Sustaining the change: Critical factors for enduring agricultural practice adoption in Great Barrier Reef Catchments

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Abstract. Agricultural runoff from sugarcane farming is a major driver of declining water quality in Great Barrier Reef catchments. This study evaluates the Reef Trust Partnership sugarcane programs, which engaged 38 per cent of farms and 41 per cent of cane land across Reef regions using a seven-method mixed-methods design. The evaluation was conducted to meet practical program-improvement needs rather than to test a predetermined theory, and we interpret its findings through established frameworks of agricultural practice adoption, including adoption as a learning process, the diffusion concept of discontinuance, and a behavioural model of capability, opportunity and motivation. Improved nutrient, pesticide, and irrigation practices were widely adopted, however, 26 per cent of enrolled land had previously received support through earlier Reef water quality programs. Follow-up investigation identified multiple instances of practice reversal, suggesting that adoption cannot be assumed to endure over time. Personalised and tailored extension support, broader communication of opportunities, delivery provider diversification, peer-to-peer learning, and well-designed financial incentives were found to be enablers of practice adoption, while workforce shortages, contradictory reseller advice, and short funding cycles limited enduring adoption. Enduring practices require longer-term, system-oriented approaches that address economic viability, social norms, and industry structures. Findings highlight the need for programs to evolve beyond short-term projects towards system-wide strategies.

Keywords: Sugarcane, Water Quality, Great Barrier Reef, practice adoption, Nitrogen, Pesticides.

Introduction

The Great Barrier Reef (GBR) is at risk from poor water quality from land-based runoff, with the greatest pollutant load originating from adjacent agricultural areas. In response, the Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) sets objectives, targets, and actions necessary to reduce pollution through the adoption of improved farm management practices (Queensland Government 2018b, 2020). For over a decade, efforts to promote the adoption of management practices in GBR sugarcane regions have relied on agricultural extension, financial incentives, industry-led programs, and direct regulations (Queensland Government 2018b; Queensland Government 2025; SmartCane BMP n.d.). However, these efforts have not achieved enduring practice adoption to meet water quality targets at the required scale (Eberhard et al. 2021). While the Reef Water Quality Report Card 2021-2022 and latest science show progress in sugarcane management practices, they also indicate it has stalled or reversed in some areas (Queensland Government 2022, Waterhouse et al. 2024, Guo et al. 2025).

The Reef Trust Partnership (RTP), established in 2019 between the Australian Government and Great Barrier Reef Foundation (GBRF), received $443 million to accelerate impact and build GBR resilience. Within it, the Water Quality Program component ($200 million) represents the greatest five-year investment in Reef water quality to date (DCCEEW 2022). It addressed land-based runoff through ten regional programs with five targeting sugarcane in the Mackay Whitsunday, Burdekin, Lower Herbert, Tully-Johnstone, and Mulgrave-Russell regions between 2020 and 2024. These programs aimed to encourage voluntary adoption of management practices that benefit water quality largely through agricultural extension, financial incentives, improved distribution of mill mud, adoption of new technologies and farmer-led monitoring projects.

Most research on agricultural practice adoption, and most evaluation of Reef water quality programs, has concentrated on the factors influencing initial uptake. Far less attention has been paid to whether adopted practices endure once program support ends. This matters because the water quality benefits of such improved practices depend not on the moment of adoption but on practices being sustained over time. Internationally, a growing body of work has begun to document the discontinuance, or disadoption, of conservation practices (Sawadgo & Plastina 2022; Pathak et al. 2024), but there has been little empirical evidence of this phenomenon in Australian contexts, and, to our knowledge, none that has examined it spatially across successive government-funded programs.

This study presents a comprehensive evaluation of the RTP sugarcane regional programs (regional programs) using multiple lines of evidence. The evaluation sought not only to assess the regional programs but also to fill foundational knowledge gaps and test long-held assumptions regarding management practice adoption and its likelihood of enduring. This included an in-depth examination of the social factors influencing adoption, the programmatic success factors of the regional programs, and, for the first time, the extent to which management practice achieved in previous Reef programs has endured, or not, and the factors influencing this. The evaluation was guided by six Key Evaluation Questions (KEQs):

1. To what extent did the program facilitate farm management practice adoption?
2. To what extent has practice adoption from past Reef water quality programs endured?
3. What social factors influence agricultural management practice adoption, and how did they change over the course of the program?
4. What were the success factors of the regional programs?
5. What barriers to management practice adoption remain?
6. What can be done in the future to create the conditions for management practice adoption to endure?

