The Adoption of Environmentally Friendly Technologies in Agriculture

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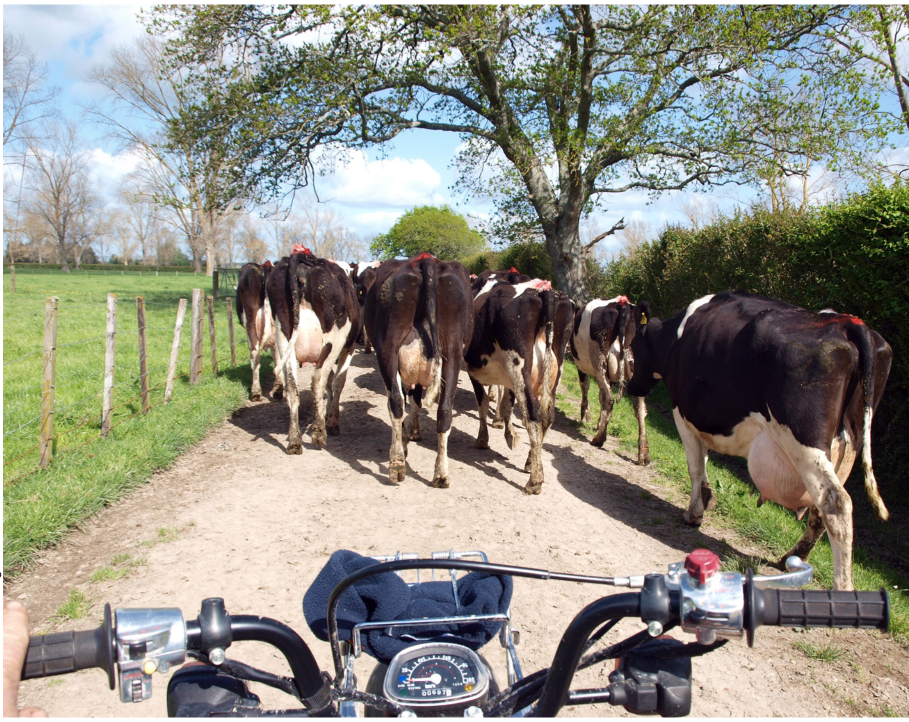
Executive Summary



This research note considers the decision faced by farmers who have the option of adopting a new, environmentally friendly production technology. It discusses why the rate of adoption is likely to deviate from the rate that is socially optimal, and outlines potential roles for intervention in reducing the difference between the two.

A farmer's decision to adopt a new technology is largely based on balancing the economic costs against the economic benefits. The technology will be adopted if it yields an expected profit that is high enough to compensate for any higher risk it offers relative to current technology. In particular, when there is an irreversible cost of adopting, there is an option value to waiting to adopt. This option value means adoption may not occur until the expected benefits are substantially larger than the costs.

The socially desirable adoption rate occurs when each farmer adopts if the present social benefits of adoption exceed the present social costs. However, the actual rate of adoption may differ from optimal because private benefits differ from social benefits, or because of other market imperfections.

In the absence of intervention, private and social benefits will differ because most of the benefits of reducing pollution accrue to society as a whole, not to the mitigating farmer. They will also differ for potential early adopters because, when making their adoption decisions, they do not consider the value to others of the information about the technology that they generate from their experiences. Suboptimal adoption may also occur because information about the new technology that would inform the adoption decision is a public good, and thus is under-provided by the market.

An intervention designed to efficiently increase the adoption of an environmentally friendly agricultural technology should address one of these problems. That is, it should reward farmers who reduce their emissions, subsidise early adoption of the technology and thus encourage the generation of knowledge about it, or directly enhance the generation and dissemination of credible information about the new technology.

However, any intervention should keep in mind that faster adoption of a new technology is not always better. Too-fast adoption can't take advantage of the benefits of learning, and risks lock-in to an inferior technology at a social cost that could potentially be very high.

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1. Introduction

Because agricultural emissions are such a high proportion of New Zealand's total greenhouse gas emissions, any strategy aimed at efficiently reducing domestic emissions is likely to involve reductions in emissions in the agricultural sector. Agricultural emissions can be reduced by decreasing the intensity of farming or changing to low-emission land uses, but this must decrease farmers' incomes. However, emissions also depend on the technologies and management practices used on farms; the development of new environmentally friendly technologies opens up possibilities for reducing emissions with minimal reductions in farm output.

