Application of ADOPT (Adoption & Diffusion Outcome Prediction Tool) to Identify Factors Influencing Adoption of Rotational Grazing

Report for Virginia

CHESAPEAKE BAY FOUNDATION
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Introduction

As part of a USDA Natural Resource Conservation Service (NRCS) Conservation Innovation Grant to promote rotational grazing in the Chesapeake Bay watershed, the Chesapeake Bay Foundation (CBF) used ADOPT (Adoption and Diffusion Outcome Prediction Tool), a tool developed by social scientists in Australia, to predict an agricultural practice's likely rate, and peak level, of adoption.[1] It's designed to be "quick and dirty" but also to provide insights to the importance of various factors influencing the adoption of a particular practice, in our case, rotational grazing. The first step in using ADOPT is to clearly define the population of farmers whose adoption behavior we are interested in influencing. This is a crucial step as responses are likely to be different for the same practice among different groups of farmers.

The actual tool is an Microsoft Excel spreadsheet and users are asked to respond to 22 questions related to: a) characteristics of the practice that influence its relative advantage, b) characteristics of the population influencing their perceptions of the relative advantage of the practice, c) characteristics of the practice influencing the ease and speed of learning about it, and d) characteristics of the potential adopters that influence their ability to learn about the practice. Most questions have five possible responses with a gradation of options (i.e., highly likely, likely, no effect, unlikely, very unlikely).

According to the developers of the tool, answers to the questions are best acquired in a workshop setting. To that end, CBF will be hosting three workshops, one each in Maryland, Pennsylvania, and Maryland, to run ADOPT. Workshop participants will be local experts, e.g., staff from local soil conservation districts, extension, and/or NRCS, who work with producers on grazing, but other conservation practices as well. We want participants who can give relatively objective answers to the questions based on their experience working with producers.

This report presents the results of our first workshop held at the USDA NRCS Service Center in Harrisonburg, Virginia on March 20, 2018. Beth McGee (CBF) facilitated the workshop that was attended by 10 participants, including CBF field staff, NRCS, and Virginia Tech extension personnel, who work with producers in the Shenandoah Valley. The workshop participants and their affiliations are listed below.

Workshop Participants: Alston Horn (CBF), Matt Kowalski (CBF), Alan Hawkins (NRCS), Dale Gardner (NRCS-ACES), Bill Patterson (NRCS), Matt Booher (Virginia Cooperative Extension), Mike Phillips (NRCS), Philip Davis (NRCS), Cory Guilliams (NRCS), John Benner (Virginia Cooperative Extension).

Description of the population: As noted above, identifying the target population is important as it will dictate the answers to the questions. The group decided to focus on beef cow/calf operations, most of which are already on pasture. The group estimated that roughly 75 to 80 percent of producers in the Shenandoah Valley had cow/calf operations, though many included other types of livestock, poultry, and/or crops. Participants also noted that given the price of milk, some existing dairy operations might be transitioning to beef. It was also noted that many grazing operations also have sheep.

Information Entered into ADOPT

The predictions about time to peak adoption and the percentage of the target population likely to adopt the practice are based on the following information entered into the Adoptability and Diffusion Outcome Prediction Tool. Highlighted questions were found, in the resulting sensitivity analysis, to be in the top five, in terms of the effect on time to peak adoption.

Relative Advantage to the Population

Question 1: Profit Orientation

Potential answers range from 1—almost none have maximizing profit as a strong motivation, to 5—almost all have profit as a strong motivation.

Response:
5—Almost all have maximizing profit as a strong motivation.

In the initial voting, two votes for 3; three votes for 4; and five votes for 5.

Reasoning:
Those who voted for 3 said that producers wanted to maintain a certain life style, it was a "by-product of land ownership," and, for example, many made their money off of poultry. Those who voted for 5 said if you are doing it, of course you want to make a profit; many are motivated by wanting to continuously improve their operation and efficiency.

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1 Kuehne, G, Llewellyn, R, Pannell, DJ , Wilkinson, R, Dolling, P, Ouzmana, J, Ewing, M. 2017. Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy. Agricultural Systems 156: 115-125. See attachment, Appendix A.

Question 2: Environmental Orientation

Potential answers range from 1—almost none have protection of the environment as a strong motivation, to 5—almost all have protection of the environment as a strong motivation.

Response:
3—About half have protection of the environment as a strong motivation.

In the initial voting, seven votes for 3 and three votes for 2.

Reasoning:
Those who voted for 2 said it was related to the first question about profitability: many can't afford to do conservation practices. During discussion, it was noted that there is a lack of understanding about environmental impacts; others opined that "a lot of farmers think they are doing a good job;" also there are generational differences, with younger farmers tending to be more conservation-minded. Those who voted for 3 said there is an incentive to improve practices to pass something better along to the next generation. Many agreed, though, that farmers like to say: "I'm only farming half as good as I know."

Question 3: Risk Orientation

Potential answers range from 1—almost none have risk minimization as a strong motivation, to 5—almost all have risk minimization as a strong motivation.

Response:
4—A majority have risk minimization as a strong motivation.

In the initial voting, seven votes for 4 and three votes for 5.

Reasoning:
Those who voted for 5 indicated that reducing additional risk is a major driver; it is also age-related, e.g., older farmers are in a "holding pattern" until they can pass along their farms. Others noted that many farmers won't change/try something new until basically they simply don't have another choice.

Question 4: Enterprise Scale

Potential answers range from 1—almost none of the target farms have a major enterprise that could benefit, to 5—almost all the target farms have a major enterprise that could benefit.

Response:
5—Almost all of the target farms have a major enterprise that could benefit.

All voted for 5.

Reasoning:
This is an outcome of defining the target population in the way we did.

Question 5: Management Horizon

Potential answers range from 1—almost none have a long-term (greater than 10 years) management horizon, to 5—almost all have a long-term management horizon.

Response:
2—A minority have a long-term management horizon.

In the initial vote, one vote for 1, seven votes for 2, and two votes for 3.

Reasoning:
This outcome was surprising to the facilitator. Participants were very pessimistic about the economics and future of farming in the Shenandoah Valley, e.g., many children are scared of inheriting farms because they can't afford them, development pressures, and the aging population of farmers. All of these factors make conservation hard to afford. One participant made the observation that there two types of farmers: those who are "farming with money and others that are farming for money." Those in the latter category are really struggling.

Question 6: Short-term Constraints

Potential answers range from 1—almost all currently have a severe short-term financial constraint, to 5—almost none have a severe short-term financial constraint.

Response:
2—A majority have a severe short-term financial constraint.

In the initial voting, six voted for 2 and four voted for 3.

Reasoning:
Those who voted for 3 noted that last year, for many producers, was better than they thought—based on doing taxes. Also, it was noted that in many instances, a spouse works off the farm and this can help buffer any short-term financial constraints. Those that voted for 2 looked more strictly at the farm financial constraints. Also, it was noted that years can be very variable, e.g., a drought year would be much different. It was also noted that farming practices could make a difference, e.g., well-managed pasture could help mitigate drought losses.

Learnability Characteristics of the Innovation

Question 7: Trial Ease

Potential answers range from 1—not easy to trial, to 5—very easy to trial.

Response:
4—Easy to trial.

In the initial voting, four votes for 3, five votes for 4, and one vote for 5.

Reasoning:
Those that voted for 4 and 5 noted it was fairly easy to do a demo plot with polywire or plant different forage on a small scale, though water access could be an issue. There was general agreement, however, that in order for producers to commit to full conversion, some "hand holding" and individual attention are necessary. It was also noted that one "problem" with the existing programs is they don't really allow for experimentation, e.g., a farmer must sign up and commit to full implementation or they don't get NRCS funding.

Question 8: Practice Complexity

Potential answers range from 1—very difficult to evaluate effects of use due to complexity, to 5—not at all difficult to evaluate effects due to complexity.

Response:
4—Slightly difficult to evaluate effects due to complexity.

Initial vote: one voted for 2, two voted for 3, four voted for 4, and three voted for 5. Lots of variability in the responses due in part to confusion of what the question was trying to ascertain.

Reasoning:
Participants noted that it is easy to see benefits of improved pasture by moving to more intensive grazing, but not as easy to see benefits to the animals in terms of weight gain. Also, it was challenging to note differences as you increase the complexity of the grazing system, e.g., adding more paddocks. Some farmers will choose convenience over management, and therefore not see the value in more intensive grazing. It was also noted that benefits, in terms of improved animal weight, would be influenced by the existing condition of the farms, e.g., whether farms are currently understocked versus overstocked.

Question 9: Observability

Potential answers range from 1—not observable at all, to 5—very easily observable.

Response:
5—Very easily observable.

In the initial vote, three voted for 4 and seven voted for 5.

Reasoning:
This answer was also a surprise for the facilitator. Apparently, the visual indicators of the benefits of more intensive grazing are readily apparent. Healthier-looking pastures and even increases in rooting depth appear within a year.

Learnability of Population

Question 10: Advisory Support

Potential answers range from 1—almost none use a relevant advisor, to 5—almost all use a relevant advisor.

Response:
2—A minority use a relevant advisor.

Ten votes for 2.

Reasoning:
We decided this question did not necessarily mean the producer paid the advisor, but rather the advisors could include NRCS and extension staff. Also, we clarified that once a producer committed to grazing, they would use an advisor. The response was focused on the target population, prior to any decision to convert to grazing.

Question 11: Group Involvement

Potential answers range from 1—almost none are involved with a group that discusses farming, to 5—almost all are involved in a group that discusses farming.

Response:
5—Almost all are involved with a group that discusses farming.

In the initial vote, four voted for 4 and six voted for 5.

Reasoning:
When participants responded to this question, they noted that they interpreted this to include one-on-one discussions/mentoring with other farmers, as well as informal and formal farmer groups.

Question 12: Relevant Existing Skills and Knowledge

Potential answers range from 1—almost all need new skills and knowledge, to 5—almost none need new skills and knowledge.

Response:
2—A majority will need new skills and knowledge.

In the initial vote, four votes for 1 and six votes for 2.

Reasoning:
It was noted that the additional knowledge wasn't too difficult to attain, but it would require some changes and some advice.

Question 13: Practice Awareness

Potential answers range from 1—it has never been used or demonstrated in their district, to 5—almost all are aware it has been used or demonstrated in their district.

Response:
4—A majority are aware that it has been used or demonstrated in their district.

In the initial vote, five voted for 3, four voted for 4, and one voted for 5. Re-vote: four votes for 3 and six votes for 4.

Reasoning:
A range in participant responses. Those that voted for 3 were considering the entire Shenandoah Valley, not just Rockingham County, for example. Also, it was noted that farmers might be "aware" it was being implemented, but really do not have an understanding of the value or what it really was.