These questions guided the practical conduct of the evaluation. In presenting the findings, we organise them thematically around a single question: what makes practice adoption endure? The remainder of the paper sets out the conceptual frames through which we interpret the findings, the mixed-methods design, the results organised by the level at which adoption and endurance are determined, and a discussion of the implications for program design, system-level action and the measurement of practice adoption.

Conceptual framework

This evaluation was designed and conducted to meet the practical program-improvement needs of the Reef Trust Partnership, within the established policy architecture of the Reef 2050 WQIP and informed by the Scientific Consensus Statement on Great Barrier Reef water quality. The selection of interventions and evaluation methods was shaped by more than a decade of accumulated policy and practice experience in the region, and by the requirements of the funding body, rather than by an explicitly articulated theoretical framework adopted at the outset. We make this origin explicit because it is relevant to how the findings should be read, and because applied evaluation of this kind is common in environmental programs yet rarely positioned within the scholarly literature on practice adoption.

Applied work of this nature is, however, never conducted in a theoretical vacuum. The intervention strategies the programs employed, and the dimensions the evaluation chose to measure, embodied implicit and practice-embedded theories of how agricultural practice change occurs and endures. In the following section we reconstruct these frames and situate them within the relevant literature, not to impose a single unifying theory after the fact, but to make the underlying logic visible, to interpret the findings, and to connect them to wider debates in agricultural extension and practice change. One component, the behaviour change research and campaign, applied an explicit behavioural framework from the outset, and we identify it as such.

The implicit evaluation logic: Bennett's hierarchy

The evaluation drew on the Paddock to Reef Human Dimensions method (Australian and Queensland Governments 2024) to measure the social factors considered most influential in practice adoption: attitudes, perceptions of social norms, confidence, motivations, barriers and attribution. Measuring these intermediate, attitudinal precursors alongside practice change itself, and ultimately water quality outcomes, reflects the logic of Bennett's hierarchy (Bennett 1975; Rockwell & Bennett 2004), the long-established framework for extension program evaluation in Australia. Bennett's hierarchy describes a sequential chain from inputs and activities, through participation and reactions, to changes in knowledge, attitudes, skills and aspirations (KASA), then to practice change, and finally to end results in social, economic and environmental conditions. The structure of this evaluation maps onto the upper levels of that hierarchy: the social monitoring surveys assess KASA-level change, the practice adoption records assess practice change, and water quality improvement represents the end result. This logic was implicit in the established Paddock to Reef methods rather than adopted deliberately for this study, but naming it clarifies why these particular dimensions were measured and how they relate to one another.

Adoption as a dynamic learning process

The regional programs relied principally on agricultural extension, financial incentives, peer-to-peer learning and diversified local delivery to encourage voluntary adoption. These choices are consistent with, and can be interpreted through, Pannell et al.'s (2006) account of conservation

practice adoption as a dynamic learning process. In that account, adoption depends on the landholder's perception that a practice will advance their personal goals, whether economic, social or environmental, with perceived relative advantage central to the decision. This perception develops over time through trial, observation and experience, and is shaped by the characteristics of both the landholder and the practice. Practices that are readily trialable, compatible with existing systems, and that yield observable benefits are more likely to be adopted, while practices whose benefits accrue mainly to the environment or the public, rather than to the landholder, face a structural adoption disadvantage (Pannell et al. 2006; Kuehne et al. 2017).

Discontinuance: interpreting practice reversal

A central and unanticipated finding of this evaluation was empirical evidence of practice reversal, identified through the spatial overlay analysis rather than predicted by any framework guiding the study. To interpret this finding and connect it to the wider literature, we draw on the concept of discontinuance. Rogers (2003) distinguishes replacement discontinuance, where a practice is abandoned in favour of a superior alternative, from disenchantment discontinuance, where it is abandoned due to dissatisfaction or failure to deliver expected benefits, and notes that discontinuance is more likely where relative advantage proves insufficient. A growing body of empirical work has begun to document the scale of this phenomenon in agricultural conservation (Sawadgo & Plastina 2022; Pathak et al. 2024).

