailers and consumers in the EU. The economic impact of the legislation will grow as the technology evolves and as more GMOs are placed on the market worldwide and in the EU.

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[16] European Commission (2013) outlines the Commission's motivation for labelling and traceability.

The major question prior to the Court of Justice's judgment in 2018 was whether NGTs should be legally considered as GMOs and regulated as such. Traditional breeding methods that invoke mutations through irradiation or chemicals and also genetically modify the plants are considered GMOs in the legislation (European Commission, 2021), but they are exempted in the regulation. This legislative exception assumes that, GMOs aside, traditional plant breeding has been conventionally used in numerous applications and has a long safety record. In contrast to GMOs and NGTs, traditional plant breeding techniques have, in other words, been considered "safe enough" not to invoke the precautionary principle due to their long history on the market that stretches back more than 70 years. This notion thus differs from statements by the scientific community that NGTs in themselves are not riskier than other breeding technologies and that the trait and/or product, i.e. the genetic change, should be regulated rather than the technology.[17]

2.2 Enforcement of the EU regulation

Enforcement uncertainties in the ruling by the Court of Justice in 2018 occur as the object is to regulate the outcome of the technology, i.e. in this case the plants and products thereof, by basing the regulatory framework on the underlying technology (plant breeding) and not the products *per se*. While GMOs can be detected analytically, NGT products may not be distinguishable from those resulting from products derived from natural mutations or other plant breeding techniques.[18] It is unlikely that any unauthorized NGT food and feed entering the EU market will be detected (European Commission, 2021). Further, even if the DNA alteration is detected, it would not be possible to conclude that it was created by NGTs (JRC, 2017). There is hence no current detection technology available for unambiguously tracing a DNA alteration to the new genome editing techniques. Moreover, it is acknowledged that the lack of reliable detection will impede the authorization of some NGTs. The mandated traceability and labelling will only be feasible for NGT products that have a known DNA alteration and that are unique. Many

[17] See for instance EASAC (2020) and the Royal Society (2021).
[18] GMOs can be traced by so-called polymerase chain reaction-based screening methods (European Commission, 2021).

NGT products may not be permissible on the EU market as it is not possible for existing technology to trace them. Further, the regulatory uncertainty is expected to increase as innovation in the biotechnology sector progresses (European Commission, 2021).

The difficulty of monitoring NGT products reflects the diverse enforcement strategies of the legislation among EU members. Most member states have not adapted their GMO enforcement system to cover NGT products. The main argument for not doing so is the absence of reliable detection methods. Other EU members are waiting for a harmonized approach (European Commission, 2021). EU members that have adapted the enforcement system report difficulties with its implementation in practice (European Commission, 2021). The enforcement of the GMO legislation therefore applies mainly to issues associated with the cultivation of NGT plants and not market access for NGT products.

2.3 Regulation of NGTs in non-EU countries

A disparity in regulation among jurisdictions impedes trade by creating technical barriers to trade or even an import ban on the product. The enforcement of a mandatory labelling scheme for transgenic plants at the federal level in the USA was, for instance, motivated by a harmonization effort to prevent individual states applying their own labelling legislation and so creating trade barriers in the US market (USDA, 2018). Harmonization hence lowers trade costs and promotes international trade, lowering prices to consumers and enhancing firms' ability to compete in export markets. Thus, just as the EU regulation of NGTs matters for non-EU countries, the regulation of NGTs in non-EU countries is significant for the EU.

The European Commission (2021) provides an outlook for non-EU regulations of NGTs in 31 countries. The survey includes major agricultural producers and trading partners of the EU, such as the United States, the United Kingdom, China, India, Canada, Argentina and Brazil.[19] If their

[19] The sample includes Argentina, Brazil, Canada, Chile, China, Colombia, Egypt, Guatemala, Honduras, India, Israel, Japan, Kenya, Mexico, New Zealand, Nigeria, Norway, Paraguay, Philippines, Russian Federation, South Africa, Switzerland, Turkey, Uganda, Ukraine, United Kingdom, United States, Uruguay, and Vietnam.

legislation harmonizes with EU legislation and if there are common standards for labelling and traceability of NGT products in the food and feed chain, it will facilitate international trade in food and agriculture products. A third of the countries in the review have adapted their GMO legal framework to cover NGT plants and/or NGT products. However, the adaption often includes exemptions which may be based on products, processes, or both. Of the other two thirds of the reviewed countries, half are debating whether to adapt their legislation specifically to NGTs. NGT regulation hence differs significantly across major trading partners and is in some cases up for debate and alteration just like in the EU. The current EU legislation on GMO products that also applies to NGT products remains strict from an international perspective, hampering trade in food and feed between the EU and other parts of the world.