Relative Advantage of the Innovation

Question 14: Relative Upfront Cost of Practice

Potential answers range from 1—very large initial investment, to 5—no initial investment required.

Response:
2—Large initial investment needed.

Initial vote: four votes for 2, four votes for 3, and two votes for 4. Re-vote: eight votes for 2 and two votes for 3.

Reasoning:
Those that voted for 2 noted that practices like water systems, stream crossings, and fencing required large upfront expenditures. Those that voted for 4 noted that for minimal investment, one could get buy-in to the concept, that is, it could be done on the cheap—not with NRCS specifications. Re-vote was taken and participants were asked to consider just the cost of grazing and not necessarily include the cost of stream exclusion per se.

Question 15: *Reversability of Practice*

Potential answers range from 1—not reversible at all, to 5—very easily reversed.

Response:
5—Very easily reversed.

Initial vote: one voted for 4 and nine voted for 5.

Reasoning:
Participants agreed it was very easy to stop using, e.g., "just leave the gates open." In fact, it was observed that some producers do it for the money and then don't implement the grazing system. Participants highlighted the need for follow-up with producers receiving contracts.

Question 16: *Profit Benefit in Years that It is Used*

Potential answers range from 1—large profit disadvantage in the years it is used, to 8—very large profit advantage in years it is used.

Response:
6—Moderate profit advantage in years that it is used.

In the initial vote, six votes for 6 and four votes for 7.

Reasoning:
Participants believed the practice would lead to moderate or large profits based on reduced feed costs, reduced diesel fuel for hay making, improved animal health from fresh water, increased carrying capacity, improved pounds-per-acre in terms of animal weight gain (though not necessarily total pounds), and improved dry matter intake. "Healthy pastures lead to healthy animals."

Question 17: *Future Profit Benefit*

Potential answers range from 1—large profit disadvantage in the future, to 8—very large profit advantage in the future.

Response:
7—Large profit advantage in the future.

In the initial vote, three votes for 6, five votes for 7, and two votes for 8. Re-vote: three votes for 6 and seven votes for 7.

Reasoning:
Those that voted for 8 said the longer you do it, the more benefits will accrue ,e.g., building soil health, reduced inputs, increased resiliency to drought, better forage, etc. Those that voted for 6 indicated the future has unknown variables (e.g., drought) and noted there might be "diminishing returns." One participant thought "potential for profit" would be a better way to ask the question.

Question 18: *Time Until Any Future Profit Benefits are Likely to be Realized*

Potential answers range from 1—more than ten years, to 5—almost immediately.

Response:
4—One to two years to realize profit benefits.

Initial vote: two votes for 3 and eight votes for 4.

Reasoning:
Participants noted the relative rapid response in terms of streambank repair due to fencing, pasture visual improvement due to resting, and increased root depth—indicating healthier pasture/better forage. Soil health benefits are probably more on a three-to-five year time horizon.

Question 19: Environmental Costs and Benefits

Potential answers range from 1—large environmental disadvantage, to 8—very large environmental advantage.

Response:
7—Large environmental advantage.

Initial vote: seven voted for 7 and three voted for 8.

Reasoning:
We didn't really discuss this as benefits to soil health, water quality, and climate change are fairly well established.

Question 20: Time to Environmental Benefit

Potential answers range from 1—more than ten years, to 5—almost immediate.

Response:
4—One to two years for environmental benefits.

In the initial vote, seven voted for 4 and three voted for 5.

Reasoning:
Some discussion was focused on benefits of stream fencing, e.g., reductions in bacteria and improvement in bank stability; but also as noted for question 18, pastures can also start to improve rapidly.

Question 21: Risk Exposure

Potential answers range from 1—large increase in risk, to 8—very large reduction in risk.

Response:
8—Large reduction in risk.

In the initial vote, two voted for 5, two voted for 6, and six voted for 7. Lots of discussion.

Reasoning:
Participants that voted for 5 indicated producers might perceive more risk in that, for example, they could have issues with pipeline/water sources or stream fencing could be susceptible to flooding. Those that voted for 7 were focused on the improved pasture being less susceptible to climatic extremes. There were a lot of diverse opinions on this and it was noted that farmers may have a different view on this than our participants.

Question 22: Ease and Convenience

Potential answers range from 1—large decrease in ease and convenience, to 8—very large increase in ease and convenience.

Response:
6—Moderate increase in ease and convenience.

In the initial vote, two voted for 2, one voted for 3, two voted for 5, and four voted for 6. Re-vote: Five votes for 6 and the rest of the votes were mixed.

Reasoning:
A range in responses and opinions on this question. Those that voted 2 (moderate decrease in ease and convenience) noted that grazing does mean more management in terms of thinking and record keeping. Those that voted for 6 noted it involves less labor (e.g., not needing to make hay) and that it can "makes life easier"—though acknowledging it does require thought. One participant related a story of a farmer noting his neighbor (a rotational grazer) was outside "moving polywire freezing his a$$ off while I'm sitting in my heated tractor." It appears that the question of whether or not grazing increases “ease and convenience” is in the eye of the beholder!

Predicted Adoption Levels

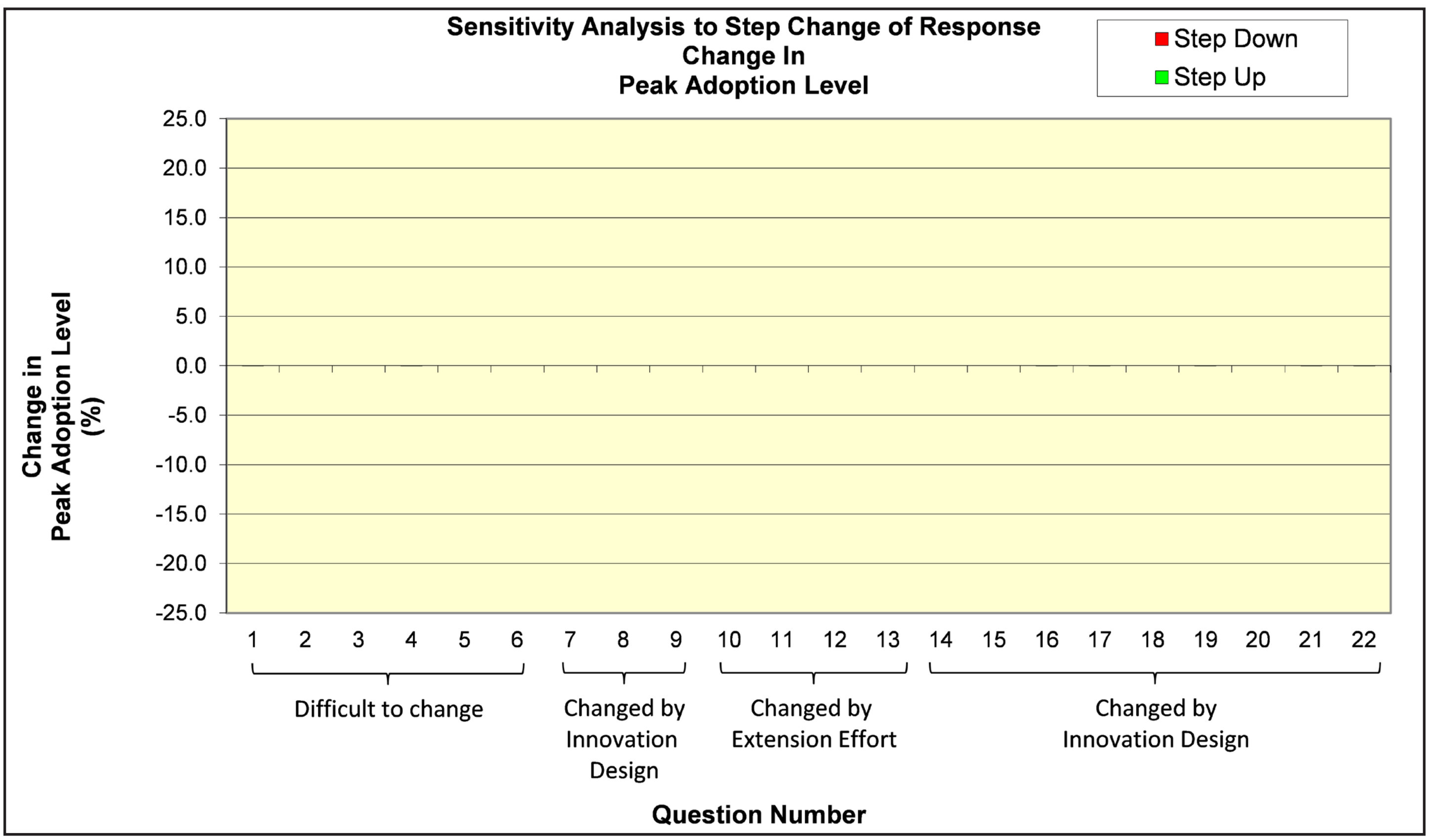
Predicted peak level of adoption[1]	98%
Predicted years to peak adoption[2]	11
Predicted years to near-peak adoption[3]	9
Year innovation first adopted or expected to be adopted	N/A
Year innovation adoption level measured	N/A
Adoption level in that year	N/A
Predicted adoption level in 5 years from start	71.2%
Predicted adoption level in 10 years from start	97.9%

