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I have been asked to speak about new breeding technologies in plants, which can be variously seen as an issue of science, economics, ideology or indeed, politics.

Let me make some initial remarks to set the scene.

The beauty of our society is its diversity, reflected in diverse perspectives and values, and our democratic processes are designed to find a way to reconcile that diversity which, in general, requires time, dialogue, respect for other views and access to information.

But it has become apparent that it is difficult to collectively evaluate and reach consensus on fast-moving technologies that interact with very diverse interests and contested stakeholder values; whatever decisions are made, significant tradeoffs are inevitable, but it is this latter dimension which is too often ignored. Arguments on what matters can be reduced to a single preferred dimension, whether it be the environment, the economy, or social considerations or some other interest. But societies and governments must look more holistically at complex issues such as those linked to the issue of today, then be explicit and transparent about the tradeoffs made with respect to any decision.

So let us first turn to the biology.

Plant breeding has progressed enormously over the last 10,000 years. Over that time, we have seen progressive changes in the heritable characteristics of plants, which importantly from the biological, economic and agricultural perspectives, have been matched to prevailing environment conditions breeders face in making a better crop. Nowadays, conditions can in turn be manipulated by fertilizers, pesticides, and so forth.

For most of history, farmers and breeders selected plants with desirable traits and bred from them, slowly changing their genetic makeup, although they had no real concept of the underlying biology. Today, we can explain that in terms of the progressive selection of the inherent variation in genomes that is in turn associated with spontaneous mutations, leading to stable inherited and desirable traits.

Charles Darwin's 1869 magnus opus, the *Origin of Species*, starts by discussing how quickly pigeon breeders could develop new strains, or sports as they were then called, with very distinct and consistent characteristics. So too with dogs. Pekinese and Irish wolfhounds, despite their physical differences, are the same species and can mate – at least if they can get around the physical limitations. These are dramatic examples of artificial selection – that is, the intentional selection of desirable heritable traits and the rejection of undesirable traits. And plant breeding is the same. The watermelon and peach have been selected over time from very unappealing ancestral species. Maize as we know it was derived from teosinte by meso-Americans. Artificial selection remains the basis of all plant breeding, and, importantly, remains central to new breeding techniques.

Gradually, plant breeders came to supplement this artificial selection by intentional hybridization between the germplasm of different plants, to create hybrids such as the nectarine. Some hybrids are sterile, but grafting and other simple methods of cloning allowed even sterile hybrids to be sustained for productivity value. Many commercial crops such as cavendish bananas are clones rather than sexually reproduced plants.

Then, Thomas Morgan, working on fruit flies in the early 20th century, received the Nobel prize for showing that mutations could be induced by radiation and chemicals. The plant industry was soon transformed: chemical and radiological treatment of germplasm of plants induced multiple random mutations, and the few advantageous ones were then used in the development of plants with the desirable traits. So, artificial selection was again being used to screen for desirable mutations, although this was entirely in the absence of an understanding of the underlying genetic mechanisms.

Then in the 1970s, molecular biologists learned how to insert whole genes from one organism into another. This process, known as genetic modification or transgenesis, was first done in bacteria and yeast, and later in animals and plants. The goal was to allow an organism to make a protein it could not previously make. A whole gene, that is a large segment of DNA coding for a protein, was cut out of the DNA of one species, and inserted – initially randomly, and later more selectively – into the genome of another species at the one-cell stage. Many of the side effects of early transgenesis arose because of the random site of insertion, which could disrupt other genes.

Soon, GM crops and plants appeared. Again, artificial selection acted as the bridge between molecular biology manipulations, and release of the plants. First came Monsanto's *Bt*-corn, so called because of the bacterium *Bacillus thuringiensis*, or Bt, that naturally makes an insecticidal protein. This was inserted into the plant's genome, thereby suppressing pests. Then came Roundup-ready corn, which allowed Monsanto's herbicide, glyphosate, to be used to kill various weeds but not the transgenic crops. Many other transgenic plants and crops have since been developed in many different laboratories, many in the developing world.

All sorts of objections to transgenesis or GM rapidly emerged. For example, there were concerns that the transgenes might horizontally transfer between different species, or that 'super-plants' might be created that would lead to environmental catastrophe. Thirty years of experience have shown this to be an unfounded fear. Indeed, such theoretical risks were always remote, in part because artificial selection still acted as the intermediate phase after the transgenic plants were made, to ensure only desirable traits were selected. Moreover, nature has long been coopting genes for other purposes, and much research has not supported these concerns.

Indeed, far bigger issues can arise from whole gene pools in the form of a species rather than a single gene entering environments. Look at the impact of gorse, or thistles, or *Mycoplasma bovis* – these are all massive injections of new genetic material into our environment, and their effects are very much related to their own specific traits as whole organisms rather than to any single mutation.