3 Costs and benefits if NGTs are treated as traditional bred plants

In this section we identify and discuss possible benefits and costs for producers, consumers, and society if NGTs were to be treated as traditional breeding technologies (and not GMOs). The scope of the cultivation of NGTs and the welfare implication it will bring depends on the costs NGTs incur for plant breeding, cultivation and industry as well as the extent to which consumers are willing to buy NGT products. Lowering regulatory barriers for NGTs will affect not only consumers and producers, by increasing the prospect of developing, cultivating, and selling NGT products, but also society, depending on the impact on the environment and food security. The effects may be positive or negative, i.e. inflict benefits or costs, and differ across individuals and so have a distributional effect.

3.1 Potential public benefits and costs from cultivating NGT plants

As mentioned, no identified public costs or risks from NGTs *per se* have been identified, compared to traditional breeding techniques. Only public benefits are hence identified if NGTs are regulated as traditional breeding techniques and if the plant traits that come with NGTs are properly regulated. NGTs therefore increase the opportunity to provide plants with environmental benefits, make food more nutritious and ensure a secure food supply while not posing any additional risks to either human health or environment.

NGTs are, as mentioned, applied to many crops, including major arable crops such as wheat, potatoes and rice, which amplifies the potential for NGTs. The rich variety of traits and crops largely corresponds to the challenges agriculture faces in satisfying the future demand for food in the EU and globally, as well as the challenges of reducing negative environmental impacts from intensive farming. NGT plants therefore have a potential to help fulfill intermediate goals stated within the Farm to Fork Strategy (European Commission, 2020) such as that the food system should:

- have a neutral or positive environmental impact
- help to mitigate climate change
- reverse the loss of biodiversity.

The benefit of improving agriculture technology is stressed, as agriculture is one of the main sources of climate gas emissions, with annual emissions of 7.2 billion tonnes at the farm in 2019 (UN, 2021). Higher yields allow less land to be dedicated to agriculture, thus reducing deforestation and leaving more land available for climate mitigation efforts such as afforestation. Literature also supports the notion that policy efforts to increase land productivity may significantly decrease GHG.[20] In 2019, it was estimated that land use change attributed to farming contributed as much as 3.5 billion tonnes of GHG emissions, corresponding to 6.5 % of all global GHG emissions (Tubiello et al., 2022). Potential gains from using NGT crops can be illustrated by the cultivation of GMO crops, although the actual gains will depend on the specific NGT crops developed and their uptake in agriculture around the world. It has been estimated that the cultivation of GMOs has reduced farmland use by 25 million hectares globally due to productivity gains (Qaim, 2016).

Reduced demand for agricultural land not only decreases GHG emissions but also makes it more economically feasible to preserve biodiversity hotspots. Although the most important natural habitats for biodiversity are identified outside Europe, greater land productivity in Europe decreases world market prices for agricultural commodities and so

[20] See for instance Laborde et al. (2021) and Searchinger et al. (2018).

reduces demand for agricultural land, which spares land for other purposes in other countries.

Crops with increased stress tolerance improve food security and moderate price spikes due to extreme weather conditions and climate change. The opportunity for agriculture to keep up with demand increases notably if NGTs enable cultivation on degraded soils. Better storage performance in turn lowers food losses in the food chain. Finally, food security can be supported, as NGTs can improve the nutritional value in plants.

3.2 Benefits and costs along the supply chain

Plant breeders will be subjected to lower regulatory costs if the NGT plants are treated as conventional and not GMOs. Regulatory costs impose a fixed irreversible cost for firms in the process of gaining market acceptance for NGTs and food and feed therefrom. Bullock et al. (2021) find that adding a GMO regulatory phase including paperwork and time-consuming mandatory field trials to the R&D process increases the cost of the market approval process for NGT plants by 74 %. The costs therefore pose a risk to the firm, as it is not able to recover the costs if the NGT does not receive market acceptance from the regulators.

Bullock et al. (2021) argue that if NGT plants are treated as conventional plants, they require a little less than one million hectares to cover the anticipated R&D expenses for plant breeding.[21] NGTs therefore have great potential to be adopted across many crops, traits and countries globally, and it is still the case if the regulatory framework is demanding but not prohibitive. As noted, NGT plants are also being developed for many minor crops such as asparagus, cauliflower, and lettuce, each of which is cultivated on less than 2 million hectares globally. Technology such as CRISPR/CAS9 therefore has greater potential to fulfill a technological leap in plant breeding, since comparably low R&D costs make it economically feasible to apply NGTs in a large variety of plants compared to GMOs. The comparably low R&D costs may therefore secure

[21] Based on a shared trait value of USD 60 per hectare. A larger shared trait value proportionally decreases the required cropland area for break-even.

market access for many NGT traits and plants worldwide already in the short run.