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Examples of such technologies that are available now or that may be available in the near future include nitrification inhibitors, breeds of low-emission animals, the manipulation of forage type for greater digestibility, feed additives (such as garlic, spices or yeasts), "vaccines" that affect processes in the rumen, and feed pads for effluent management. Of course, new technologies only reduce farm emissions when farmers adopt them, a process that sometimes occurs seemingly inexplicably slowly.[1]

This research note takes as given the existence of a new agricultural technology that reduces pollution from farming, and considers the decisions of individual farmers who must choose whether and when to adopt the new technology. It asks why the rate of adoption of a new technology may differ from the rate that would be optimal from society's point of view, and considers how policy might reduce the divergence between the two. It does not explicitly deal with the question of how policy could increase the development of such agricultural technologies.

Theoretical and empirical studies suggest uncertainty and the need for learning play important roles in limiting the speed of diffusion of a new technology; their effects can be mitigated or exacerbated by policy. By providing farmers with incentives to reduce their emissions, facilitating the generation and dissemination of information about new technologies, and providing incentives for early adoption, policy can efficiently increase the speed of adoption. On the other hand, uncertainty over future environmental policies makes adopting a green technology riskier and will slow adoption.

2. The Individual's Adoption Decision

This section describes an economic framework for thinking about how the individual farmer makes his decision of whether to adopt an environmentally friendly technology. It draws upon and summarises insights from Marra et al. (2003).

2.1. The Decision Framework

In order for a farmer to adopt an environmentally friendly technology, he must first know that the technology exists. Given that he knows about the existence of a new technology, he weighs the private present discounted benefits against the costs of adoption, and adopts only if the former exceed the latter.[2] Numerous empirical studies, beginning with Griliches (1957), have demonstrated that the primary

[1] Jaffe et al. (2002) discusses the empirical paradox that many new technologies that appear cost-effective diffuse only slowly, which dates back at least to Shama (1983).

[2] Note if the technology is divisible, meaning it can be adopted on some fraction of a farm, the farmer's decision is the proportion of the farm on which to use the new technology. This proportion may be zero, and will be chosen to maximise expected private net benefits. For simplicity of exposition, this note discusses the discrete case only.

considerations in the adoption decision are economic; the earliest adopters of a new technology tend to be those for whom it offers the greatest expected financial benefit, and the slow and non-adopters are those for whom the technology offers marginal gains at best.

The economic model of adoption has the farmer focussing solely on private costs and benefits. However, for the adoption of technologies that reduce the environmental damage caused by agricultural production, it is relevant to ask whether farmers consider the environmental benefit to society of their choice of production technology. In their meta-analysis of a large number of studies of the adoption of Best Management Practices in the USA, Baumgart-Getz et al. (2012) find that farmers with a better understanding of the environmental impacts of their technology choices are more likely to adopt environmentally friendly practices. This suggests environmental impact is a consideration in the adoption decisions of farmers. However, the extent to which farmers are willing to face higher costs to generate environmental benefits is unlikely to be high enough to cause the socially optimal level of adoption.

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Static Setting

In a static (or single-year) setting, the choice faced by a farmer considering adopting a new technology can be characterised as a choice between two distributions of possible profits. Because the farmer has experience with the existing technology, he will have a good idea what profits it will yield under various states of nature (weather conditions, commodity prices etc) and will perceive it as relatively low risk. Based on the knowledge he has, he will form a subjective perception of the distribution of profits given the new technology. This profit distribution is likely to involve higher risk because the uncertainty about the state of nature will be joined by uncertainty about the performance of the technology both in general and in the farmer's particular circumstances.[3] Importantly, the farmer's choice of technology is based on his *perceptions* of the expected profit and risk offered by the new technology, which are formed from the information available to him and his beliefs about it. Thus if scientific information about the new technology exists but has not reached the farmer, it will not affect his decision.

If the farmer is risk-neutral, meaning he only cares about his expected profit, not its riskiness, he will choose to adopt the new technology if it offers higher expected profit than the current technology. However, it's likely many farmers are risk-averse, meaning they are willing to give up some expected profit for a reduction in risk. Such farmers will not adopt the new, more risky technology unless it offers expected returns that are considerably above expected returns from the existing technology.