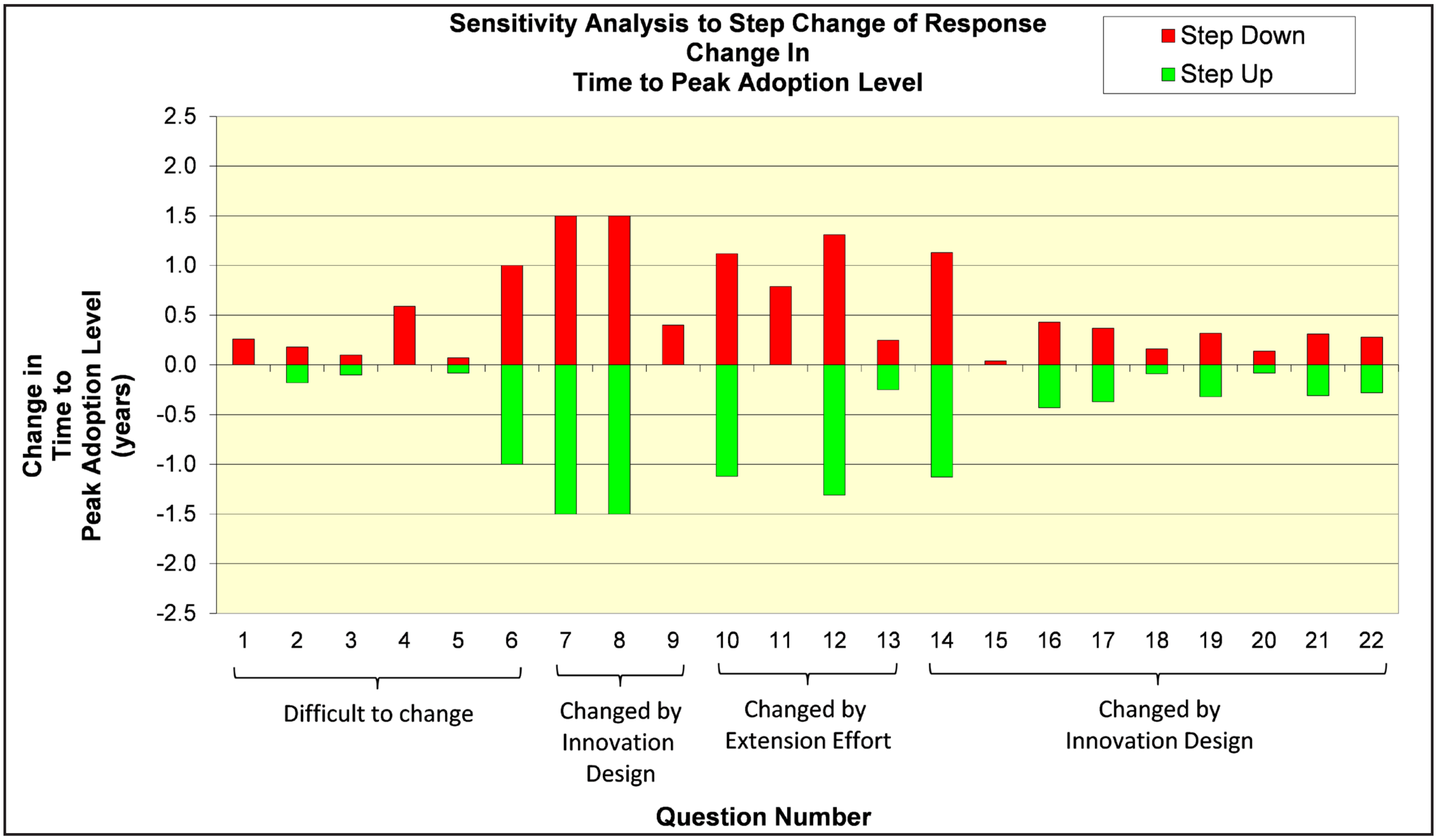
PLEASE NOTE:

1. The prediction of 'Peak Adoption Level' is a numeric output that is provided to assist with insight and understanding, and like any forecasts, should be used with caution.
2. The prediction of 'Time to Peak Adoption Level' is a numeric output that is provided to assist with insight and understanding, and like any forecasts, should be used with caution.
3. 'Time to Near Peak Adoption' represents the time to 95% of the maximum predicted adoption level.

Sensitivity Analysis

The following charts show the effects on 'Peak Adoption Level' and 'Time to Peak Adoption' of single step changes up and down for all questions.





Observations

ADOPT predicts that a high proportion of the target population (98%) should be willing to implement rotational grazing and that the time to the peak adoption is 11 years. While very encouraging, these estimates are probably optimistic. Our workshop participants, many of whom grew up on farms or are still farming, likely represent the perspective of the “early adopter” end of the spectrum of agricultural producers. The overall sense of the group is that rotational grazing is relatively simple and makes good financial sense. As noted below, however, the financial challenges of many producers farming in the Shenandoah Valley will reduce the likelihood of adoption. Nonetheless, the results do suggest there is great potential for adoption with the right approaches and messages.

One somewhat surprising outcome was the broad view among participants that the future of farming in the Shenandoah Valley is in jeopardy. This was evident in the response to question 5 about the portion of the population that had a long-term management horizon. Participants noted there is an aging population of farmers and that it is basically unaffordable for new farmers to enter into farming. Even those who would inherit their parents’ farm are reluctant to become farmers because they are concerned they can't afford it. Land values are competing with development pressures. Fewer people grow up on farms or have agricultural backgrounds, and the gap between landowners and producers seems to be expanding. Overall, these factors make affording conservation practices challenging. In addition, it was noted that many beef producers lease land, creating a need to educate landowners about the benefits of rotational grazing, so they are more receptive to have their land managed in that way.

On the positive side, participants were convinced of the financial and environmental benefits of rotational grazing and that those benefits would be observable in the short-term and accrue over the long-term (questions 9, 16-20). The challenge is how to convey that information in a compelling way to farmers, especially given high up-front costs (question 14), short-term financial constraints (question 6), and the fact that the majority of producers do not rely on advisors for their information (question 10).

Responses to question 13 indicate there is room for improvement in terms of awareness of the practice and its benefits. In addition, the practice is easy to trial (question 7) and farmers do rely on other farmers for advice (question 11).

The results of the sensitivity analysis indicated the five characteristics that would have the most influence on the time to peak adoption are: trialing ease—how easy can a practice be trialed before a decision is made to adopt; practice complexity—related to how easy or difficult it is to discern the benefits of the practice; advisory support—what proportion of the producers rely on paid advisors for information; relevant existing skill and knowledge—are substantial new skills and knowledge necessary to implement the practice; and the relative upfront cost of the practice.

We queried Rick Llewellyn, one of the tool developers, to ask why we did not see any changes in the sensitivity analysis for the peak level of adoption. He suggested that we did not see any step up sensitivity effects because we were at roughly maximum adoption (i.e., there was little room for improvement). The lack of step down effects is because the answers our group gave indicate a high level of assumed relative advantage from future profit, environmental, risk, and ease and convenience measures that all contribute to high cumulative amounts of advantage. Basically, if one would take a step down in one of these there would still be enough combined net relative advantage for maximum adoption to eventually be reached.

Recommendations

Taken together, these observations lead us to the following recommendations:

First, continue and expand farm field days, pasture walks, etc. where farmers talk to other farmers about rotational grazing and its benefits—to their bottom line, to their increased resiliency, to their animals' health, etc. Also ensure that "new grazers," e.g., those that have recently enrolled or completed state or federal grazing-related contracts, are aware of these opportunities. This conclusion logically draws from observations that there are environmental and economic benefits to be shared: from the responses to question 11, that farmers get information from other farmers, and from the discussion around reversibility (question 15), that producers sometimes don't follow through on their grazing plan because there is little technical assistance follow up.

Second, outreach efforts should make connections between established rotational grazers and new grazers, perhaps by organizing local "grazing roundtables," and doing intentional outreach to producers who recently completed NRCS or state contracts related to grazing management. This conclusion logically draws from the responses to question 11, that farmers get information from other farmers, and the discussion around question 15: workshop participants noted that one reason producers failed to follow through on their grazing plans was insufficient follow up and continued technical support. For example, a producer may receive EQIP funds for a rotational grazing plan and grazing infrastructure, but once the practices are implemented, NRCS has limited capacity to continue to provide additional technical assistance. So, linking new rotational grazers with experienced grazers in a structured, yet informal, setting of information sharing (e.g., a bi-monthly grazing round table) could provide the support new grazers need to succeed. In addition, this approach could include newly transitioned rotational grazers to provide another perspective on grazing.

Third, there should be efforts to provide more opportunities to trial rotational grazing. As noted in discussion of question 7, rotational grazing is relatively easy to trial on a small-scale basis, but as noted in responses to question 14, there are substantial upfront capital costs for producers in completely transitioning to rotational grazing. So, more opportunities for producers to "try out" more intensive grazing systems, without investing significant resources, would be useful. In addition, it was also noted that federal programs often require a commitment to "whole farm" conservation that may preclude "trying out" rotational grazing systems. State cost-share programs in Virginia do allow producers to pick and choose practices and fields, and so might be a good fit for some experimentation. In addition, private or grant funds could also be pursued to enhance outreach and technical assistance efforts by non-government organizations, while also providing materials like polywire fencing and portable watering systems that can be used for grazing demonstration areas.

In conclusion, application of ADOPT provided the forum for an informed and engaged discussion about potential barriers to adoption of rotational grazing in the Shenandoah Valley. More importantly, the results led to some tangible recommendations that, if implemented, could lead to greater adoption of this beneficial practice.