Treating NGTs as traditional breeding techniques in the EU will not just favor plant breeding firms. If NGT food and feed are recognized as conventional, trade between the EU and third countries will be facilitated, as non-tariff barriers will be less significant. EU farmers are then able to embrace the technology at a comparatively low cost and increase their competitiveness in the international market. Farmers cultivating GMOs have, for instance, been found to increase their profits by 68 % (Qaim, 2020). Export opportunities, and so the competitiveness of EU farmers, will be reinforced as other countries liberalize and harmonize the regulation of NGTs. Again, the export opportunities increase if other countries embrace NGTs. A liberalization of the regulatory framework in the EU also facilitates the export of NGT products to the EU. Trade liberalization at home and abroad may, on the other hand, lower the competitiveness of EU farmers in the internal market compared to the current legislation that hinders imports of NGT food and feed. The difficulty of monitoring the use of NGTs in products, however, may make current legislation redundant for imposing a non-tariff barrier to trade for the imports of NGT food and feed to the EU. A liberalization of the regulation of NGTs in the EU is therefore most likely to increase competitiveness among breeders, farmers and industry in the EU. The European farming community has also stated that a deregulation of NGTs is important for their competitiveness (Copa-Cogeca, 2021).

3.3 Potential consumer benefits and costs

Demand for NGT products determines the extent of the public benefits that can be reaped from NGTs. NGT plants can enhance the nutritional value and improve attributes such as texture and taste. A deregulation of NGTs will also lower food prices and increase access to imported food. NGT plants can therefore both lower the price and increase the quality of food. Nes et al. (2022) found that if NGT plants are approved, access to food imports from international markets in relevant categories increases by a third, while the approval of NGT and GMO plants lowers the price of food imports by 6 %. The price effect will likely increase if the cultivation of NGT plants increases worldwide not least for major crops such as wheat and rice. The impact on consumer prices will therefore be more profound if the legislation of NGTs is liberalized in parallel with other countries.

Despite quality improvements and a lower price, consumers may dismiss NGT food if they put a negative value on the attribute "NGT" *per se*. If NGT food is regarded as conventional food by legislators, there is no mandatory labelling or other information scheme that tells the consumer whether the food product is NGT or not. As the inherent breeding technique is a credence attribute hidden from the consumer even after consumption, information pass-through from producers is necessary to enlighten consumers as to whether the food contains NGT ingredients. The legislation will hence not ensure consumer choice based on whether the food is NGT food, if such food is treated as conventional. If no option exists, the introduction of NGT products may therefore lower welfare by decreasing consumer surplus, i.e. the difference between what consumers are willing to pay and what they actually pay for a good or quality.

Mandatory labelling may, however, not be necessary to provide consumers with choice, as producers signal credit attributes to consumers voluntarily. Private initiatives such as voluntary labelling and private standards may create a selection mechanism based on whether or not food is derived from NGTs. Private standards are common in Europe and are often set by retailers mainly based on food safety but also other concerns (Rao et al., 2021). US consumers have, for instance, been able to choose non-GMO labeled food on the initiative of food processors and retailers (Kalaitzandonakes et al., 2018). The voluntary GMO labelling has been found to be an efficient disclosure mechanism without enforced mandatory labelling (Adalja et al., 2022).[22] GMO food in the EU, on the other hand, has been rejected by retailers citing consumer concerns, in a sense rendering mandatory labelling of GMO obsolete, as it does not provide a choice for the consumer. In Sweden for instance, no

[22] The study assesses the mandatory labelling of GMO in the state of Vermont.

major retailer sells GMO food (KFS, 2018). The major pan-European retailer Lidl in turn sells non-GMO labeled dairy and eggs where animals are not fed with GMO feed, despite such labelling not being mandatory. Further, organic food prohibits the use of GMOs. The market can therefore provide choice regarding NGTs depending on the cost of providing the information, the regulation of labelling and consumers' willingness to pay for choice regarding whether the food stems from NGT plants. The degree to which voluntary measures provide information and how consumers act upon it will then determine commercial success and so the scope and public benefits that may come with cultivation of NGT plants.