Dynamic Setting

The farmer's decision is complicated further by the fact that she does not have just one opportunity to adopt the new technology. She can choose not to adopt today, and reconsider her choice at any point in the future. By waiting to adopt the new technology, the farmer foregoes any higher expected profits offered by it in the

[3] There may be some new technologies that are actually less risky than their predecessors, but a new technology that is subjectively more risky would seem to be the norm. See, for example, Marra et al. (2003).

meantime and the learning experience from using it, but she may gain in several ways, particularly if adopting involves a large sunk (irreversible) cost.

First, the price of the new technology may fall or its quality may rise. This could occur, for instance, if the manufacturers learn more about the technology by producing it and are thus able to improve its quality or produce it more cheaply. Thus, the farmer who waits to adopt may gain the option of purchasing a superior version of the technology at lower cost.

Second, the farmer may gain information that improves her predictions of her profit if she were to adopt the new technology. The new information might show that adopting the new technology will be profitable, or that it won't; either way, the information is valuable because it helps the farmer to make a better-informed adoption decision, and potentially avoid a costly mistake. This new information may be generated by active research and development, or by the experiences of farmers who adopted the new technology early.[4]

Third, the farmer may gain new information about how to best use the new technology, allowing her to avoid low initial profits while she learns about it. This type of new information is likely to be obtained most effectively by the farmer's own experimentation, but it is reasonable to expect it can also come from external sources.[5]

Fourth, government environmental policy might change, altering the relative returns from the old and new technologies.

Finally, while the farmer is waiting new technological advances may arrive and prove preferable to the one under consideration. By waiting, the farmer thus saves herself the irreversible costs of adopting the inferior technology.

All these possibilities mean that if there are sunk costs to adopting a new technology and uncertain returns, farmers have an *option value* to waiting to adopt: waiting until

[4] Empirical studies such as Conley and Udry (2010) demonstrate that farmers learn from each other about the best way to use new technology; Feder and Slade (1985) show that extension services can enhance adoption.

[5] Skill improvement is generally considered to be an important private benefit of early adoption, and may be gained from small-scale trials if the technology is divisible. Conversely, the inability to conduct small-scale trials because of indivisibility or other reasons can act as an additional hurdle to adoption (Marra et al., 2003).

some uncertainty is resolved allows a farmer to avoid paying the sunk cost if the benefits turn out to be particularly low. Consequently, farmers may not adopt a new technology until the expected present value exceeds the cost of adoption by a large hurdle (Carey and Zilberman, 2002). This option value can potentially lead to delays in adoption of a decade or more.[6]

In particular, it should be noted that credibly committing to future policy and maximising the predictability of any policy changes that must occur is likely to improve the adoption of environmentally friendly technologies.

2.2. Sources of uncertainty

The uncertainty that reduces adoption of a new technology and makes waiting to adopt more beneficial may stem from a number of sources. Some uncertainty is unavoidable, but some can be reduced (or worsened) by the actions of government or other groups.

Sources of uncertainty about the net benefits from adopting a new environmentally friendly technology include:

(i) Uncertainty about the performance of the technology in general and in the farmer's specific environment. This may relate to either the productivity of the technology or its effectiveness at pollution mitigation. It may be:

  (a) Genuine scientific/technological uncertainty; or

  (b) Uncertainty to the farmer, to whom existing knowledge on the matter has not diffused.

(ii) Policy uncertainty. Local or central government policies aimed at modifying environmental outcomes differentially affect the profits farmers make using different technologies. Uncertainty about whether or how policy will change in the future thus increases uncertainty about the benefits from adopting a new technology.

(iii) Uncertainty about consumer responses to output produced using a specific technology. For instance, will consumers perceive the new technology as organic, or "green", and thus be willing to pay a premium for output produced using it? How large a premium will they be willing to pay?

In general, the greater the uncertainty from any of these sources, the more the adoption rate will lag behind its optimal level. Consequently, resolving any of these types of uncertainty will efficiently increase adoption of a new technology. In particular, it should be noted that credibly committing to future policy and maximising the predictability of any policy changes that must occur is likely to improve the adoption of environmentally friendly technologies.