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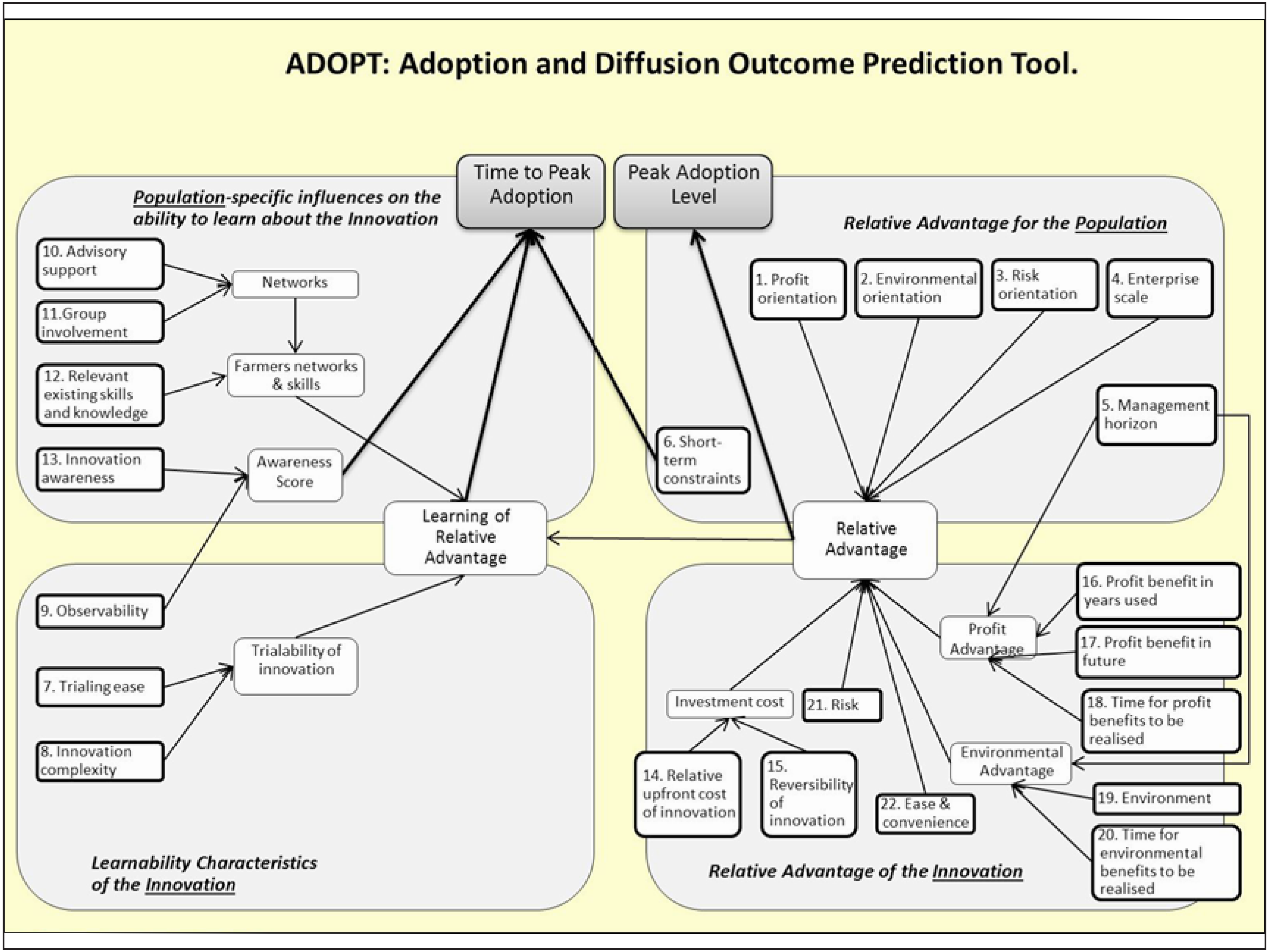
ADOPT: Adoption and Diffusion Outcome Prediction Tool.
Time to Peak Adoption
Peak Adoption Level
Population-specific influences on the ability to learn about the Innovation
Relative Advantage for the Population
10. Advisory support
11.Group involvement
Networks
12. Relevant existing skills and knowledge
Farmers networks & skills
13. Innovation awareness
Awareness Score
1. Profit orientation
2. Environmental orientation
3. Risk orientation
4. Enterprise scale
5. Management horizon
6. Short-term constraints
Learning of Relative Advantage
Relative Advantage
9. Observability
Trialability of innovation
7. Trialing ease
8. Innovation complexity
16. Profit benefit in years used
Profit Advantage
17. Profit benefit in future
18. Time for profit benefits to be realised
Investment cost
21. Risk
Environmental Advantage
14. Relative upfront cost of innovation
15. Reversibility of innovation
22. Ease & convenience
19. Environment
20. Time for environmental benefits to be realised
Learnability Characteristics of the Innovation
Relative Advantage of the Innovation

APPENDIX A

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Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy

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ABSTRACT

There is much existing knowledge about the factors that influence adoption of new practices in agriculture but few attempts have been made to construct predictive quantitative models of adoption for use by those planning agricultural research, development, extension and policy. ADOPT (Adoption and Diffusion Outcome Prediction Tool) is the result of such an attempt, providing predictions of a practice's likely rate and peak level of adoption as well as estimating the importance of various factors influencing adoption. It employs a conceptual framework that incorporates a range of variables, including variables related to economics, risk, environmental outcomes, farmer networks, characteristics of the farm and the farmer, and the ease and convenience of the new practice. The ability to learn about the relative advantage of the practice, as influenced by characteristics of both the practice and the potential adopters, plays a central role. Users of ADOPT respond to 22 questions related to: a) characteristics of the practice that influence its relative advantage, b) characteristics of the population influencing their perceptions of the relative advantage of the practice, c) characteristics of the practice influencing the ease and speed of learning about it, and d) characteristics of the potential adopters that influence their ability to learn about the practice. ADOPT provides a prediction of the diffusion curve of the practice and sensitivity analyses of the factors influencing the speed and peak level of adoption. In this paper the model is described and its ability to predict the diffusion of agricultural practices is demonstrated using examples of new crop types, new cropping technology and grazing options. As well as providing predictions, ADOPT is designed to increase the conceptual understanding and consideration of the adoption process by those involved in agricultural research, development, extension and policy.

1. Introduction

Adoption of new farming practices has been studied intensively, but predicting such adoption remains a challenge (Ekboir, 2003). To date there has been no successful attempt to distil the vast body of research knowledge into a model for making quantitative predictions of adoption of agricultural practices. This is despite ongoing demand for improved evaluation of potential investments in agricultural research, development and extension (Alston et al., 1995) or policy adjustments (Pannell et al., 2006) that depend crucially on assumptions about rates of adoption of new practices.

There is also increasing demand for agricultural researchers to have a greater understanding of the farming-systems context of practice change, and the broader innovation system (Leeuwis 2004; Foran et al. 2014). This is seen as necessary in order to improve the relevance and impact of their research (Van de Fliert, 2003; World Bank, 2006) or to prepare agricultural agencies for the process of 'scaling' a new farming practice (Wigboldus et al. 2016). A number of frameworks and approaches have been developed to facilitate deeper understanding of the context for agricultural innovation systems (e.g. Schut et al. 2015). These can often involve structured workshop programs to create comprehensive impact pathways and logic models (e.g. Douthwaite et al. 2008; Wigboldus et al. 2016) and to assess societal impacts of research (e.g. Joly et al. 2015). These approaches are capable of qualitatively capturing complex innovation contexts and outcomes. However, there are situations where simpler, less burdensome approaches are needed

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(Thornton et al. 2017), or where quantitative prediction are needed. We set out to develop a tool with the joint aims of predicting the future level of adoption of a new farming practice by a particular population of farmers, and of enhancing the understanding of practice adoption by diverse agricultural stakeholders. The relatively narrow focus on prediction of adoption for a specific practice was selected to allow for a tool that could be applied in a relatively rapid consultation and elicitation process. In this paper we present the resulting tool, ADOPT (Adoption and Diffusion Outcome Prediction Tool).

The conceptual framework and functional design of the ADOPT model is described, after which we present its application to several case studies of practice adoption in Australian agriculture. We use these case studies to test the validity of outputs from ADOPT. Demonstrated and potential roles for the tool are discussed. This includes provision of information for those investing in agricultural research and development, and building knowledge of the adoption process among those engaged in projects that are intended to result in changed farming practices.

2. Existing approaches to predicting adoption in agriculture

The most prominent and influential attempt to organize and classify the factors influencing adoption and diffusion of practices is that of Rogers (2003). However, Rogers' framework is designed for conceptualizing adoption rather than for quantitatively predicting adoption of novel practices.

There have been a number of efforts to predict diffusion of technologies among a population, particularly in the field of marketing and consumer technologies (see reviews by Mahajan et al., 1990; Turner et al., 2010). These approaches have not been widely used in agriculture. They tend to focus on awareness and imitation but neglect profitability and other non-profit related factors such as environmental or risk-related benefits that we know are important drivers of adoption in agriculture. Also, they are not usually designed to account for the complexities of farming systems and the specifics of practice adoption by farmers.

For agricultural systems there is a comprehensive body of research explaining the broad range of factors influencing adoption and diffusion of practices. See Feder and Umali (1993), Knowler and Bradshaw (2007) and Pannell et al. (2006) for reviews or Alcon et al. (2014) or Kassie et al. (2013) for recent research studies. However, there have been relatively few attempts to develop approaches to make predictions about adoption outcomes using those factors. In agricultural research and development, policy and extension, unstructured guesswork has been a common approach among practitioners for making such predictions.

A technology that received particular attention in *ex-ante* adoption studies was bovine somatropin (bST) for use in the U.S. dairy industry (Caswell et al., 1998; Lesser et al., 1999; Zepeda, 1990). From these studies Caswell et al. (1998) identified three main approaches used in the prediction of adoption and diffusion. These were: 1) a survey of producers' intentions (e.g. Kaine et al., 2011; Karali et al., 2014; Lesser et al., 1999); 2) an expected-profits approach which uses farm-level financial and other data to determine which producers would find practice adoption profitable and would therefore probably adopt it; and 3) an historical market trends approach which predicts adoption through extrapolation. Dearing and Meyer (1994, p. 45) used a different qualitative approach and predicted diffusion by identifying perceptions of both the potential adopters and the 'innovator' delivering and communicating the new practice. They suggested that this approach is especially useful when attempting to determine the likelihood of adoption of practices with similar characteristics. A method based on a panel of experts and the development of heuristic models and rules for the behavior of people as part of the adoption process has also been described (TAMU, 2000, Section 6.8).

Models based on attitudes, beliefs and norms (e.g. Ajzen 1991) have had agricultural application in improving understanding of adoption (e.g. Jansen et al. 2009; Meijer et al. 2014). However, these generally demand specific survey data from the population and are often not suited to ex ante scenarios where there is little awareness of a new practice. Limitations of survey-based methods include their cost, the time required to collect and analyze data, and the potential lack of familiarity with the new practices among respondents (Dearing and Meyer, 1994). The expected-profits approach (Caswell et al., 1998), although widely used by economists, neglects non-profit-related factors that are known to influence adoption of new practices in agriculture (Alston et al., 2002; Lewin, 1939). The historical-trends approach or surveys of past adoption behavior to predict farmers' adoption of a new practice is of limited usefulness when there has been no corresponding similar practice or if relevant data is unavailable (Caswell et al., 1998; Langley et al., 2005).

There is a gap in the availability of a tool that is based on a strong understanding of the literature on adoption by farmers of agricultural practices, but could be applied effectively and efficiently to new scenarios without requiring additional research. We set out to fill this gap.

Earlier we noted the recent development of approaches that emphasize the complex social, economic, and institutional environment within which agricultural innovation occurs, and that aim to help off-farm stakeholders to better support the processes of innovation and scaling up of usage (e.g., Schut et al. 2015; Wigboldus et al. 2016). ADOPT's quantitative predictions may complement the qualitative approaches used in those approaches. In turn they may add value to ADOPT by providing a more detailed overview of what hinders or enables changes in the innovation system, and by assisting researchers to engage better, such as by creating more appropriate technologies or catering better for farmer diversity.

3. Model development

3.1. Procedure

The development of ADOPT commenced with establishment of a research team, which included experienced researchers in agricultural practice adoption and agricultural systems from several disciplinary backgrounds including rural sociology, agricultural economics, and farming systems research.

The first stage of the model development was to establish a set of guiding principles for the study. We agreed that the framework should:

- account for a comprehensive range of practice-specific and population-specific factors that influence adoption by farmers;
- build on and be consistent with evidence from the established literature;
- predict adoption for a population of farmers, rather than for any individual farmer;
- be relevant to agriculture in a developed-country context;
- not have high data demands because there is usually a lack of available data and resources to collect extensive data for prediction of adoption;
- be simple enough to be readily used and understood by project practitioners who are not specialists in adoption; and
- promote systematic and structured consideration of the factors influencing adoption of new farming practices.