Assessing consumer valuation of NGT food

There are a number of studies aimed at revealing how EU consumers value NGT food. Both Beghin and Gustafsson (2021) and Strobbe et al. (2023) conclude in their literature surveys that EU consumers, like other consumers, tend to favor food that stems from traditional breeding techniques. Another key finding is that most consumers tend to prefer NGT food over GMO food. One reason is that consumers acknowledge that NGTs are cisgenic and so regarded as more "natural" than GMOs.[23] A survey by the European Commission (2010) suggest that citizens in the EU27 have greater acceptance of biotechnology use if it is cisgenic than if it is transgenic.[24] Literature also supports the notion that consumer acceptance increases if NGT plants generate public benefits as opposed to purely cost-saving attributes for the farmer (Beghin and Gustafsson, 2021). GMOs have almost always been exclusively framed as being cost-saving attributes for the farmer and seed companies. Another conclusion Beghin and Gustafsson (2021) make is that there exists a "heterogeneity among consumers" both within and across countries regarding the valuation of NGTs.

An even harder task is to monetarize the negative valuation of NGTs, as NGT foods are not yet sold to EU consumers. Economists often rely on willingness to pay (WTP) studies, where consumers face a more or less

[23] See Beghin et al. (2021), Busch et al. (2021), Gaskell et al. (2011) and Strobbe et al. (2023).
[24] The study concerns the cultivation of apple trees.

hypothetical choice, to pin down citizens' monetary valuation of products or qualities that are not on the market.[25] WTP measures the maximum amount consumers are willing to pay for a good, service or quality. Results from WTP studies for GMO can also serve as a proxy for NGT, but as noted, consumer preferences for NGT and GMO may differ substantially. In their literature review, for instance, Beghin and Gustafson (2021) found that WTP was lower for GMO food than NGT food (Beghin and Gustafson, 2021).

Comparing stated and actual behavior illuminates how difficult it is to interpret results from WTP regarding NGT and GMO. The emphasis on Europe-North America in the literature makes it possible to compare EU consumers' stated valuation of NGTs with US consumers' stated valuation *and* actual purchases of GMOs. When Shew et al. (2018) assessed consumer WTP for glyphosate resistant NGT rice and GMO rice in the US, Canada, Australia, Belgium, and France, they found no difference in WTP for NGT and GMO rice and that US consumers needed at least a price discount of 50 % to choose the NGT rice over conventional rice. Hu et al. (2022) in turn found no difference in US consumers' WTP for NGT and GMO and that US consumers were willing to pay a price premium of 42 % for conventional orange juice. WTP studies hence suggest that consumers have a strong negative valuation of NGT and GMO products relative to traditional products, even in the US where GMO food has been sold for a long time.

The results in the WTP studies do, however, starkly contrast with actual buying behavior. Kalaitzandonakes et al. (2018) found that de facto price premiums for food labelled non-GMO in four product groups (salad and cooking oils, tortilla chips, breakfast cereal and ice cream) in the US stretch from 9.8 % to 61.8 %, with market shares ranging from just 2.3 % to 5.7 %.[26] Actual behavior hence suggests that only a small share of US consumers actually actively choose conventional food, even when the price premium is as low as 9.8 %. There is hence strong evidence for a

[25] WTP studies choice experiments, consumers facing multi price lists and experimental auctions where real money is exchanged for real goods.

[26] The price premiums were estimated using a hedonic price regression which singles out the price premium for GM for otherwise similar goods.

wide discrepancy between claimed and actual WTP. According to Penn and Hu (2018), WTP studies generally tend to overvalue the real WTP by an average factor of 1.94. In the case of GMO food, the discrepancy between actual and estimated WTP seems even larger. The case of GMOs in turn suggests that the actual WTP to avoid NGTs may be far lower than the stated WTP.

Moreover, it is difficult to reach a conclusion about how the average EU consumer will embrace NGT food if launched on the market. Consumer preferences are time-dependent and may be contingent on acquired knowledge of NGTs. Surveys repeatedly reveal that consumers have no or only modest knowledge of NGTs.[27] A varying degree of knowledge also seems to partially explain the valuation of NGT food across consumer segments, as consumers with objectively better knowledge of science and genetics tend to value NGT higher (Beghin and Gustafsson, 2021). NGT plants have a short history and may gain further trust and approval in the future as consumers gain more information. GMO with a longer history has also seemed to gained acceptance in the EU in recent decades, with stated concerns about GMO food and GMO ingredients considerably higher in 2010 than in 2019.[28]