In this paper we use the term *practice reversal* to describe the reversion from an improved management practice to a previous or less beneficial practice following a period of program-supported adoption. Drawing on Rogers' (2003) typology and extending it in light of our findings, we distinguish three forms: volitional reversal, where the landholder actively reverts owing to insufficient relative advantage, contradictory advice or dissatisfaction, analogous to disenchantment discontinuance; structural reversal, where external factors such as change of ownership, loss of advisory support or workforce constraints drive reversion independent of landholder preference; and apparent reversal, where a practice was reported while still in a trial phase, so that what appears as reversal reflects premature reporting rather than genuine discontinuance. These categories were developed as an interpretive framework for organising the forms of reversal reported by farmers and extension officers during the evaluation, rather than as mutually exclusive empirical classifications.

Social norms and networks

Rogers' (2003) diffusion theory also provides the language for understanding social influence in adoption: the rate and extent of adoption within a community are shaped by social norms, opinion leaders and trusted networks. Empirical research in agricultural settings confirms that farmers are more likely to adopt, and to sustain, practices when they perceive that similar others in their community have done so (Liu et al. 2018; Dessart et al. 2019). This social dimension bears on both initial adoption and its endurance, since practices unsupported by prevailing social norms may face pressure to revert even among motivated adopters.

Behavioural determinants: an explicit application of COM-B

In contrast to the implicit frames described above, one component of this work applied a behavioural framework intentionally and from the outset. The behavioural insights research (Herd et al. 2022), and the subsequent CaneRise behaviour change campaign, were designed around the COM-B model (Michie et al. 2011), which holds that behaviour results from the interaction of capability, opportunity and motivation. We use COM-B here as it was used in that component: to organise and interpret the barriers and enablers of practice change identified across the evaluation, distinguishing, for example, capability barriers such as low digital literacy, opportunity barriers such as contradictory reseller advice, and motivational factors such as social norms and perceived profitability.

Key concept definitions

In the context of this paper, *improved practices* refer to agricultural management practices that result in better outcomes for water quality and come to no cost to the farmer, under the broad categories of nutrient, pesticide and irrigation management. These are described in detail in the "management practice frameworks" under the Reef 2050 WQIP (Queensland Government, 2020). Following Pannell et al. (2006), *practice adoption* is understood as the implementation of a management practice by a landholder, as a process of learning about relative advantage through trial and observation rather than a discrete event. *Practice endurance* refers to the sustained maintenance of an adopted practice beyond the period of program support, such that it becomes embedded in routine farm management, extending the literature on persistence (Dayer et al.

2018) and *sustained adoption* to emphasise the active effort required to maintain a practice against pressures favouring reversion. *Practice reversal* is defined as above.

Methods

Overview

The evaluation employed a mixed-methods approach with seven distinct but complementary methodologies comprising quantitative and qualitative methods. This design was appropriate because practice adoption and its endurance are multidimensional, spanning the attitudinal precursors, practice change and end results of Bennett's hierarchy: the quantitative methods established the scale and patterns of adoption and reversal, while the qualitative methods explained why adoption occurred or reversed and how social norms and relative advantage operated. Combining them allowed triangulation across independent lines of evidence, which is particularly important for contested, policy-relevant questions where a single method would leave the conclusions exposed to its own limitations. The evaluands comprised farmers participating in the regional programs (that is, receiving support), industry stakeholders (for example, members of an industry group but not participating in the regional programs), individuals from the broader agricultural community (farmers or family members not participating in the regional programs) and extension officers delivering the program (agronomists from private businesses or industry bodies contracted by the regional programs to support farmers). An explanation of how the methods were integrated is shown in Figure 1. The number of participants in the methods is not additive, as the same individuals sometimes were sampled in more than one method, and this was not quantified. While most of the methods were conducted by GBRF staff, some were undertaken by external consultants, where independence or specialised skills were required. References to the standalone reports are provided.