2.3. Empirically, Who Adopts First?

Numerous international studies have investigated the characteristics of farmers who tend to be early adopters of new technologies. The types of farmers who are more amenable to early adoption could be good targets for interventions aimed at increasing early adoption of a new technology.

(i) Baumgart-Getz et al. (2012) conduct a meta-analysis of a large number of research papers that investigate the adoption of agricultural Best Management

[6] See, for example, the studies discussed by Sunding and Zilberman (2001), p. 243.

Practices in the US, and summarise the factors that are widely correlated with adoption:

(ii) Farmers with larger farms are more likely to adopt. This may be because they have better access to finance, or because the larger scale of their operations allows them to take advantage of economies of scale.

(iii) Farmers with higher incomes are more likely to adopt. This could suggest the presence of binding credit constraints on lower-income farmers.

(iv) Farmers with more capital (higher investment in their farms, excluding acreage) are much more likely to adopt.

(v) Farmers who receive a higher percentage of their income from farming are more likely to adopt. This may be because such farmers are more financially committed to farming, and thus put more effort into optimising their farming practices.

(vi) Younger farmers are more likely to adopt. This may be because older farmers have shorter planning horizons,[7] lower environmental awareness, or higher personal costs of changing their practices.

(vii) Length of farming experience is not correlated with adoption.

(viii) Education is widely interpreted by this literature as a measure of individual capacity, which may lower the costs of evaluating a new technology and learning to use it optimally. However, Baumgart-Getz et al. do not find formal education is significantly correlated with adoption.

(ix) Farmers with more or better information about best management practices are more likely to adopt them.

(x) Farmers who have been exposed to extension training are more likely to adopt, and the magnitude of the effect is relatively large given most of the extension training experiences considered were one-day events.

(xi) Farmers with more specific environmental knowledge about the effects of their farming practices and the goals of environmental programmes are more likely to adopt.

(xii) Farmers with stronger network ties (to agencies, the agribusiness sector, neighbouring farmers, grass-roots organisations, or a university extension office) are more likely to adopt.

(xiii) Farm operators who own the land they work are weakly more likely to adopt.

Although Baumgart-Getz et al. do not find that risk aversion significantly decreases adoption, they do find that it became less important for adoption over time. This suggests risk aversion may decrease adoption early in the diffusion process of a new technology when uncertainty about its performance is very high. Other studies have found the risk preferences of the farmer do affect adoption: Abadi Ghadim (2000) shows that farmers who are less risk-averse tend to adopt sooner, and this effect is stronger for riskier technologies and when the scale of adoption is larger.

[7] As proposed by Ervin and Ervin (1982).

Several of these determinants of adoption emphasise the importance of information in the adoption decision, and thus the value of improved access to information for increasing adoption.

3. The Socially Optimal Rate of Adoption

Numerous studies have showed that diffusion of a new technology through the relevant market tends to be S-shaped. That is, adoption is slow initially, but then it gains speed and the technology penetrates a large proportion of the potential market in a short space of time. The market then becomes saturated, and the rate of diffusion slows. Kerr et al. (2002) discuss the leading models that could drive this pattern of diffusion. The pattern of diffusion that is socially optimal may also be S-shaped but is unlikely to coincide with actual adoption in the absence of intervention.

By definition, the rate of adoption of a new technology is socially optimal if, at each point in time, individuals adopt if and only if the present social benefit of them adopting (the benefit to society as a whole, including to the adopting farmer) exceeds the present social cost. Any interventions that aim to improve social outcomes by altering the adoption of new technologies should aim to move the adoption rate towards this socially optimal level. Because of the complexity of calculating the socially optimal rate of adoption, it is useful to approach this problem in terms of thinking about reasons actual adoption is likely to deviate from socially optimal levels, and then designing interventions to reduce these deviations. Broadly speaking, adoption will differ from the socially optimal rate if private benefits of adoption differ from social benefits, or there are other market imperfections.