A recent study of Swedish consumers' knowledge of and attitudes towards plant breeding and food by the Swedish Gene Technology Advisory Board (2022) puts the lack of general knowledge of plant breeding technologies in perspective and how it may affect consumers' stated WTP. Only about half of the respondents in the study knew whether a tomato contains DNA and only one third of the consumers recognize that there are no GMO foods in the stores. Later in the questionnaire, the respondents were briefly informed about different mutagenesis techniques. A majority still expressed concern about NGTs and almost two thirds state it is important to label NGT food. The respondents

[27] See for instance EFSA (2019), The Swedish Gene Technology Advisory Board (2022), and Beghin et al. (2021).
[28] A comparison between the EU surveys in 2010 and 2019 reveals that two thirds of EU consumers were concerned about GM in 2010 and a little more than a quarter in 2019 (EFSA, 2019). The questions were not identical, though, so a comparison between the years is not straightforward.

found it equally important though to label whether the food was produced with traditional mutagenesis or GMOs. Swedish consumers therefore do not seem to assign more value to being able to choose between NGT food and food that has been derived from other mutagenesis techniques.

Finally, besides Gaskell et al. (2011)[29], who cover consumers in all EU countries, most of the studies regarding consumers' attitudes and WTP toward NGT food concern only two individual EU countries, France and Belgium. Only consumers in three EU countries that constitute less than a fifth of the EU population are, for instance, represented in the literature review by Beghin and Gustafson (2021) concerning WTP.[30] The small sample makes it difficult to draw inferences about the average EU consumer, not least since consumer attitudes towards the use of cisgenic and transgenic gene transfer seem to vary significantly among the 27 EU countries, according to Rousselière and Rousselière (2017).

To summarize, consumers repeatedly state in surveys that they prefer food that stems from traditional breeding techniques. Studies on consumer attitudes towards NGTs in the EU are, however, restricted to only a few member states. Actual purchase behavior in the US food market regarding GMOs also strongly supports the claim that stated preferences reveal little about actual consumer conduct. Consumers may also have negative attitudes towards traditional breeding techniques, stating a preference for labelling of some traditional breeding techniques such as irradiation. Voluntary labelling of NGTs may be a way to satisfy consumer demand but it may, like mandatory labelling, be misleading as traceability most likely relies on documentation.

3.4 Distribution of costs and benefits

How cost and benefits will be divided among producers, consumers and taxpayers depends on firms' ability to pass on costs to consumers and how different consumers value NGTs. For instance, depending on their

[29] Based on data from the European Commission (2010).
[30] Included countries are Belgium, France, and Denmark.

preferences for GMOs, some consumers are hurt economically by the de facto moratorium on GMOs in the EU, others are not.

Estimates for GMO crops may provide guidance on how gains may be divided along the supply chain. According to Barrows et al. (2014), on average farmers and consumers combined share a little less than half of the overall gains from the cultivation of GMO crops, while seed developers capture the rest. However, the estimated intervals are wide and the distribution of gains in different locations and among stakeholders depends on market structures and demand elasticities. Research and development costs for NGT crops are, however, lower than for GMOs, suggesting that farmers and consumers will reap a larger share of the benefits, as low R&D expenditure usually facilitates competition among firms. A large share of NGT plants are also developed by public institutions such as universities and not major seed companies. Treating NGT plants as traditional bred plants and not GMOs also provides a cost saving in terms of administrative costs – costs that would otherwise result in higher taxes and/or costs for firms, depending on the extent that fees cover the costs. In Sweden, for example, field trials for GMOs come with an administrative fee of SEK 3,900 for every stipulated field visit by the authorities. Compliance costs for field trials, traceability and labelling may vary across EU member states, as revealed by their disparate enforcement strategies.

4 Costs and benefits for cultivating two NGT potato variants – A case study

NGT potatoes are in the pipeline for commercialization and can be used as an illustration of the costs and benefits that could come from market access where NGTs are treated as traditional breeding techniques. Potatoes are a major crop both in the EU and globally. In 2021, 50 million tonnes were harvested in the EU and 376 million tonnes globally, and enhancing potato cultivation and quality therefore has the potential to benefit producers, consumers, and society as a whole.[31] Calculations are done for two NGT traits that lower the production costs for farms and processing firms without adding consumer qualities. The calculations are simplified but serve as a guide for possible benefits and costs that may occur if NGT plants are commercialized and if NGTs are treated as traditional breeding techniques.

4.1 An NGT potato that has a resistance to late blight

One of the NGT variants that has been genome-edited using CRISPR/Cas9 is a potato that is resistant to late blight. It was developed by the Swedish University of Agricultural Science and the University of Copenhagen (Phuong Kieu et al, 2021).[32] The CRISPR/Cas9 developed potato variant should be viewed as a step forward in developing a potato that is fully late blight resistant, i.e. it is not fully resistant as yet. For simplicity, we base our estimate on a fully resistant potato variety and our estimation therefore serves as an upper bound.