Figure 4: Mixed methods approach to the RTP sugarcane regional programs evaluation

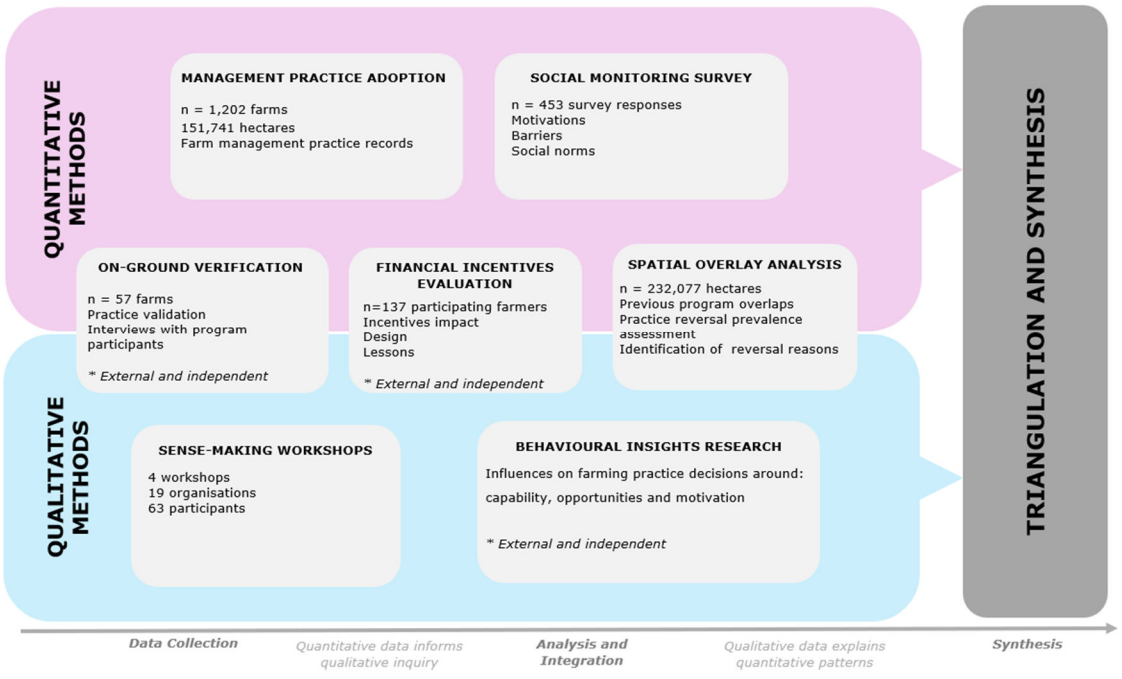


Table 2 maps each method to the dimension of practice change it investigates and its alignment with the conceptual frames described above.

Table 2: Mapping of methods to dimensions of practice change and conceptual frames

Method	Scale	Dimension investigated	Conceptual framework alignment
Management practice adoption records from the RTP program database	1,202 farms; 151,741 ha	Extent and type of adoption (practice change)	Bennett (practice change); Pannell (relative advantage)
Spatial overlay analysis	232,077 ha	Endurance and reversal	Rogers (discontinuance)
Social monitoring surveys	453 responses	Motivations, barriers, social norms, confidence (KASA)	Bennett (KASA); COM-B; Rogers (social norms)
On-ground verification	57 farms	Validation of adoption; farmer perspectives	Pannell (perceived relative advantage in practice)
Financial incentives evaluation	137 recipients	Role of incentives in accelerating adoption	Pannell (reducing trial cost and risk)
Behavioural insights research	17 interviews; literature and desktop review	Influences on practice decisions	COM-B (capability, opportunity, motivation)
Sense-making workshops	63 participants; 19 organisations; 4 workshops	Practitioner interpretation across dimensions	Integrative (triangulation)

Primary data collection

Management practice adoption

The adoption of improved farm management practices was tracked using the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef) method (Queensland Government 2018a), initially captured in an in-house database designed for the program which follows the Paddock to Reef requirements. Following the Paddock to Reef methodologies is a requisite of all publicly funded investments in the area of water quality improvement in the Great Barrier Reef (Queensland Government, 2018b). Extension providers mapped the areas of practice adoption in a spatial database with details about the practices before and after receiving program support. 1,202 farms were mapped.