The second stage was to identify variables that most often have substantial, predictable and consistent influences on adoption outcomes for inclusion in the model. The set of 22 primary variables included in the model is outlined in later sections, and presented in Table 1 and Fig. 2. The starting point was the extensive set of variables included in existing review articles and syntheses from various disciplinary backgrounds (Feder and Umali, 1993; Lindner, 1987; 2006; Rogers, 2003; Vanclay, 2004).

Table 1
ADOPT variables and questions.

Quadrant	ADOPT variable	Question asked in ADOPT
Relative advantage for the population	1. Profit orientation	What proportion of the target population has maximising profit as a strong motivation?
	2. Environmental orientation	What proportion of the target population has protecting the natural environment as a strong motivation?
	3. Risk orientation	What proportion of the target population has risk minimization as a strong motivation?
	4. Enterprise scale	On what proportion of the target farms is there a major enterprise that could benefit from the practice?
	5. Management horizon	What proportion of the target population has a long-term (greater than 10 years) management horizon for their farm?
	6. Short-term constraints	What proportion of the target population is under conditions of severe short-term financial constraints?
Learnability characteristics of the practice	7. Trialing ease	How easily can the practice (or significant components of it) be trialed on a limited basis before a decision is made to adopt it on a larger scale?
	8. Practice complexity	Does the complexity of the practice allow the effects of its use to be easily evaluated when it is used?
	9. Observability	To what extent would the practice be observable to farmers who are yet to adopt it when it is used in their district?
Population-specific influences on the ability to learn about the practice	10. Advisory support	What proportion of the target population uses paid advisors capable of providing advice relevant to the practice?
	11. Group involvement	What proportion of the target population participates in farmer-based groups that discuss farming?
	12. Relevant existing skills & knowledge	What proportion of the target population will need to develop substantial new skills and knowledge to use the practice?
	13. Practice awareness	What proportion of the target population would be aware of the use or trialing of the practice in their district?
Relative advantage of the practice	14. Relative upfront cost of the practice	What is the size of the up-front cost of the investment relative to the potential annual benefit from using the practice?
	15. Reversibility of the practice	To what extent is the adoption of the practice able to be reversed?
	16. Profit benefit in years that it is used	To what extent is the use of the practice likely to affect the profitability of the farm business in the years that it is used?
	17. Profit benefit in future	To what extent is the use of the practice likely to have additional effects on the future profitability of the farm business?
	18. Time for profit benefit to be realized	How long after the practice is first adopted would it take for effects on future profitability to be realized?
	19. Environmental impact	To what extent would the use of the practice have net environmental benefits or costs?
	20. Time for environmental impacts to be realized	How long after the practice is first adopted would it take for the expected environmental benefits or costs to be realized?
	21. Risk	To what extent would the use of the practice affect the net exposure of the farm business to risk?
	22. Ease and convenience	To what extent would the use of the practice affect the ease and convenience of the management of the farm in the years that it is used?

Population characteristics that could potentially be ambiguous, onerous to measure, difficult to assess at a population-level (relative to other populations) or not clearly distinct from other variables were not included. Age, for example, was excluded as an explanatory variable because its direction of influence is inconsistent between studies (De Souza Filho et al., 1999; Pannell et al., 2006) and 'compatibility' (Rogers 2003) was not included due to the concept being largely captured by other variables, including *Relative upfront cost of the practice*; *Profit benefit in years that it is used*; *Profit benefit in future*; *Risk*; and *Ease and convenience*. Variables also needed to be relevant to a developed country agricultural context. For example, access to credit and to markets was not included as it was assumed to be close to universal in developed countries. Government regulation is not represented explicitly but is captured in ADOPT users' responses to the profitability or cost variables.

In the third stage, a conceptual framework of the adoption process was developed, showing the interactions between the variables and their influences on adoption outcomes. The framework was developed using an expert knowledge elicitation workshop (Aspinall and Cooke, 2013) with the research team and then refined over time as the model was tested. The conceptual framework is outlined in the next section.

Fourthly, questions and response options were developed to elicit scores for each of the independent variables in the framework (Table 1). These were further developed through an extensive process of consultation, including at a series of workshops where the model was tested with potential end-users (Kuehne et al., 2012).

Fifthly, the framework was quantified. Steps included selection of the scoring system for each variable, selection of specific functional forms for each relationship in the model, and estimation of parameters for each equation. The selection of functional forms and estimation of parameters could not be based on statistical analysis of extensive data sets because, in most cases, the required data was non-existent. Even where factors influencing a particular type of practice change have been analyzed across multiple studies, consistent statistical relationships between common factors and adoption rates have not been able to be quantified for reasons such as inconsistent definitions and model structure across studies, and/or interactions with the particular conditions within individual populations (Knowler and Bradshaw, 2007). Instead, expert knowledge elicitation was initially undertaken with members of the research team, involving calibration of the model outputs to achieve results judged to be realistic against known diffusion examples across the relevant range of each function. The model predictions were then tested in a variety of ways (outlined below), resulting in modifications to the model structure and parameters.

The preliminary version of the tool was used to pilot test the approach. ADOPT was used as part of a process of developing a new research program by a major Australian research funder, the Grains Research and Development Corporation. Based on feedback from stakeholder participants and the research funding body, it was concluded that ADOPT played an effective and valuable role in encouraging thinking about the influences on adoption (Kuehne et al., 2012) and the tool was further revised based on feedback received.

In December 2011 a revised beta version of the model was made available for download from www.csiro.au/ADOPT. After 6 months, 250 people who had downloaded the model were asked to participate in a web-based survey, requesting feedback on its design, accuracy, usability and usefulness and suggestions for improvements. 57 responses were received. The research team also delivered a series of workshops to various professionals working with farmers across a range of industries including grains, dairy, sugar, cotton and livestock. Participants in these workshops applied ADOPT to specific farming practices of their choosing. Detailed feedback was collected during and after each workshop. Feedback from all sources has led to further improvements to the model structure and tool design. The result is the version presented here.

3.2. Overview of conceptual framework

Based on past research and conceptual thinking, we identified two overarching factors influencing the adoption process: the relative advantage of the practice, and the effectiveness of the process of learning about the practice (Abadi Ghadim and Pannell, 1999; Lindner, 1987). Relative advantage is the main driver of how many in a population decide to adopt, while the learning process influences the time lag before decisions to adopt are made. A number of variables influence these overarching factors. For example, the relative advantage of a practice may depend on its riskiness and costs, while learning depends on the observability of the practice and growers' access to extension services.

The variables of the conceptual framework can be separated into two categories: those that relate to characteristics of the target population and those that relate to characteristics of the practice. In some cases, individual variables from the target population and the practice can be closely linked. For example, the relative advantage of a practice can depend on its environmental benefits (a characteristic of the practice) but the value of that can depend on farmers' attitudes towards environmental benefits (a characteristic of the target population).

Combining these two pairs of issues (relative advantage and learning; the practice and the population) gives us four sets of issues to be considered (see Fig. 1). The two 'learning' quadrants on the left hand side of Fig. 1—*Population-specific influences on the ability to learn about the practice* and the *Learnability characteristics of the practice*—influence the time taken to reach peak adoption. Past research (e.g., Marsh et al., 2000) suggests that these learning-related factors do not significantly influence the peak adoption level but can have a substantial influence on the *Time to peak adoption* as they help to overcome a scarcity of information and experience, particularly before adoption becomes widespread.

The right-hand 'relative advantage' quadrants are *Relative advantage for the population* and the *Relative advantage of the practice*. These combine to determine the overall relative advantage of a practice, which directly influences the peak level of adoption (Griliches, 1957; Marsh et al., 2000). Aspects of relative advantage may also influence the *Time to peak adoption*. This is because when there is high relative advantage, learning of their relative advantage is likely to be easier and therefore more rapid (e.g. Abadi Ghadim and Pannell, 1999).

Fig. 2 shows how the variables were organized into a logical structure to provide the conceptual framework. The meanings of these variables are clarified by the questions used to elicit them, which are listed in Table 1. Table 2 includes the range that can be generated by question responses and examples of the resulting numerical inputs into the equations that generate the predictions. The equations and parameters are detailed in the Appendix (Supplementary information). In the following sections we explain how the variables in each quadrant are combined to make predictions about adoption.

Our aim is to characterize adoption for a population of farmers, rather than individual farmers. We recognize the learning-related heterogeneity often found within a population (e.g. Jansen et al. 2010). The approach explicitly acknowledges heterogeneity in the population, asking questions of the form, "What proportion of the target population …" has a particular characteristic (Table 1).

3.3. Predicting the time until peak adoption

The *Time to peak adoption* is modeled as being influenced by four main factors (some of which are in turn influenced by other factors). First is *Awareness score*, which combines farmers' existing level of awareness of the practice with the ease with which farmers can gain awareness through local observation (*Observability*). The higher the value of the *Awareness score*, the lower the predicted *Time to peak adoption*, reflecting that there is often a delay to adoption while awareness among farmers of the local existence of a new practice builds (Lindner et al., 1982). The influence of initial awareness on the speed of diffusion is modest relative to other variables. The second learning-related variable that influences *Time to peak adoption* is the intermediate variable *Learning of relative advantage*, which brings together the five remaining primary variables in the learning quadrants and often has substantial influence. It depends on *Trialability of the practice*, which in

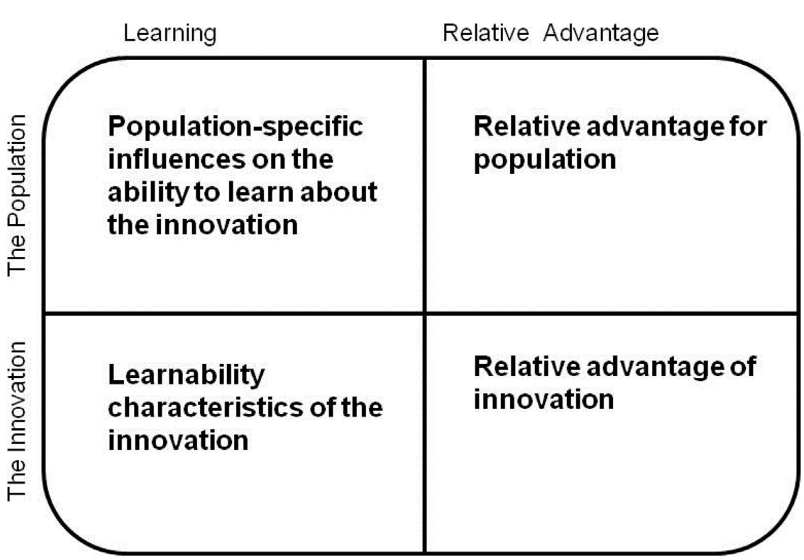

Fig. 1. The basic conceptual framework shows relationships between: learning, relative advantage, the population and the practice.