[31] See https://www.fao.org/faostat/

[32] The NGT potato is based on the King Edward variety, which is the most popular ware potato in Sweden and constitutes roughly 10 % of all Swedish field area dedicated to ware potatoes (according to Anders Andersson at the Swedish Association of Potato Growers).

Potato late blight is considered the most serious potato disease worldwide and is caused by the pathogen *Phytophthora infestans*, which can infect the leaves, stems and tubers of potato plants (Phuong Kieu et al, 2021). This was the disease that caused the devastating Great Famine in Ireland in the 1840s.[33] The disease may cause major yield losses if not treated and farmers spray fungicides more than ten times per year to stop the disease from evolving and spreading. It has been estimated that the annual global cost of potato late blight is USD 6.7 billion due to yield losses and treatment costs (USDA, 2021).

Several benefits would result from a fully resistant NGT variety. First, treatment costs will decrease. We estimate the cost saving per tonne of potatoes (unit cost) that would emerge from a fully resistant NGT variety by a calculus for cultivating a Swedish potato provided by the Swedish Association of Potato Growers.[34] No purchase of fungicides and less use of machinery and labor constitutes the major cost saving for the farmer when using a fully resistant potato. A minor cost saving per kilo of potatoes also occurs, as it is possible to plant more rows of potatoes since fewer treatments are more lenient on soils and plants. Cultivating the NGT variety requires 3.8 % less land per tonne compared to cultivating the non-resistant potato.[35] In total, fewer treatments and more rows per hectare save the farmer 4.2 % of the cultivating cost, which equals EUR 8.7 per tonne.[36]

Second, a significant benefit for the farmer arises due to reduced yield losses. Although potatoes are treated, it has been estimated that late blight decreases the potato yield by an average of 3.24 % in northwestern Europe (Savary et al., 2019). We assume this figure to be valid for cultivation in Sweden and all other EU countries, and calculate the lost revenues due to the disease according to the average yield and average price for potatoes at the farm gate in the period 2020–2022.[37] The revenue

[33] See Great Famine | Definition, Causes, Significance, & Deaths | Britannica.
[34] Based on a yield of 48 tonnes per hectare cultivated on 30 hectares.
[35] Based on the expertise of Anders Andersson at the Swedish Association of Potato Growers, which estimates that a resistant potato would increase yields by 4 % per unit of land.
[36] Calculated according to the exchange rate EUR 1=SEK 11.50.
[37] Data on prices and yields are found at Eurostat. The average price is a weighted price according to yields across EU countries.

loss from potato late blight, and hence the benefits associated with using a fully resistant NGT variety, corresponds to EUR 6.7 per tonne. Increased revenues and the cost saving in total hence correspond to EUR 15.4 per tonne.

Third, replacing traditional bred potatoes with a blight resistant variety also comes with environmental benefits that are external to the farmer, i.e. benefits for society. These external benefits stem both from the non-use of fungicides and from less land and other inputs such as diesel being necessary to produce the same volume of potatoes. Some of the benefits are, however, already monetarized by environmental taxes on diesel and fungicides and so internalized by increasing the price of inputs. The OECD has, though, stated that in practice environmentally related tax rates concerning ecotoxicity are set far below the cost of the external environmental effects they cause (OECD, 2017). The tax rate may hence not fully reflect the environmental damage caused by using the pesticide. In addition, GHG emissions from land use are not regulated by means of economic instruments such as taxes, so farmers will use more pesticides and land than is optimal from a societal point of view when considering the negative environmental impact.

It is possible to appreciate the public value of lower GHG emissions due to land use. The yield increase due to no harvest loss from potato late blight will increase the harvest per tonne of potatoes by 3.35 %. More rows per field will in turn increase the yield per hectare by 4.0 %. Combined, the yield will increase by 7.5 % (1.04 x 1.035) per hectare and so increase land productivity by the same amount. In total, 7.0 % less land is needed to produce the same quantity of potatoes, if the potato is fully blight resistant. We assume that the cost of GHG emissions is EUR 90/t according to the EU emissions trading system.[38] The farm gate CO2e per tonne potato is estimated to be 120 kg/t.[39] Land use accounts for half of the GHG emissions in the cultivation of potatoes (Crippa et al., 2021). Reducing GHG emissions by cultivating more rows and having no harvest loss due to potato late blight is worth EUR 0.4/t potatoes.