Scientific arguments were also used to support other objections, such as that GM food would be unsafe. The logic of such arguments was never clear; we eat all sorts of DNA and RNA every day, and unless a gene for a toxic protein or allergen was constructed, it is hard to envisage a real risk. GM foods are extensively consumed, and there is absolutely no robust evidence that they pose any health risk or that they are less nutritious.

Those who persist in these arguments that there still might be a risk, are primarily relying on fallacious logic, for as Karl Popper pointed out science can only disprove something, but never absolutely prove anything. So while we can prove something to be unsafe, it is impossible to prove absolutely zero risk. Life is based on dealing with levels of probability, not absolutism, so the extreme precautionary argument that you cannot proceed unless something is absolutely proven to be safe, means no innovation is ever safe and no action can ever be taken.

The real arguments over GM crops were – and remain – values based. This led to quite diverse regulatory approaches, reflecting the nature of the society, variable perceptions of risk, benefit and precaution, and variable efforts for social license. In retrospect, in this and most other situations, the ethical and societal issues had not been deeply considered prior to industry appearing with an innovative technology. We shall return to this point later.

Many objectors focused on the corporate capture of the food system by mega- companies, with any risks being borne by consumers. There was also a deeper fear of what the promotion of industrial farming might do to smaller farmers and rural culture. However, the technology involved is now democratized and is used across the world, often in public sector-based organizations, and GM seed costs have reduced. Still, other objectors felt and still do feel that playing with the genome intentionally was philosophically wrong.

In New Zealand, the debate quickly became conflated with politics, and still is. Activism and extreme rhetoric reduced the quality of informed debate. I chaired a committee at that time charged with putting out educational material to promote informed dialogue in a very non-judgmental manner, and even that was objected to by activists who did not want the dialogue to start.

To somewhat depoliticize the debate, a Royal Commission was established. The outcome was a moratorium that effectively became enshrined in law as the HSNO act. This still remains in place, and for political reasons appears almost immutable. This outcome is unusual in that we are regulating a whole technology rather than the use of that technology. As a generality, this approach to technology regulation is increasingly seen as unwise and static in global technology policy. It does not allow evolving knowledge to inform regulatory changes of any technology to either become more restrictive or more empowering as we learn more.

The development of much more precise ways to induce specific mutations in the genome is at the heart of what are called new breeding techniques. Initial efforts such as the zinc finger methods were somewhat hybrid, with GM technology inserting some exogenous DNA along with the edit. But with the arrival of so-called CRISPR techniques, there is nothing left in common with GM technology except the word 'gene'. Still, the term 'gene editing' unfortunately leads many to conflate this with GM. With gene editing, new genetic material is not inserted into the recipient germplasm. Rather, with relatively high but not absolute reliability, scientists can now replace one letter in the DNA alphabet at one specific site of the target species' whole genome. The usual goal is to change the regulation of the gene, that is, when and how much it is turned on, rather than changing the gene itself.

But the products of gene editing still need to be checked through the processes of artificial selection in the appropriate environmental contexts to be sure that the desired trait is achieved. Additionally, such screening by selection ensures that undesirable side effects are avoided – these might occur because of either inadequate knowledge of the gene's effects or less than complete accuracy in the editing.

Very diverse regulatory approaches have been taken depending on whether gene editing is caught in process-based rather than trait-based regulation, and on the legal interpretation of the words 'gene modification'. In some countries the approach has been very relaxed, with the view being that these mutations might theoretically occur naturally rather than by human interference, and therefore need not be regulated any differently to any other new plant variety. Other countries such as NZ and those of the EU have used legal definitions created 20 years ago during the early stages of the GM journey, when gene editing technologies just did not exist and were not even conceived. Had they been so, a much more nuanced regulatory approach might have emerged.

Generally, with fast moving technologies, adaptive approaches to regulation seem logical. As GE is the biggest change, along with synthetic biology, in our ability to manipulate the gene-environment interaction, GE can vastly enhance production and value via increased productivity traits, reduced fertilizer need, increased bioactive or nutrient content, and improved biosecurity and pest management. When linked to the need to reduce greenhouse gas emissions in agriculture, global food security issues, climate change, declining global fertilizer stocks and so on, the technologies have immense and widespread potential.

As the food industry gradually moves from commodity and consumer-based marketing to understanding the potential of food as a health and wellbeing market, the opportunity to change concentrations of bioactives or nutrients may radically change markets. Some plant-based alternative meats and milks already use GM products. GM grasses with much higher energy content have been developed, GM crops with specific micronutrient changes such increased vitamin content have also been developed.