3.1. Why Private and Social Benefits May Differ

In the case of the adoption of an environmental technology, private and social benefits are very likely to differ dramatically because, in the absence of environmental policy that rewards pollution mitigation, the benefits from mitigation accrue to society as a whole, not primarily to the mitigator. Formally, there are positive environmental externalities from the adoption of environmentally friendly technologies.[8]

Private benefits from early adoption are likely to be lower than social benefits for the additional reason that early adopters generate information about the performance of the new technology and how best to use it. Their adoption decisions account for the private value of this information, but not its value to other potential adopters. This learning effect is an additional positive externality from adoption, particularly adoption that occurs very early in the diffusion process of the technology.

In addition, social benefits will exceed private benefits from adoption if there are network benefits from adoption; that is, if the value from having adopted the technology is higher the greater the number of other farmers who have adopted it. Such a situation could occur, for instance, if the technology requires ongoing service, which will be more readily available if there is greater demand for it. While positive environmental externalities and externalities from learning are likely to be present for almost any new environmental technology, whether network externalities are present or not, and their importance, will depend on the nature of the technology.

Finally, tenure arrangements wherein the agent who makes the decision about the adoption of the new technology does not receive all the usual private benefits of adoption will drive a wedge between actual and socially optimal adoption. For instance, under a short-term contract where the operator pays a fixed rent to the landowner, the operator is unlikely to gain many of the benefits from adopting a technology that involves purchasing physical infrastructure or improving the land, so will not invest in such a technology.[9]

3.2. Other Market Imperfections

An important market imperfection is likely to occur because the information required for adoption is a public good, meaning it is non-rivalrous (its use by one does not interfere with its use by any other) and non-excludable (people who have not paid for it cannot be prevented from using it). As a result, a producer of this information cannot fully capture the benefits of the information's creation, so incentives to generate it are too small and it will be under-provided by the market.

In cases where the technology is a product manufactured by a firm, the firm may have a strong incentive to provide information about the technology in order to stimulate demand for it. However, because it is clearly in the firm's interests to portray the technology in as favourable a light as possible, information generated and disseminated by the firm may suffer from credibility issues, leading farmers to place less weight on it or disregard it entirely.

In addition, some farmers may face credit constraints that prevent them from borrowing the money that they need to pay the fixed costs of adopting the new technology. Such farmers will not adopt the new technology even when it would

[8] Or, in a situation such as New Zealand's where there is an international obligation to pay for any shortfall relative to agreed-upon mitigation targets, the recipient of the externality is the New Zealand taxpayer.

[9] On the other hand, if a well-operating rental market for land allows single operators to work a larger acreage than would otherwise be possible, this may increase the adoption of technologies that are only profitable at large scales (Sunding and Zilberman, 2001).

be both socially and privately optimal to do so.[10] If land can be used as collateral or lenders perceive small farmers as riskier, credit constraints may be more binding for farmers with less land. In cases where the technology is embodied in a capital good, the manufacturer may provide finance or guarantee a loan for its purchase.[11]

Network externalities in the use of a technology can also cause lock-in. Here, because individual users benefit from using a technology that is widely used by others, it is never beneficial for one individual to switch to a different technology, though everyone would be better off if it were possible to coordinate everyone switching simultaneously.

3.3. The Costs of Excessively Fast Adoption

In the absence of government or private interventions aimed at altering the rate of adoption of green agricultural technologies, adoption is likely to be slower than socially optimal. However, in designing interventions, it must be remembered that excessively rapid adoption, too, could be very costly.

First, adoption is more costly before learning by the producer of the technology or its early adopters improves the quality of the technology or increases knowledge about how best to use it.

Second, if widespread adoptions occurs while uncertainty about the profitability of the technology is still high, and its profitability turns out to be low, many farmers end up paying the price of the bad adoption decision. In contrast, if adoption is more moderate when the uncertainty is resolved, the overall cost to society is lower.[12]

Third, too-rapid adoption creates a risk of lock-in, the situation in which an inferior technology remains widespread just because it was adopted first. This may occur because the technology proved less profitable than was initially expected, or because a superior technology was subsequently developed. Endogenous learning is one mechanism that can cause lock-in. Under endogenous learning, farmers create knowledge about a new technology by adopting and using it. This makes the technology less uncertain and thus more attractive to other farmers, who also adopt, generating an increasing spiral of knowledge creation and adoption. Knowledge about alternative (and potentially superior) technologies is lower, making them less attractive to potential adopters, and thus endogenous learning about them is never initiated.