Spatial overlay analysis

The farm area associated with a proposed practice change was spatially overlaid with GIS layers from previous Commonwealth government-funded Reef water programs. Where overlaps existed, the overlap analysis was treated as a screening mechanism rather than direct evidence of reversal. Follow-up examination of previous program records and discussions with participating farmers were used to determine whether the same practice had previously been adopted and whether it was still being maintained., ascertaining if reversal had occurred and if so, the reasons. The total area assessed for overlaps was 232,077 hectares.

Social monitoring surveys

As for management practice adoption, all publicly funded investments must use the Paddock to Reef methods. Thus, for social monitoring the Paddock to Reef Human Dimensions method (Australian and Queensland Governments 2024) was used, surveys were conducted with participating farmers to assess the social factors deemed most influential in management practice adoption: attitudes, perception of what others are doing (social norms), confidence, motivations, barriers and attribution. Surveys were asked at the beginning and end of a project, with additional questions asked at the end to understand perceptions around productivity and profitability impacts and likelihood to continue the practice. Surveys were offered to all farmers but voluntary to complete, with 453 responses were obtained from 1,202 participating farmers, a response rate of 38 per cent. As responses were not collected from all participants, the survey findings should be read as indicative of participating farmers who responded rather than as a complete census, and the potential for response bias cannot be excluded.

Behavioural insights research

Undertaken by an external consultant, and designed around the COM-B model, this mixed-methods research investigated the influences on farming practice decisions and opportunities for leverage across capability, opportunity, and motivation domains in the in Mackay Whitsunday and Lower Burdekin regions (Herd et al. 2022). It included a desktop review of program data,

literature review, 17 structured interviews with delivery providers, industry stakeholders, and the broader agricultural community (farmers or family members not participating in the program).

On-ground verification

An independent assessor visited 57 farms that had participated in the regional programs verifying the reported practice adoption and conducting semi-structured interviews exploring farmer perspectives on the regional programs and recently adopted practices (Dench 2024). The 57 farmers were selected randomly from a cohort of farmers selected because they had been recorded significant management practice improvements, with significant estimated water quality impact.

Financial incentives evaluation

An independent mixed methods evaluation of the financial incentives scheme under the regional programs reviewed project documentation, surveyed 137 incentive recipients, and interviewed grant managers to understand the outcomes of the scheme and lessons for future similar initiatives (Eberhard 2024).

Sense-making workshops

Sense-making workshops were used to generate insights and identify recommendations through collaborative analysis as described in Storvang et al. (2024). The purpose of the workshops was to involve the program extension officers and partners in a participatory analysis and sense making of data. Four one-day workshops were held between July-October 2023 with extension officers from all five programs. Evaluation findings were presented followed by group discussion. Each workshop was attended by 12-20 people, with an overall total of 63 people representing 19 organisations. Attendance composition and discussion prompts are listed in the Supplementary Methods. The format of the workshops followed a presentation of preliminary results of the mixed methods along with the interpretation. The audience was prompted for reflection questions about whether that resonated with their experience, unpacking the nuance around reasons that explain the results, other contributing factors and opportunity for improving the challenges and barriers (the reflection questions are available as supplementary methods). Detailed notes were captured by a dedicated scribe. Two rounds of descriptive coding were conducted: deductive against prompt questions and inductive for emerging themes (Braun and Clarke 2006; Saldaña 2021). Qualitative material from the on-ground verification and behavioural insights interviews was analysed thematically and triangulated with the workshop findings.

Limitations

Several limitations should be noted. The extent of practice reversal was not quantified, owing to gaps in the availability of data from previous programs. The overlap analysis was conducted only with Commonwealth government-funded programs, as data on State government-funded programs were not available; it is likely that overlaps, and therefore the potential for reversal, are higher when State programs are considered. Additionally, data for the Lower Burdekin catchments were not available for the overlap analysis. The survey response rate and the reliance on self-reported intentions to continue practices are further constraints. Due to these limitations, the findings should be interpreted as evidence that practice reversal occurs and may be widespread, rather than as a quantitative estimate of the prevalence of reversal across participating farms.