However, the possible consumer reactions and potential non-tariff trade-barrier issues need the most analysis. Hypocrisy abounds: Europe is an enormous importer of GM crops for stock feed, while several European countries have GE field trials under way, and China has very big GE crop trials. Organic and GM farmers have co-existed easily in the U.S. and other places for years.

The potential for GM and GE crops to address climate change, food security and other issues has not been discussed in an informed and balanced way to consumers.

For example, in my last report as Chief Science Advisor to Prime Minister Ardern in July 2018, I suggested that the GM grasses already developed by NZ scientists, but not able to be field trialed here, may be a very effective way of sustaining productivity while lowering dairy cow numbers and the environmental burden of methane emissions, and avoiding the need for chemical inhibitors yet to be developed or licensed that have their own issues that may well affect consumers' attitudes.

But without field trials in local conditions, we simply do not know how effective they might be. And even if the effects are less than that claimed, it is probable that with scientific advances we might achieve much more. Yet, we cannot do anything to find out. The market advantages of doing or not doing so need to be considered in light of the environmental effects, which may turn out to be a bigger impetus for a decision to use these technologies, as consumers, especially those in premium markets, increasingly demand climate-friendly and environment-friendly food production. But the introduction of such grasses could not be done in isolation from other measures such as ensuring associated stocking rate reduction and appropriate land-use decisions, all of which would need additional discourse and perhaps regulation.

New Zealand is both a biological-based and a tourist-based economy, and the country's environment is critically important for both. Yet, the present model can put these two goals in conflict. New technologies such as GE may have the potential to affect the tradeoff and balance between the environment and the biological economy and allow both to be better sustained and protected.

There is an increasing number of market competitors exploring these technologies. Can New Zealand maintain its market position over the next two decades without at least thinking about the opportunities and the risks?

But we also have to explore the downsides with more than rhetoric. Beyond the challenges of individual philosophical positions from our citizens, would there be consumer challenges in market? Most of our target market in Europe is already eating meat and milk from animals fed on GM forages. GM food ingredients abound in NZ. As food security and other environmental imperatives emerge as global concerns, objections on this basis may well evaporate.

There is a potential for GM or GE technologies to be the basis of non-tariff trade barriers, but NZ faces these in other ways on occasions and our trade negotiators are perhaps the world's best in confronting these issues. We also must be realistic – even if consent was given now to commence field experimentation, it would be a decade until market, during which our target markets are increasingly looking to these technologies.

The GM-free organic industry makes a number of claims. Does the GM free status for the country really mean anything in the market place? The evidence suggests this is a hyperbolic statement. The U.S. has also shown that organic/GM free and GM production can coexist.

The issue remains fundamentally one of social license to use such technologies. Hyperbolic claims must be avoided on both sides of any dialogue, and an adaptive approach to regulation is likely to be adopted in many countries. What position New Zealand takes will depend on the progress in science, global trends in its use, relative market advantage, and domestic politics. However, as a progressive biological economy, these types of technology will sooner or later become inevitable. Yet research in NZ on these techniques cannot currently progress beyond the laboratory stage, and in the absence of a path to exploitation there is little incentive to even do that. In fact in some cases, political messaging actively inhibits it, such as a ministerial directive not to undertake GM/gene editing research in reaching biosecurity goals.

NZ should be much more confident about its ability to engage in values debates, irrespective of outcome. Yes, such debates are hard, but avoiding them harms ourselves as a nation.

And so we come to the real questions we must consider. How should society regulate fast moving and evolving technologies? Is our current political system and approach appropriate for technological-societal debates that must be held and will become more frequent in the future, given the pace of technological development?

In the rest of this talk, I am going to refer both to the life science technologies and the internet/social media/AI/IOT cluster of technologies. By way of introduction, let us just contrast these two forms of technology and how they have been treated. They demonstrate the challenges of short-term versus long-term thinking, and different perceptions of risk and precaution that are determined both by prior cognitive biases, and by individual and group assessments of cost and benefit.

I need not say much more about GM – the initial reaction in most countries was an extreme precautionary position because farmers and industry were perceived as the primary beneficiaries, while the costs and risks were seen to apply to the ordinary citizen. But some such as the U.S. and now many food producing countries have taken a more proactive approach.

In marked contrast, the internet and social media technologies were left entirely in the hands of the market. Consumers saw immediate advantage in terms of convenience and access to knowledge, reliable or not. They discounted the loss of privacy, the culture change of digital giants destroying many smaller retail players, the aggregation of power in the platform companies and the fact that they make money out of your data. Governments made little or no effort to regulate or consider the issues of standards, governance or ethics.