[38] It corresponds roughly to the average price in 2023 (registered June 2, 2023).
[39] An average based on Röös et al. (2010) for Sweden and Smith et al. (2019) for the UK.

Some of the GHG emission reduction may be offset by a higher total production of potatoes, as demand will increase when the price of potatoes decreases due to the lower production cost. Demand for potatoes is, however, found to be price inelastic, i.e. consumers are not sensitive to price changes. Säll et al. (2020) estimate that demand for potatoes in Sweden only increases by 2 % if the price drops by 10 %. Lower prices will thus have a rather limited impact on quantities consumed. As potatoes become relatively cheaper than for example pasta and rice, a substitution effect will also likely occur as consumers partially replace other food products with potatoes. Replacing close substitutes such as pasta and especially rice with potatoes will, in itself, lower GHG emissions as LCA assessments show that potatoes have comparably low GHG emissions.[40] We therefore assume that this substitution effect cancels the increase that follows from the moderate output growth of potatoes per hectare.

In total, as shown in Table 2, the identified benefits from a late blight resistant variety correspond to EUR 15.4/t. The vast majority is attributed to cost reduction and yield improvements and only 2.5 % corresponds to environmental benefits. The actual environmental benefits from a fully resistant potato are, however, likely to be somewhat higher since, as mentioned, environmental taxes tend to be set too low from the perspective of society.[41]

The calculated benefit per tonne enables us to estimate the possible total benefits in Sweden and at EU level respectively, if all potatoes were fully resistant to late blight. In Sweden, based on the average yields and prices for the years 2020–2022, a full conversion to a late blight resistant variety would provide an annual gain of EUR 8 million. The gain increases to EUR 677 million at EU level.[42] The example is, however, hypothetical. First, any success depends on the uptake of the variety. The

[40] Both pasta and rice have significantly higher GHG emissions per kg according to Säll et al. (2020). However, the difference between potatoes and pasta becomes insignificant if GHG emissions are measured according to the protein and calorie content of the commodities. GHG emissions are still twice as high for rice when accounting for calorie and protein content.
[41] See OECD (2017), which argues that in practice environmental taxes are set far below marginal external costs.
[42] The annual prices in the years 2020–2022 have been weighted according to national yields to more truly reflect an EU price.

uptake in turn depends on consumer acceptance and consumers' reluctance may lower any potential benefits. If some consumers wish to buy but are not able to choose a "NGT-free" potato, commercialization will lower consumer welfare for some consumers. Second, it takes a long time to produce large quantities of seed potatoes – full-scale commercialization of an approved variant, which then becomes a variety, may still be several decades away.[43] Third, the trait must be implemented in all sorts of cultivated potatoes. For now, the trait has only been inserted in the King Edward variety. Fourth, the calculation is based on current technologies for treating potato late blight. Any technology improvement that lowers the treatment cost will in turn reduce the benefits from a resistant potato.

Table 2: Annual benefits from a fully late blight resistant variety

Benefit	Benefits per tonne of potatoes (share of total benefit)
Cost reduction farming	EUR 8.7 (54 %)
Yield improvement	EUR 6.7 (42 %)
Environmental benefit (climate only)	EUR 0.4 (2.5 %)
Total	*EUR 15.8 (100 %)*
Total benefits ware potatoes*	Million EUR
Sweden	8
EU	677

Notes: Data for yields are found at Eurostat and the Swedish Board of Agriculture.
**Total benefits are based on the average price and yield for the years 2020–2022.*

4.2 NGT starch potato for improved storage

Another NGT potato in the pipeline for commercialization is a starch potato that is genome-edited to improve its storage performance. Starches for industry use are extracted and yield a wide range of products that are used in both the food and non-food industry (Ellis et al., 1998). Starches are often chemically modified to change their properties and substantially extend the range of applications (Ellis et al., 1998).

[43] Personal communication, Anders Andersson, the Swedish Association of Potato Growers, May 3, 2023.

Modified starches are, for instance, used to improve viscosity and increase stability when heating and freezing food (Ellis et al., 1998). Starch is a mixture of two components, amylose and amylopectin, and changing the ratio of the components alters the properties of the starch (Andersson et al., 2017).