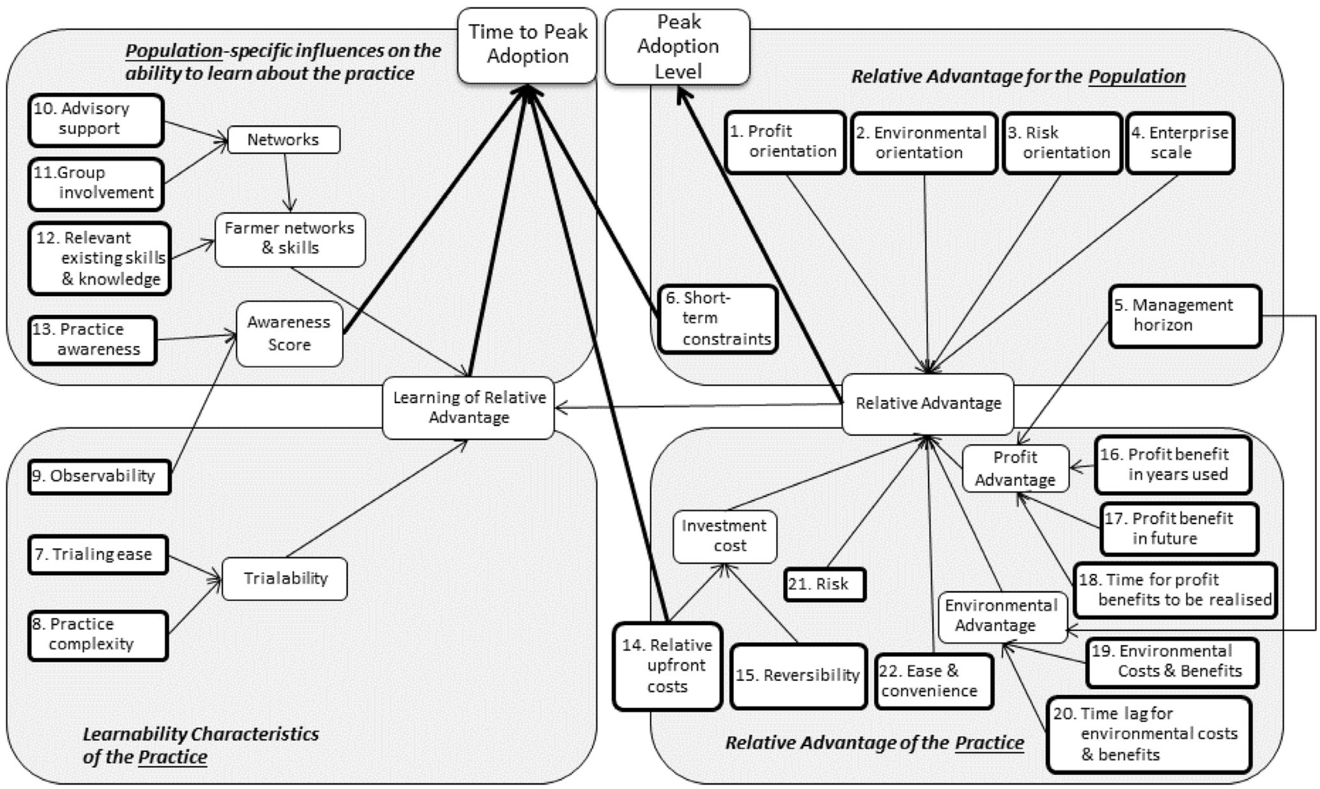

Fig. 2. The conceptual framework of influences on *Peak adoption level* and *Time to peak adoption*.

turn depends on the ease of trialing the practice (Feder and Umali, 1993; Kvale and Brinkmann, 2009; Rogers, 2003) and the complexity of its impact on the farming system (Pannell, 1999; Rogers, 2003; Vanclay, 1992).

Learning also depends on several characteristics of the population of farmers: their existing skills and knowledge, their involvement in farmer groups (De Souza Filho et al., 1999), and their usage of farm advisors (D'Emden et al., 2006), which combine into an intermediate variable *Farmer networks and skills*. Importantly, learning also depends on the *Relative advantage* of the practice. For example, if a practice performs very well its merits are relatively easy to recognize and learn about (Jensen, 1982; Lindner, 1987). Because of the input from *Relative advantage*, *Time to peak adoption* is influenced to some extent by all of the variables from the two relative advantage quadrants. A high score for *Learning of relative advantage* can be achieved for a population through diverse avenues such as when a practice is easily observed and trialed, it is not complex in terms of being able to evaluate its relative advantage, farmers have good networks and relevant skills practice, and relative advantage the practice is high.

A direct influence on *Time to peak adoption* that comes from the *Relative advantage of the practice* quadrant is *Relative up-front cost* of the practice. Practices that have high upfront costs are likely to have greater delays on average before the investment in adoption is made relative to practices with no initial financial hurdle to first use, even when the likely relative advantage from use of the practice is recognized. High upfront costs can constrain adoption through delays in having available finances for investment (Pannell et al., 2006; Vanclay, 1992) and, in the case of equipment, consideration of the optimal replacement time (D'Emden et al., 2006; Vanclay, 1992).

The *Time to peak adoption* can be affected by transient *Short-term constraints*, which come from the *Relative advantage for the population* quadrant. For example, these constraints may include a lack of finance resulting from a drought or a period when inputs are unavailable (Marangos and Williams, 2005) or a current natural disaster such as a flood. These constraints are assumed to have a short-term influence of only a few years and not to affect *Relative advantage* in the long term.

3.4. Predicting the peak level of adoption

Peak adoption level is dependent on the intermediate variable *Relative advantage* (Fig. 2). This is based on the 14 independent variables in the two relative-advantage quadrants with *Relative Advantage* being derived from a combination of factors relating to profit, risk, environmental,convenience, investment cost, enterprise scale and management horizon.

Profit advantage is the most complex of the intermediate variables. It depends on the profit benefit (or loss) of the practice in years when it is used plus any delayed effect on profit in later years (e.g. a pesticide resistance prevention strategy may not generate profits until some years later (Weersink et al., 2005)). The latter is discounted based on any expected time lag between implementing the practice and observing its later benefits. Where the planning horizon over which farmers consider the benefits and costs of their management is short (e.g. for a farming population with an uncertain future in a vulnerable industry or region) the discount rate is higher.

Environmental advantage is somewhat similar, depending on a measure of the environmental impacts of the practice, the time lag for environmental impacts to occur, and the farmers' time horizon for management. Environmental impacts may be positive or negative, depending on the particular practice, so their influence on relative advantage may be positive or negative. *Environmental advantage* is also discounted if the benefits (or environmental costs) are not expected to occur until future years.

The other important practice characteristic contributing to relative advantage is *Risk*. This captures the extent to which the practice will reduce or increase the exposure of the farmer to risk. For example, a practice involving higher yield potential but greater yield variance and downside losses in poor years may increase average profit but also increase risk. Alternatively a practice may reduce risk, resulting in decreased variance in farm income, but not substantially increase average

Table 2
Numeric inputs to ADOPT for six different practice examples.

ADOPT variable	Wording of minimum response	Question responses (model inputs)						Wording of maximum response
		Autosteer	Bt cotton	Lupins	Mace wheat	No-till	Saltbush	
1. Profit orientation	Almost none have maximising profit as a strong motivation[a] (1)[b]	4	5	4	4	4	4	Almost all have maximising profit as a strong motivation (5)
2. Environmental orientation	Almost none have protection of the environment as a strong motivation (1)	3	3	3	3	3	3	Almost all have protection of the environment as a strong motivation (5)
3. Risk orientation	Almost none have risk minimisation as a strong motivation (1)	3	3	3	3	3	3	Almost all have risk minimisation as a strong motivation (5)
4. Enterprise scale	Almost none of the target farms have a major enterprise that could benefit (1)	5	5	5	5	5	3	Almost all of the target farms have a major enterprise that could benefit (5)
5. Management horizon	Almost none have a long-term management horizon (1)	4	3	4	4	4	4	Almost all have a long-term management horizon (5)
6. Short-term constraints	Almost all currently have a severe short-term financial constraint (1)	4	4	4	4	4	4	Almost none currently have a severe short-term financial constraint (5)
7. Trialing ease	Not trialable at all (1)	3	3	4	5	2	2	Very easily trialable (5)
8. Practice complexity	Very difficult to evaluate effects of use due to complexity (1)	4	4	3	5	2	2	Not at all difficult to evaluate effects of use due to complexity (5)
9. Observability	Not observable at all (1)	4	3	5	3	5	4	Very easily observable (5)
10. Advisory support	Almost none use a relevant advisor (1)	3	5	2	3	2	2	Almost all use a relevant advisor (5)
11. Group involvement	Almost none are involved with a group that discusses farming (1)	3	5	3	3	3	3	Almost all are involved with a group that discusses farming (5)
12. Relevant existing skills & knowledge	Almost all need new skills and knowledge (1)	2	2	2	5	1	1	Almost none will need new skills or knowledge (5)
13. Practice awareness	It has never been used or trialed in their district (1)	2	5	5	5	4	4	Almost all are aware that it has been used or trialed in their district (5)
14. Relative upfront cost practice	Very large initial investment (1)	2	3	4	4	2	2	No initial investment required (5)
15. Reversibility practice	Not reversible at all (1)	4	5	5	5	3	2	Very easily reversed (5)
16. Profit benefit in years that it is used	Large profit disadvantage in years that it is used (−3)	1	2	1	3	1	0	Very large profit advantage in years that it is used (+4)
17. Profit benefit in future	Large profit disadvantage in the future (−3)	1	1	3	0	1	1	Very large profit advantage in the future (+4)
18. Time for future profit benefits to be realized	More than 10 years [c](16)	2	2	2	na	4	2	Immediately (1)
19. Environmental impact	Large environmental disadvantage (−3)	1	3	0	0	4	1	Very large environmental advantage (+4)
20. Time for environmental impacts to be realized	More than 10 years [c](16)	2	1	na	na	1	4	Immediately (1)
21. Risk	Large increase in risk (−3)	0	1	0	1	−1	1	Very large reduction in risk (+4)
22. Ease and convenience	Large decrease in ease and convenience (−3)	3	3	0	0	0	0	Very large increase in ease and convenience (+4)

Minimum and maximum [a]question responses and corresponding [b]values used for formulas. [c]This question has 5 response options representing 1, 2, 4, 8 and 16 years.

profit.