Network externalities in the use of a technology can also cause lock-in. Here, because individual users benefit from using a technology that is widely used by others, it is never beneficial for one individual to switch to a different technology, though everyone would be better off if it were possible to coordinate everyone switching simultaneously.

Finally, the widespread adoption of one new technology can negatively affect incentives to develop a superior technology. If there are learning or network externalities, or farmers are averse to switching the technology they use too frequently, widespread adoption of one new technology decreases demand for a substitute clean technology. Firms thus have lower incentives to develop competing technologies, and technological progress may be slower.

[10] If the technology is divisible, they may adopt it at a lower intensity than would be optimal.

[11] Sunding and Zilberman (2001).

[12] Of course, the resolution of the uncertainty depends on a certain level of adoption. However, the marginal learning effect decreases rapidly in adoption, whereas the marginal cost of adoption if the technology turns out to have low productivity does not. This suggests there is some optimal level of early adoption that is well below universal.

The reasons private benefits from adoption differ from social benefits, discussed in Section 3, suggest several main roles for interventions that would move the rate of adoption of new technologies closer to the socially optimal rate. First, interventions could alter the incentives faced by farmers so they fully take into account the environmental consequences of their choices. Second, they could address the imperfection in the market for information by generating and disseminating credible information to reduce uncertainty about new technologies. Third, they could subsidise (implicitly or explicitly) early adopters to internalise the learning externality of early adoption. Because the three market imperfections act independently, multiple policies that targeted more than one of them would be more effective than a single policy at efficiently increasing adoption. Note that the following discussion is not intended to be a detailed recommendation of specific policy interventions; rather, it lays out principles to which policies that efficiently increase farm adoption of green technologies are likely to adhere.

4.1. Addressing the Environmental Externality

Realistically, in the absence of government policy that rewards farmers financially for reducing pollution, the majority of clean agricultural technologies that farmers could adopt will unambiguously result in lower farm profits. Although some farmers might adopt such technologies out of personal concern about the environment, in the absence of additional incentives adoption is likely to be well below the socially optimal level. One instrument that could align the private benefits of reducing pollution with the social benefits is farm-scale emissions trading. Under such a system, every unit of pollution a farmer avoids earns him or her a financial reward equal to the value to society of that pollution reduction. Thus a risk-neutral farmer will adopt an environmentally friendly technology whenever the adoption will benefit society as a whole.

As discussed extensively in the economics literature, assuming transactions costs are not too high, such a system achieves the resulting emissions reduction at least cost, because it equalises the marginal cost of abatement across farmers. Specifically, those who can abate more cheaply do so and gain from selling permits to those for whom abatement would be more costly.

An additional advantage of such a system is that it stimulates the invention of new technologies that reduce environmental damage.[13] In essence, because farmers benefit financially from reducing pollution, they are willing to pay for pollution-reducing technologies. Their demand for such technologies makes increased investment in inventing them or adapting them from overseas worthwhile.

However, because the pollution-reduction benefits of adopting a green technology are spread over a number of years following the adoption, the efficacy of farm-scale emissions trading at reducing emissions will depend critically on farmers' expectations about future policy. If farmers expect the policy to be reversed after a year, they will adopt the new technology only if their benefits from reducing pollution in that year are sufficient to compensate them for the upfront expenditure, and will ignore any benefits from future pollution reduction. Thus a policy that is expected to be temporary will result in much less adoption than one expected to remain in place permanently. Consequently, for such a scheme to be effective at inducing efficient adoption of green technologies, it must be perceived to be unlikely to be reversed.[14]

Because the pollution-reduction benefits of adopting a green technology are spread over a number of years following the adoption, the efficacy of farm-scale emissions trading at reducing emissions will depend critically on farmers' expectations about future policy.

Although a farm-scale emissions scheme could efficiently reduce farm-generated pollution, it should be noted that the abrupt introduction of such a scheme could impose high costs if it meant too many farmers had to risk adopting untried new technologies. A more gradual introduction that allowing learning about the new technologies by a smaller number of early adopters and the diffusion of the information they learned could reduce the overall costs to society dramatically.

While attractive from an economic standpoint, this type of scheme may suffer from low political acceptability that could prevent it becoming a reality in New Zealand in the foreseeable future. An imperfect alternative that would encourage farmers to consider at least some of the social cost of their emissions could be a non-financial incentive scheme, wherein farmers who take certain actions to reduce their emissions receive social recognition, or benefits from branding or certification.