Results

Substantial adoption achieved at scale

The regional programs engaged a substantial portion of the industry, providing one-on-one extension support and recording practice adoption in 1,202 farms. With 3,140 cane farms in Queensland (Australian Bureau of Statistics 2025), the program had a footprint on 38 per cent of sugarcane farms in the state. The specific area of practice adoption mapped was 151,741ha, which makes 41 per cent of the area under sugarcane cultivation in Queensland (total area from CANEGROWERS 2024 was 366,470 hectares).

Under the broad categories of nutrient, pesticide and irrigation management, specific practice improvements included targeted (and often reduced) nutrient application using precision agriculture and planning tools; reducing other yield constraints to increase Nitrogen use efficiency; upgrades to equipment to allow more targeted nutrient application, fallow management changes; changing pesticide products for less toxic alternatives; automated irrigation systems; and more sophisticated calculation of irrigation regimes. Practice adoption was verified through the on-ground verification process.

Adoption is not endurance: overlap analysis and indications of practice reversal

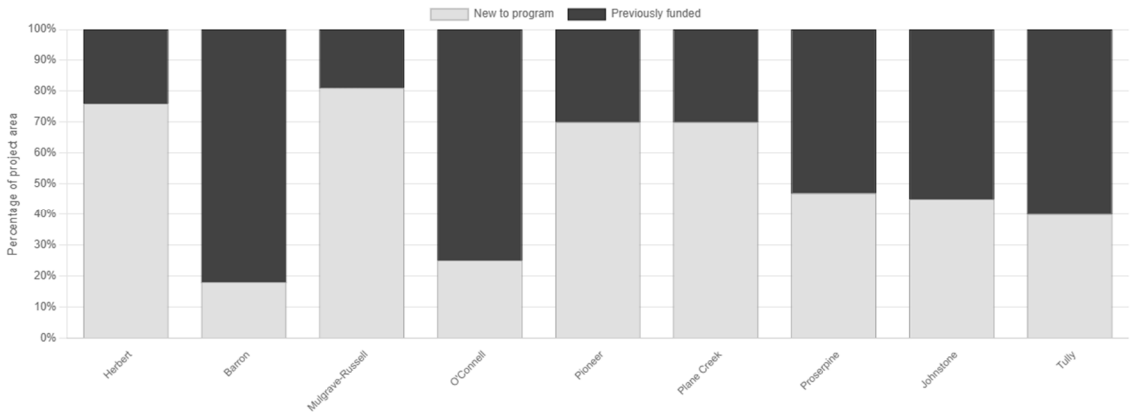
While the regional programs achieved substantial adoption, the spatial overlay analysis revealed that a substantial proportion of enrolled land had previously received support through earlier Reef water quality programs. This finding raises important questions about the extent to which previously supported practices endure over time. Of the 232,077 hectares of land initially enrolled in the RTP regional programs, 60,993 hectares (26 per cent) had received support from previous Commonwealth government-funded Reef water quality programs. There was variation in the proportion of overlap across catchments, ranging from 19 per cent of all the Mulgrave-Russell catchment to 82 per cent in the Barron (Table 3 and Figure 5).

Table 3: Areas overlapping with previous Reef water quality programs

Program	Catchment	Proposed project area (ha)	Area overlapping with previous Reef water quality programs (ha)	% of proposed area which had previously been funded
Lower Herbert	Herbert	52,908	12,893	24
Mulgrave Russell	Barron	769	633	82
Mulgrave Russell	Mulgrave-Russell	33,253	6,188	19
Mackay Whitsunday	Oconnell	3,840	2,884	75
Mackay Whitsunday	Pioneer	17,094	5,065	30
Mackay Whitsunday	Plane Creek	51,507	15,587	30
Mackay Whitsunday	Proserpine	3,300	1,762	53
Tully Johnstone	Johnstone	10,892	5,985	55
Tully Johnstone	Tully	16,625	9,996	60
Lower Burdekin	East Burdekin	1,773	NA *	NA *
Lower Burdekin	Haughton	24,328	NA *	NA *
Lower Burdekin	Lower Burdekin	15,788	NA *	NA *

*Data for Lower Burdekin catchments was not available.