The extent to which *Profit advantage, Environmental advantage* and *Risk* contribute to *Relative Advantage* is influence by the *Profit orientation* (Pannell et al., 2006), *Environmental orientation* (Cary and Wilkinson, 1997; Lynne et al., 1995; Lynne et al., 1988), and *Risk orientation* (Marra et al., 2003) of the farmer population. A population of farmers may have a strong orientation to one of these objectives, (profit, environmental or risk reduction) and as such, practices that align with the farmers' orientation will have greater appeal and higher potential adoption. For example, a particular population of farmers that can be identified as having lower aversion to risk in their farm business (e.g. a progressive population of generally wealthier farmers with substantial off-farm income) is more likely to gain relative advantage from a practice that increases farm business income risk (variance) than a highly risk-averse population of farmers (e.g., the population of organic farmers studied by Serra et al., 2008). The default setting for risk aversion of a typical commercial farming population in ADOPT is slight risk aversion, which is a common finding in the agricultural literature (Pannell et al., 2006) but this can be overridden by users based on their understanding of a particular target population. Similarly, a particular population may have a greater or lesser relative orientation towards environmental benefits.

Another potentially important contributing factor to *Relative Advantage* is the *Ease and convenience* of the practice. Some practices may have benefits in terms of profit, risk or environmental outcomes but will add (or reduce) inconvenience or difficulty once they are implemented, with resultant impacts on adoption (Carpenter and Gianessi, 2000). The *Relative Advantage* of some practices such as herbicide-tolerant and disease-resistant crops has been partly attributed to convenience-related attributes that are not captured by typical considerations of profit (Piggott and Marra, 2008).

The relative advantage gained from the above sources is influenced by *Enterprise scale*. This has usually been found to be a significant influence on practice adoption in agriculture (e.g. Cary et al., 2002; Fuglie, 1999; Hoag et al., 1999). Practices that can benefit a large proportion of the farm business have potentially greater overall relative advantage.

Another relevant economic factor is *Relative upfront cost of the practice*, which captures the extent to which adoption of a new practice requires upfront costs. The higher the upfront investment cost, the lower the relative advantage, other things being equal. For example, a practice that involves purchase of new seeding machinery will involve higher upfront costs and thereby higher investment costs compared to say adoption of a different crop seeding time. A high upfront cost is more important to farmers' decision making if the cost is irreversible, meaning that it cannot be fully recovered if a farmer decides to disadopt after trying the practice. Some practices are easily reversible, such as changing back to the original crop seeding time next season; some practices may involve technologies that may be able to easily resold without substantial losses if not successful, but other infrastructure practices such as an earthworks are not easily reversible, in which case the farmer's overall *Relative upfront cost of the practice* is higher (Baerenklau and Knapp, 2007).

3.5. The ADOPT diffusion curve

Based on the predicted values for *Time to peak adoption* and *Peak adoption level*, we generate an assumed sigmoid-shaped diffusion curve, showing how the level of adoption in the relevant population of farmers changes over time (Fig. A2 – see supplementary information). Although diffusion curves vary in precise shape (Ruttan, 1996), the sigmoid shape is a good approximation in the majority of cases (Dixon, 1980; Feder and O'Mara, 1982; Jensen, 1982). It is assumed that the curve begins at the time when the practice or technology is reasonably available for potential adopters to acquire at a local level, for example when supply adequately meets local adopter demand and does not require costly importation or use of early experimental prototypes.

ADOPT also provides a sensitivity analysis that graphically shows the effect on *Time to peak adoption* and *Peak adoption level* of a step up or step down in the response for each variable if all other variables remain unchanged.

4. Validation

We tested the predictive ability of ADOPT using 6 specific practices and populations with known complete or near-complete adoption outcomes in Australian agricultural systems. The practices that we examined were; a) using autosteer (GPS guidance in tractors), b) growing insect-resistant (Bt) transgenic cotton, c) growing a new species of legume crop, lupins, d) growing a new wheat variety, Mace, e) using no-till cropping, and f) planting saltbush forage shrubs (Table 2). Each was selected due to availability of data on farmer adoption and of information on the practice and population characteristics. The first step in using ADOPT is to clearly define the practice to be analyzed, and the population of farmers whose adoption behavior we are interested in. This is a crucial step as responses are likely to be different for the same practice among different groups of farmers, and for different practices within a particular group of farmers.

4.1. Data

Inputs to the model were based on current knowledge of the 22 variables. The resulting predictions of peak adoption and time to adoption are unlikely to be the same as *ex ante* predictions that would have been made if ADOPT had been used at the time of the introduction of the practice as understanding of the practice would have been more limited at that time. While ADOPT is typically intended to be used before or during the early stages of a diffusion process, the main objective here was to test the model's predictive ability without having to make assumptions about the inputs that would have been used at the time the practices were introduced. In reality, adoption rates can be influenced by largely unpredictable forces from the target population's internal and external environment, such as output price changes, cost changes (Sneddon et al., 2011) and other practices that emerge during the diffusion process (Ekboir, 2003).

Table 2 shows the assumed inputs into ADOPT for the adoption scenarios. Where possible, the inputs are derived from specific studies of the target population (e.g. Marsh et al., 2000; Llewellyn and Ouzman 2014; Llewellyn et al. 2012) but more commonly they are generated through consultation with regional experts who were active during the diffusion process. For example, for the lupin and cotton adoption scenarios, experts who were active in the research and extension processes during the early stages were interviewed and their judgements were used to generate a representative set of inputs for ADOPT. In other cases, researchers who had studied adoption of these practices interviewed to inform the inputs (see descriptions below). As several of the practice examples relate to Australian broadacre cropping, in these cases a level of consistency been assumed for several characteristics of the target population, such as their orientations towards profit and the environment. The inputs relating to relative advantage characteristics of the practices were permitted the benefit of hindsight, something not available to those using ADOPT for predictive purposes in the early stages of diffusion. The practices and target populations are summarized as follows.

Use of autosteer (*GPS guidance in tractors*). The technology became commercially available in 1998 (Rennie, 2002) and by 2012 was adopted by 77% of Australian grain growers (Llewellyn and Ouzman, 2014; Robertson et al., 2012). Later adoption has benefited from substantial cost reductions relative to the expensive models first released onto the market.

Growing transgenic Bt cotton varieties. Genetically modified Bt cotton was commercially introduced to the Australian cotton industry in 1996.

By 2005 approximately 90% of Australia's cotton growers planted the insect resistant varieties (Holtzapffel et al., 2008; Pyke, 2007), increasing to nearly 100% adoption (Fischer et al. 2014) in 2010 once the requirement for refuges of non Bt cotton was relaxed.

Growing narrow-leaf lupins in Western Australia cropping regions. While lupin varieties had been grown in Western Australia, with limited success, since the late 1960s, a new higher-yielding narrow-leaf lupin variety (Illyarrie) was launched in 1978. Supported by a major state government extension effort most districts reached peak narrow-leaf lupin adoption of between 60 and 90% in 9–10 years (Marsh et al., 2000). Here we consider a district in the central wheatbelt of Western Australia.

Growing the Mace wheat variety in Western Australia. Mace was a consistently high performing variety across a wide range of environments and soil types, released in 2008, but grown by farmers from 2009, reaching an adoption level of 67% of wheat sown in 2015 (Department of Agriculture and Food, 2016). This is a likely peak as an improved, related, variety became commercially available in 2016 as an intended replacement. It is likely that the proportion of growers who have grown the Mace variety to some extent is higher than peak proportion of area sown, but farm-level adoption data is not available.

Using no-till cropping systems in the South Australian wheatbelt. Levels of adoption reached 84% among South Australian farmers before plateauing (Llewellyn and D'Emden, 2010). Cropping without prior tillage began with the earliest pioneers and farmer developers of no-tillage technology in the 1980s, but it took some time for the system to be fully developed, so we consider that it is more realistic to consider that adoption started from 1990 (Young, 2003) when appropriate no-tillage machinery became widely commercially available and the practice became defined and extended as no-till cropping (Crabtree, 2010).

Planting saltbush as a forage shrub on southern Australian low-rainfall crop-livestock farms. Old Man Saltbush (*Atriplex nummularia*) has been recognized for its value as a forage shrub for many decades (Condon and Sippel, 1992), and although widely promoted from the beginning of the 1990s, only became practical on a commercial scale when a major commercial nursery was established in 1996 (Coull, 2008). Studies of planted areas of forage shrubs allow us to estimate that Saltbush is currently grown on approximately 5% of farms in the South Australian Mallee focus region with adoption of existing varieties plateauing by 2008 (Collard et al., 2011; Llewellyn et al., 2010).

4.2. Results

The practice examples have a wide range of peak adoption levels, from Saltbush with 5% to Bt cotton with 90%. The results generally show strong correlation between known adoption levels and those predicted by the tool (Table 3, Fig. 3 and Fig. 4). *Time to peak adoption* varied from 6 years (Mace wheat) to 22 years (No-till and Saltbush). ADOPT was able to predict the rapid adoption of the successful crop varieties (Bt cotton and Mace wheat) and the slow adoption of more complex practices such as no-till or less profitable practices such as saltbush systems. ADOPT predicted more rapid adoption of autosteer than occurred in practice (Table 3). This may be partly explained by the

Table 3
Comparison of ADOPT's predictions and actual adoption estimations.

Practice	Peak adoption level (%)		*Time to peak adoption* (yrs.)	
	Predicted	Actual	Predicted	Actual
Autosteer	83	83	15	20
Bt cotton	98	90	9	9
Lupins (WA)	72	75	14	10
Mace wheat (WA)	71	67	4	6
No-till (SA)	79	83	20	22
Saltbush (SA)	9	5	23	22

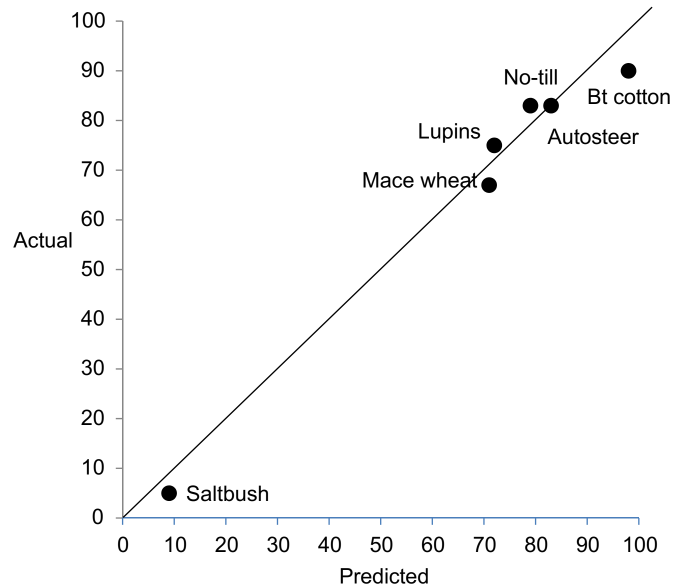

Fig. 3. The predicted vs. actual peak adoption level (%).