Only now, 20 years later, is the need for regulation and standards coming to the fore, with the emergence of numerous issues: disrupted social cohesion, impacts on personal and state security, the supranational power of the companies and the helplessness of governments to regulate social media, fake news, or the dark web. This is also undermining the traditional roles of the state in regulating tax, libel, pornography and potentially even their currencies. And still, governments largely demur in part because they do not want to stifle innovation, even though the impacts of the digital transformation will be far more pervasive and profound on humans than any other technologies we have invented in the last 10,000 years.

In the digital case we have a case of 'it is too hard, leave it to the market', and now we cannot find ways to manage the downsides, all of which are having huge impact on the human condition. On the other hand, we have preemptive blocking of new breeding techniques through constraining regulatory processes that, in the end, are now in no small part subservient to short-term political factors that impede their revision. But have we made the right choices in how we handle these two technologies?

I frequently meet with many senior policy makers in Europe, and there is a recognition of the need to find new ways of regulating rapidly evolving technologies that are responsive and adaptive, yet acknowledge that in the end, the publics' view must be the final determinant.

So now let me generalize by focusing on the broader point of political and public framing of complex, value-laden issues. I am a strong believer in the liberal democratic model, where decisions are not made by technocrats but by the population, either directly or through representation. Representative democracy requires informed decision making. Yet the reality is that parliament is not well equipped to deal with problems of the nature we are discussing here.

First, parliamentarians generally have at best uneven knowledge on any particular matter as they face a million short term issues which will impact on their re-election, whereas they can see only headaches if they pick up long-term issues of which the issue we are discussing is one. Indeed, there is a general observation that long-term thinking has increasingly taken a back seat in democracies due to changes in the nature of the political-societal interaction. Second, except for the very few issues like euthanasia that are subject to a conscience vote, the values that affect decision making in parliamentary systems are not those of citizens themselves, but of the party whip – and these values are largely driven by short-term electoral considerations. So the politicization of GM/GE, the complexities and claims and counterclaims, mean it is easier to do nothing than deal with it through normal political processes.

These issues are characteristic of what we call 'post-normal' science – that is, where the science is complex and can be contested on either scientific or other grounds, and where the real issues are values based, and these values are in dispute. In Europe, much effort is going into finding possible solutions to policy making in this context.

Science has a critical role to play, but not as the decision maker. Advocates for different positions have a role, but also not as decision makers. All must have their knowledge and views challenged by decision makers who have equal knowledge and, like a jury, hear and see all the aspects that should be considered. There are different ways of achieving this, some models being hybrid forums, mini-publics, citizen's parliaments, and so on.

Let me use the example of the Irish citizen's assembly, which has been used to deal with contentious issues such as abortion and climate change policies. Here, 99 names are randomly chosen from the electoral roll to address a particular set of problems with a supreme court judge as chair. The assembly then hears evidence from all stakeholders, including scientists and interest groups. Experts are present to answer questions from the assembly but are silent unless consulted. Over some weeks/months, the assembly then forms a view and votes on the issue. No parties are involved, and the members are not representatives, just well-informed citizens reviewing and considering the evidence. The final decision does remain with the elected parliament, but it is hard for parliament to deviate from the views of an informed and transparent public process.

Such processes may be a better way than others to break the impasse on many technological issues. Even if no change from the status quo occurs in the end, we will have had much-needed conversations, which can be repeated at another appropriate time. It is not healthy for a democracy to have problems, opportunities or challenges that cannot be discussed. And democracy will be better served by ensuring that robust knowledge is available to inform, but not direct, discourse on complex issues.

The idea of mini-publics needs obvious refinement in our context. Is this also a chance to consider properly how to address Treaty obligations? Could this be a way of regularly reviewing complex technologies that are changing fast? My own unit, SciPoDS, is deeply embedded in its thinking about these issues.

So let me summarize: GM and particularly GE may offer enormous potential for a country that is, and likely will always be, a biological based economy. But there are also arguments for why we may not choose to use them. The balance between these arguments is not static, it changes over time for many reasons, not the least being that we know more about the technologies themselves. If our country does not periodically consider how to use or not use evolving technologies, we run the risk of becoming a backwater with a declining competitive position.

It is not for science to decide on technologies, but at the same time it is doubtful that the traditional political processes are the appropriate way to deal with the complexities of the interplay between science, values and world views. This is especially so given that elections are always less than 3 years away, and coalition negotiations are always involved. We need a way to consider all fast-changing technologies – whether digital or life science or any other – on an adaptive basis, but still maintaining both rational precaution and pragmatic realism.

New models of adaptive regulatory oversight are needed globally. Similarly, new models of bringing science and citizens together to discuss these issues of post-normal science are needed. We must to find a way to have ongoing conversations about such fast moving and evolving technologies; burying our heads in the sands of short-termism can have serious long-term costs.