Figure 5: Overlaps between RTP participating farms and farms that participated in previous Reef water quality programs



*Data for Lower Burdekin catchments was not available.

Overlaps with previous programs fell into the following three types:

1. Previous project(s) had supported different categories and practices (for example, one project supported nutrient management and the other pesticides management).

2. Previous project(s) had supported the same category but different practice (for example, both projects supported nutrient management but one nutrient rate reduction and the other one fallow management).
3. Previous project(s) had supported the same category and practice (for example, both projects supported nutrient management and nutrient rate reduction). The practices had been reversed, hence the interest in additional support. Follow-up with farmers investigated the reasons for reversal.

Although the extent of each overlap type could not be quantified consistently across all catchments because of variation in historical records, discussions with farmers suggested that Type III overlaps were sufficiently common to warrant attention as a programmatic and policy issue. The findings should therefore be interpreted as evidence that reversal occurs and may be widespread, rather than as a measure of its prevalence. From these conversations, the primary drivers of practice reversal reported were:

- Farmers were still trialling practices without confidence for long-term adoption at the time they were reported.
- Practices were not financially or practically sustainable under varying conditions.
- Time constraints during critical periods (especially harvesting or planting) led to reversion to familiar practices.
- Contradictory advice from commercial resellers undermined program recommendations.
- Practice adoption applied only to limited farm areas rather than whole operations.
- Change of ownership.
- Crop diversification.

These drivers correspond to the forms of reversal set out in the conceptual framework. Practices abandoned because they were still being trialled, or were not financially or practically sustainable, reflect volitional reversal arising from insufficient perceived relative advantage. Reversal following change of ownership, or driven by time and workforce constraints, reflects structural reversal independent of landholder preference. Practices reported while still in a trial phase reflect apparent reversal, a measurement artefact rather than genuine discontinuance. The regional programs used this information to inform the final farm and project selection, to maximise coverage and complement past programs.

The overlap analysis also revealed that several of the previous programs had considerable overlap between them, although this was not quantified. As noted in the Methods, the analysis was limited to Commonwealth government-funded programs; overlaps are likely higher when State-funded programs are considered.