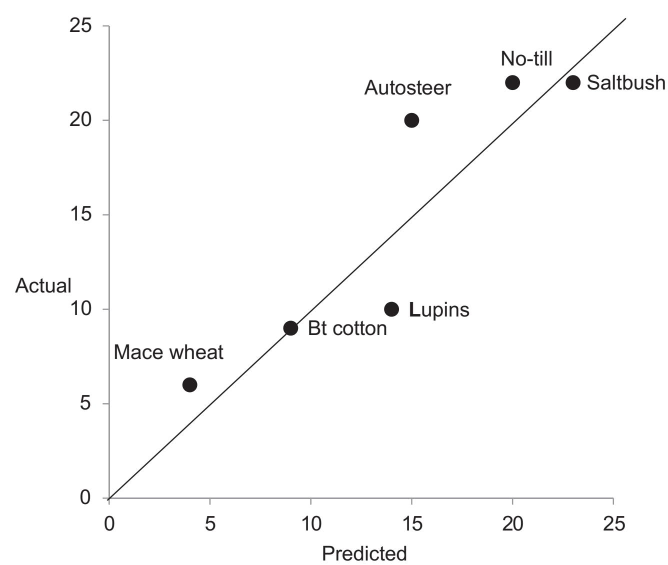

Fig. 4. The predicted vs. actual *Time to peak adoption* (years).

very high cost of the initial technology and the relative lack of support services when it was released onto the market, including the more limited availability of GPS services that enabled the technology. The *Time to peak adoption* of lupin has been over-estimated. This may be because the analysis assumed relatively low levels of experience with growing the new lupin and did not adequately represent farmer experience and skills gained with earlier, less successful, lupin options. It is also possible that ADOPT was unable to capture the fact that the extension campaign carried out by the state government Department of Agriculture to promote uptake of the new lupin was unusually intense and comprehensive (Marsh et al. 2000).

Results depend on subjective judgements about the input values, and in some cases results were sensitive to assumed inputs. We noted that the prediction of peak adoption was most sensitive to key variables determining relative advantage, particularly for practices with low to moderate relative advantage, such as lupin (Table 4). For this example, the variables with the biggest influence on predicted peak adoption were profit benefit in the year that the practice is used, profit benefit in later years, environmental impacts of the practice, and the ease and

Table 4
Effect of step changes in question responses on predicted *Time to peak adoption* (years) and *Peak adoption* (% of population adopting) for lupins.

	Peak adoption level (%)[a]		*Time to peak adoption* (years)	
	Step down	Step up	Step down	Step up
1. Profit orientation	−15	11	0.2	−0.2
2. Environmental orientation	0	0	0	0
3. Risk orientation	0	0	0	0
4. Enterprise scale	−13	[b]	0.2	[b]
5. Management horizon	−2	2	0	0
6. Short-term constraints	0	0	1	−1
7. Trialing ease	[c]	[c]	1.5	−1.5
8. Practice complexity	[c]	[c]	1.5	−1.5
9. Observability	[c]	[c]	0.3	[b]
10. Advisory support	[c]	[c]	1.1	−1.1
11. Group involvement	[c]	[c]	0.8	−0.8
12. Relevant existing skills & knowledge	[c]	[c]	1.8	−1.8
13. Practice awareness	[c]	[c]	0.3	[b]
14. Relative upfront cost of practice	−8	7	0.1	−0.1
15. Reversibility of practice	−5	[b]	0	[b]
16. Profit benefit in years that it is used	−26	16	0.4	−0.4
17. Profit benefit in future	−24	15	0.3	−0.3
18. Time for profit benefits to be realized	−5	2	0	0
19. Environmental Impact	−27	16	0.4	−0.4
20. Time for environmental impacts to be realized	0	0	0	0
21. Risk	−19	13	0.3	−0.3
22. Ease and convenience	−20	13	0.3	−0.3

Notes: The sensitivity results presented in this table are relative to the predicted *Time to peak adoption* of 13.6 years, and the predicted *Peak adoption level* of 72% for Lupins.
[a] These numbers are the changes in the percentage value of the prediction.
[b] No added effect is possible because response is already set to maximum.
[c] No effect on *Peak adoption level* from questions in these quadrants.

convenience of the practice. For *Time to peak adoption*, the most influential variables in this example were short-term constraints, ease of trialing and practice complexity.

The relative sensitivity of different variables will vary in different examples due to interactions between the variables. For example, the influence of the environmental impact of a practice depends on how environmentally oriented the farmers are. However, the example shown highlights the common sensitivity of peak adoption results to the factors influencing the relative advantage score. In reality, net relative advantage is often marginal for many innovations and incorporates some factors that involve disadvantage and some that provide advantage. A small change in one variable contributing to relative advantage can therefore make a large difference to adoption as indicated by the steep section of the curve shown in Fig. A2 (see Supplementary information). We argue that this reflects reality and the fine line that can exist between practices that gain substantial adoption and those that do not. In the case of the lupin example, the large differences in actual adoption levels between districts (Marsh et al. 2000), often adjacent, is likely to reflect the impact of relatively small differences in relative advantage of lupins in the different agro-ecological zones.

4.3. Limitations

ADOPT makes predictions on the basis of a stable external environment. Changes in costs, prices, legislation, the practice itself, or the availability of other technologies that compete or substitute are not explicitly accounted for in the model (although users may choose to respond to questions based on predicted conditions). The predictive accuracy of ADOPT can be expected to be less at times of rapid change, but even at these times ADOPT can provide value by engaging and educating its users about adoption issues. A potential enhancement to ADOPT could be to explicitly represent the adaptation and improvement of practices over time (e.g. by farmers or researchers), as is commonly observed, thereby increasing the practices' relative advantage for new adopters (Douthwaite et al. 2001; Wigboldus et al. 2016).

ADOPT also takes institutional arrangements as given, and does not, for example, seek to identify specific adoption constraints arising from the off-farm institutional environment, such as tax policies or lack of coordination between public and private sector organizations (Schut et al. 2015; Eastwood et al. 2017).

The accuracy of adopt is constrained by the accuracy of available information. Nevertheless, there is likely to still be a need for predictions of adoption in circumstances where data is scarce and uncertainty high. ADOPT can still play a valuable role in these circumstances by providing a structured and consistent process that promotes consideration of broader socio-economic factors that may not otherwise be considered.

From experience applying ADOPT in various developed countries, there appears to be adequate capacity to characterize diverse populations and adoption scenarios using the existing framework. However, in countries other than Australia there is a need for further validation studies (and probably adaptation/calibration), and inclusion of additional factors, such as the possible influence of farm subsidy schemes in some settings.

There is scope to adapt the ADOPT conceptual framework to farming systems other than broadacre agriculture, such as the horticulture and viticulture, or intensive livestock industries such as dairy, pork, and poultry. In industries where there is less cooperation and sharing between local farmers, it is likely that the model parameters that determine diffusion rates will need to be modified. Smallholder farming contexts in developing countries require some changes to the model, including greater attention to the influence of subsistence needs, supply chains, infrastructure, policy and direct farmer engagement with research and extension (e.g. Douthwaite 2001). Another potential adaptation is to accommodate farming populations that undertake high levels of off-farm work or generate non-agricultural income on their properties.

5. Application of ADOPT

ADOPT has a potentially important role in providing information for those currently investing in agricultural research and development and also with those undertaking projects or policies aimed at achieving practice change. Its structure encourages definition and characterization of both practice and target population. Many research, extension or agribusiness organizations wishing to predict adoption of a new practice currently employ ad hoc approaches with little or no structured analysis. A structured tool that incorporates and highlights factors, information and principles known to be important to adoption outcomes is likely to be a substantial improvement over these less systematic approaches.

ADOPT complements other tools, such as economic models, biological simulation models or farmer surveys, which are often used to inform decision making about research, extension or policy. Outputs from those tools can inform the inputs to ADOPT, which adds value by bringing in a broader range of factors when considering the adoption process. ADOPT also has the potential to complement and be used as an input to the comprehensive qualitative approaches to analyzing agricultural innovation systems and impact pathways that have emerged recently (e.g., Schut et al. 2015; Wigboldus et al. 2016).

ADOPT has been used across a range of industries and organizations. These included: use by research and development funders for considering characteristics of practices within investment portfolios and for promoting consideration of the adoption potential of research outputs (e.g. Kuehne et al. 2012; Botha et al., 2015; Blaesing 2013); use in training programs for extension agents (GRDC 2012); use by teams of research scientists and project practitioners (James and Harrison 2016; James et al. 2015; Farquarson et al. 2013; Kuehne et al. 2012) and use by policy advisers (e.g. Addison and Walshe 2015) to inform project design and funding priorities.

It is our experience that before applying the ADOPT process, people associated with development or promotion of a practice are likely to overestimate its net relative advantage and adoption potential. Advocates may fail to recognize that only a subpopulation of the assumed larger target population is likely to gain high relative advantage, or may overlook some factors that are likely to reduce net relative advantage (e.g. a practice may be profitable but may also reduce ease and convenience or increase risk). In this way ADOPT can help to overcome the common problem of pro-innovation bias by researchers (Röling 1988).

Many users of ADOPT comment that it deepens their understanding of the adoption process, through asking questions that they do not normally consider. Beyond its use for predicting adoption, a different mode of use is to ask what changes would be necessary to bring about a given increase in speed or level of adoption. This can contribute insights, for example, about the relative importance of improving the practice itself versus improving the communication and extension process (e.g. Leeuwis and Aarts 2011).

6. Conclusion

ADOPT is the first tool designed to allow those involved in agricultural systems research, development, extension and policy to make quantitative predictions about the adoption outcomes for new farming practices. It is based on a framework structured around a) characteristics of the practice that influence its relative advantage, b) characteristics of the population influencing their perceptions of the relative advantage of the practice, c) characteristics influencing the ease and speed of learning about the practice, and d) characteristics of the potential adopters that influence their ability to learn about the practice. While developed with ease of use and likely scarcity of available data in mind, ADOPT has demonstrated the ability to reasonably estimate the level and rate of adoption among farmer populations for a diverse range of practices. Its use to date has further demonstrated the demand and potential for further applications of such a tool.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.agsy.2017.06.007.

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