A second poor alternative to a scheme that puts a value on emissions reductions could be a performance or technology standard that mandates specific actions. Such a policy has a number of well-known drawbacks. First, it forces all farms to meet the same standards, although compliance costs will vary, and thus is not an efficient way to achieve a given reduction in emissions. Second, it may mandate the use of a technology that is not cost-effective in some of the situations where it is required to be used. Third, a performance standard is difficult to set appropriately. If set too low, it will have no effect; if set too stringently, it may require an unachievable level of performance or the use of a technology that is not fully developed. Finally, a technology standard slows or halts the development of future superior technologies by reducing demand for them.

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[13] See, for instance, Hayami and Ruttan (1985), who formalise and empirically verify that innovations respond to economic conditions.

[14] The relevant timespan over which policy certainty is desirable will depend on the expected lifespan of the new technology and how quickly it is expected to recoup its adoption costs.

However, set appropriately such a policy will force some improvement in emissions, as well as the dissemination of information about any compulsory technology. In particular, such a policy may be of some use for regulating the tail of very slow adopters, or when *any* use of the old technology has large negative effects on the environment.

4.2. Addressing the Imperfection in the Market for Information

Information about the performance and best use of new technologies is a public good. Consequently, its creator cannot fully capture the benefits of its creation, and it will be underprovided by the market. Such information would resolve uncertainty and efficiently increase adoption; its absence causes adoption to be inefficiently low. Whether or not a policy is implemented to address the environmental externality, improvements in information could also increase adoption in a socially beneficial way.

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Information about a new technology plays a number of roles in the decisions of farmers whether to adopt the technology. Most basically, in order to make an adoption decision, the farmer must know that the technology exists.

Information about the performance of the technology reduces the difference between the farmer's perception of the profit distribution from the new technology, and the true profit distribution the technology will yield. Assuming the farmer faces appropriate incentives, this more accurate information will allow her to make an adoption decision that is more likely to be optimal from society's point of view. Without incentives to abate, the improved information will allow the farmer to make a decision that is more likely to be privately optimal.

As discussed previously, a risk-averse farmer will avoid adopting a new technology that is profitable in expectation if it yields returns that are too risky. Information that reduces the perceived riskiness of a new technology thus encourages its adoption by risk-averse farmers if this adoption is socially desirable.

Another important type of information is knowledge on how best to use a new technology, to maximise profits and avoid costly mistakes. A new technology might interact with current technologies and practices in complex and unpredictable ways, meaning adopting a new technology could involve broad, fundamental changes to the running of the farm. In such cases, adoption could be a very large leap and learning from the experiences of other farmers is likely to especially valuable. The generation and diffusion of this type of information allows for improved environmental outcomes at lower social cost. Farmers who would have adopted the technology regardless may find themselves earning higher profits than expected or abating more, and some additional farmers will find it profitable to adopt the environmentally friendly technology when otherwise they would not.

Intervention may have a role in both the generation and dissemination of information about a new technology. Besides information being under-provided by the market, farmers may have high costs of searching for existing information and evaluating opposing claims about new technologies. Facilitating the diffusion of information, both from researchers to farmers and between farmers, could thus increase adoption in a socially beneficial way.

An important caveat to note is that the information must be credible to be effective at improving adoption; farmers may rightfully disregard information that is seen as advertising aimed solely at increasing sales (from firms producing the new technology) or propaganda aimed at making farmers meet a government objective to reduce emissions regardless of cost. For this reason, policies that encourage the adoption of a new technology by underplaying the uncertainty remaining in preliminary scientific findings about its efficacy can be costly in the long run. By damaging the credibility of the government in this regard, they may evoke resistance among farmers to subsequent government initiatives aiming to increase the diffusion of future beneficial technologies.

4.3. Addressing the Learning Externality from Early Adoption

Absent intervention, adoption of a new technology will be inefficiently slow in the early stages of the diffusion because, by trialling the new technology, early adopters generate information that benefits others, but do not account for this benefit in making their adoption decisions. A subsidy for early adopters, be it explicit or implicit, would remedy this situation and efficiently increase early adoption. Depending on the form of the subsidy, it could also help farmers overcome credit constraints that would otherwise prevent them from efficiently adopting the technology.