Chemically modifying starch causes environmental concerns which can be avoided if the modification is achieved *in planta* instead. The potato developed with the application of CRISPR-Cas9 contains only amylopectin starch (Anderson et al., 2017). Doing this induces natural storage stability in the potato starch. The starch industry otherwise uses large amounts of the chemicals acetic anhydride ((CH3CO)20) and propylene oxide (CH_3CHCH_2O) to make it storage stable. The genome-edited potato variant improves the potato in the sense that it eliminates the need for chemicals to gain storage stability. The chemical treatment costs EUR 33.2 per tonne of potatoes, according to the Swedish starch industry.[44] As there are no other identified gains from using the NGT option, the cost saving is hence the benefit of the new potato variety. The total quantity of starch potatoes treated in Sweden per year is 80,000 tonnes, which implies an annual cost saving of EUR 2.65 million a year. The total amount of starch potatoes treated in the EU has been estimated by the Swedish starch industry as roughly one million tonnes, making the corresponding cost saving at EU level equal to EUR 33.2 million.

Again, the use and production of the chemicals used for modification may not be fully internalized in the price due to taxes on chemicals being too low from the perspective of society. It is, however, not possible to estimate such potential additional benefits from not using the chemicals. Also, again, benefits and costs depend on consumer acceptance.

[44] Personal communication, Mathias Samuelsson, Lyckeby, June 15, 2023.

5 Concluding discussion

There are a number of identified and potential benefits from the use of NGTs. The benefits may be substantial and broad considering the wide applications in terms of plants and traits. Besides the benefits consumers can enjoy from quality improvements and lower food prices, NGTs have the potential to meet challenges associated with climate change and less availability of arable land, while improving public health and reducing negative environmental effects caused by, for example, pesticides in intensive farming. NGT plants, just like other plants, may cause environmental and health concerns because of their traits. However, the science indicates that use of NGTs poses no additional risks to either the environment or health compared with traditional bred plants. NGTs are even considered less risky because of the precision that comes with the techniques. There are hence no additional public costs or risks associated with the food system if NGTs were to be regulated as traditional breeding techniques, as long as the plants are monitored and evaluated in field trials.

Treating NGTs as traditional breeding techniques provides EU plant breeding companies and EU farmers with an additional tool and so expands their technology frontier. The competitiveness of the plant breeding industry and farming in the EU will therefore increase with the deregulation that follows if NGTs are defined as traditional plant breeding technologies and not as GMOs. The benefits for the industry and farmers will expand as more NGTs are available and as other countries choose to liberalize their legislation of NGTs.

The case studies of two different NGT potatoes reveal potential benefits from NGTs both for producers and the environment, if they are treated as conventional and commercialized. The hypothesized benefits can be estimated at more than EUR 500 million annually in the EU, although the actual number depends on consumer acceptance. If EU consumers assign a negative value to NGTs, which various studies suggest, the potential benefits are smaller (or even negative) not only for consumers, but also for producers and society. The magnitude of consumer reluctance is, however, largely unknown as studies about consumer behavior and consumer attitudes are conducted in hypothetical settings, since NGT food is not marketed in the EU. The inconsistency between stated preferences and revealed behavior in the American market regarding GMOs underscores how difficult it is to draw valid inferences from consumer surveys and analyses of consumers choices in hypothetical settings.

Treating NGTs as traditional breeding techniques may infer a reduction in consumer welfare. Providing consumer choice based on whether the food contains NGT plants may, however, be possible with voluntary labelling. Organic food is also a choice of "non-NGT" food as organic farming according to the proposal by the Commission concerning NGTs is not allowed to use NGT plants. There is, however, a risk that consumers may be misled by labelling efforts. If most consumers dislike NGT food, it is in producers' interest that the food does not contain NGT plants. A negative labelling, "contains no GMO", may however incorrectly indicate that the food otherwise may contain NGT plants, which therefore may mislead the consumer. Labelling, whether mandatory or not, may also be misleading as it may be impossible, using screening methods, to accurately determine whether the food is derived from NGTs or not. Whether mandatory or voluntary, NGT labelling must rely on documentation and trust and/or monitoring from governmental bodies or other third parties. A price premium for "non-NGT" produced food combined with monitoring difficulties creates an incentive for food fraud, as has been found in the marketing of organic food (Ferreira et al. 2021).

Finally, labelling, especially if it is mandatory, can aggravate the erroneous perception that NGT foods are not safe to eat, as the regulation treats it as a commodity – quality – that must be labelled and displayed to the consumer (Sunstein, 2021). Negative attitudes to GMOs may partially be attributed to the strict regulation of and de facto moratorium on cultivating GMOs in the EU. If NGTs are treated as traditional breeding techniques by regulators, this could increase consumer acceptance. Information to consumers about breeding techniques may, in parallel, gain consumer trust in the use of NGTs in food production, thereby fulfilling goals for the environment stated in the Farm to Fork Strategy while promoting public health.

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