An optimal subsidy scheme would have several important characteristics. First, it would decrease in magnitude and be phased out over time as the technology became more widespread and learning about it from new adopters slowed down. Second, because the purpose of increasing early adoption is to make more information about the technology available faster, those who received the subsidy would have a formal obligation to share what they learned from their adoption. There are many possibilities, but this might involve allowing their farm to be studied by an outside party and the findings made public. Third, because the performance of a technology varies with environmental conditions and farmers thus place more weight on information derived from local experience, the early adoption encouraged by the scheme should be geographically dispersed rather than clustered in one region.

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If a subsidy were to be offered, it would be taken up by the farmers most likely to adopt the technology in the absence of the subsidy, namely those for whom the technology offered the greatest expected net benefits. Some of the characteristics such farmers tend to have are discussed in Section 2.3. Ensuring farmers with these characteristics were made aware of the subsidy programme would likely be beneficial for its uptake.

A subsidy for early adoption could take any number of forms, including, for instance, a monetary transfer, aid in accessing financing for adopting the technology, access to independent consulting advice, or access to networks for better information sharing.

It could prove a cost-effective way of inducing early adoption: empirical studies have shown that adopters are more sensitive to decreases in the cost of adopting a technology than to equivalent future cost savings.[15] On the other hand, subsidies suffer the drawback that they must be paid to all early adopters, including those who would have adopted early regardless, which reduces their cost-effectiveness.

[15] See, for instance, Jaffe and Stavins (1995).

Possibly the greatest difficulty with a subsidy for early adoption is that the policymaker must decide which of competing technologies to subsidise, and must do so at a time when uncertainty is high, both about the profitability of the technologies and their effectiveness at reducing emissions. Backing a poor choice of technology could result in lock-in to an inferior technology down the line, with potentially very large social costs. One potential solution is to subsidise multiple technologies until some are shown to be clearly inferior. This can be thought of as funding on-farm research and development, spreading the risk between promising avenues to maximise the probability of at least one bearing fruit.

5. Conclusions

A farmer deciding whether, when, and to what extent to adopt a new environmentally friendly technology is faced with a complex decision involving a high degree of uncertainty. If no policy is in place to reward him for reducing his emissions, the new technology may well appear risky and unprofitable even in expectation. However, even if he expects a higher profit from adopting, he may delay doing so for a number of reasons. He may be risk averse and uncertainty about profits from the new technology may be too high; he may be hoping the price of the new technology will fall or its quality will rise; or he may be waiting for the experiences of others with the technology to reduce his uncertainty about its profitability so he can be more confident that adopting will be profitable before he pays the upfront cost.

Genuine uncertainty about a new technology is likely to be high, especially in the early stages of its diffusion, but the farmer's subjective perception of its riskiness may be even higher if he does not have ready access to all relevant information about the performance of the technology.

There are many possible rational reasons why adoption sometimes occurs at a rate that seems inexplicably slow. Although a farmer's delay may be rational for him individually, it may be costly to society as a whole. His delay will mean that he won't reduce his emissions to the same degree, nor generate knowledge about the technology.

Several market failures can be considered to drive a wedge between adoption in the absence of policy interventions and adoption that would maximise society's welfare. First, without a policy to reward emission reductions, the farmer will not fully take into account the benefit to society of adopting the green technology and thus reducing his emissions. Second, because information about the new technology is a public good it is likely to be under-provided by the market (or may not be credible if provided by the manufacturer of an embodied technology). Third, because early adopters are not compensated for the value of the knowledge they create, early adoption will be too low. In addition, some farmers may be subject to credit constraints or tenure arrangements that impede optimal adoption.

These market failures suggest policy could efficiently increase adoption of environmentally friendly technologies by offering financial (or other) rewards for emission reductions, facilitating the generation and dissemination of information about new technologies, or subsidising early adoption. Furthermore, minimising uncertainty related to future environmental policy is likely to increase adoption. However, it should be remembered that faster adoption is not necessarily better: it doesn't take full advantage of the benefits of learning, and it risks a bad adoption decision being very widespread or society becoming locked-in to an inferior technology at a social cost that may be very high.

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