Drivers of adoption and its endurance

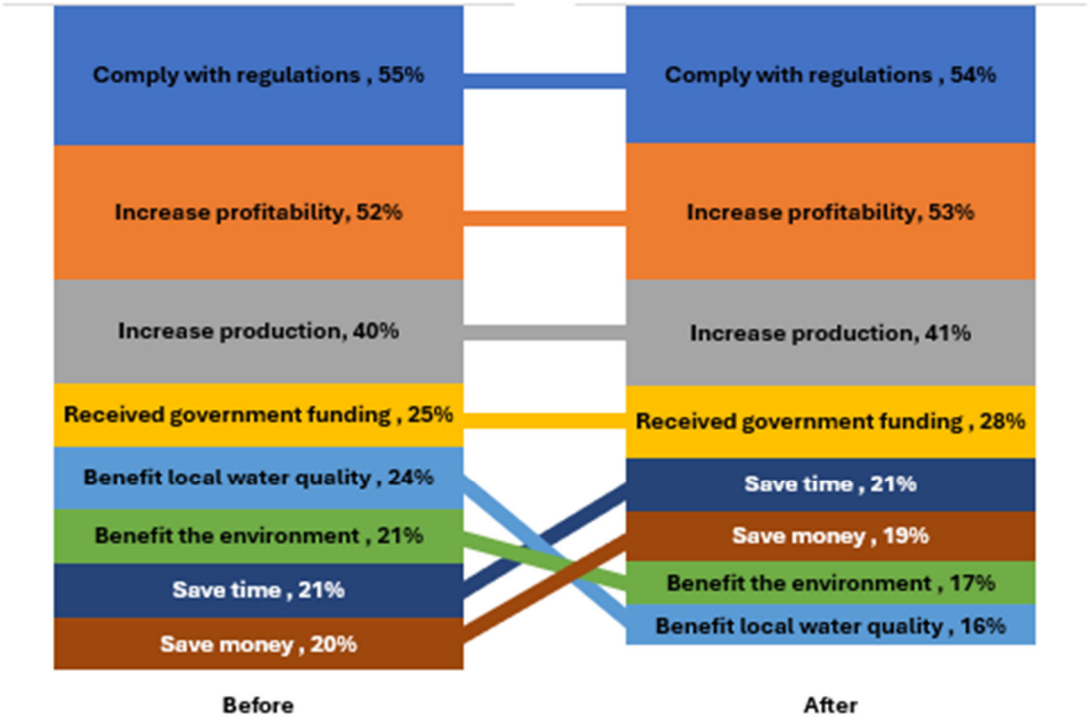
Individual and economic drivers

Primary motivations among farmers participating in the program differed from those of the broader agricultural community. Social monitoring surveys revealed that complying with regulations and opportunities to improve productivity and profitability were dominant drivers for adopting management practices, both initially and after receiving support (Figure 3). Extension officers in workshops believed that, while farmers were initially drawn to the program to help comply with regulations, upon realising the broader business benefits their interest in maintaining the support and the recently adopted practices was sustained.

The main barriers to adopting practices centred on concerns about productivity and profitability loss, and a lack of time (Figure 4). After receiving support, the most common response was that there were no challenges to adopting the practice, followed by weather and seasonal issues.

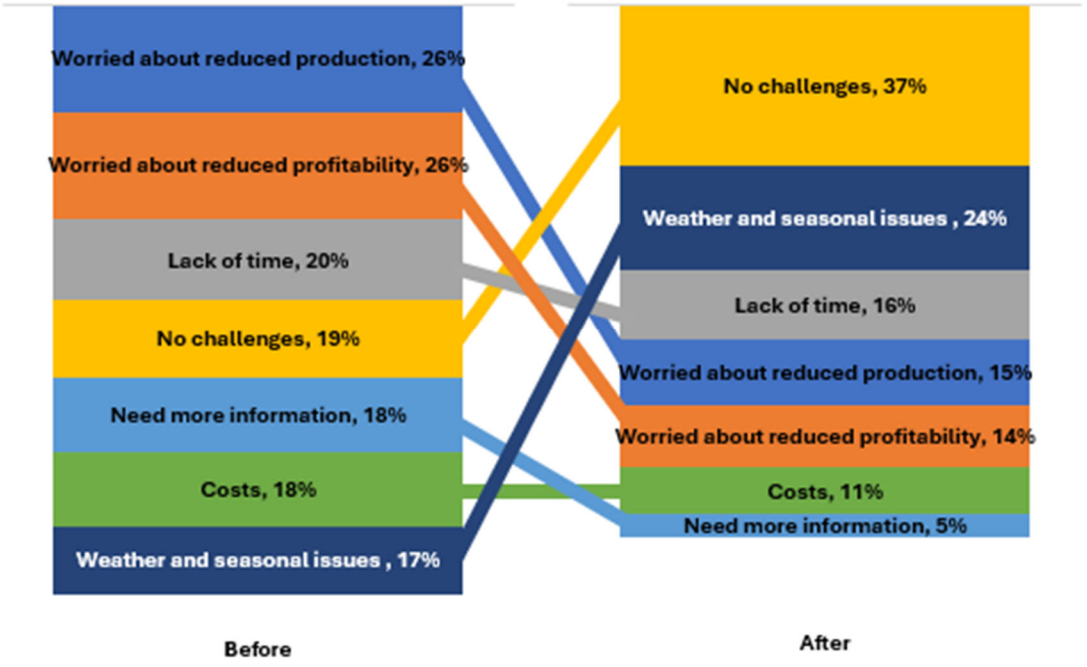
These patterns can be interpreted through the relative advantage logic central to adoption as a learning process (Pannell et al. 2006), whereby perceptions of profitability and productivity shape decisions regarding adoption and maintenance. The dominance of productivity and profitability among motivations, and of productivity or profitability loss among barriers, reflects the centrality of perceived private benefit. The shift after support, towards reporting no challenges, is consistent with farmers learning about a practice and revising their perception of its relative advantage through experience. The same logic helps explain regional variation: workshop participants noted that there was limited incentive for Lower Burdekin farmers to optimise nutrient inputs voluntarily, as higher regional profit margins meant little financial benefit from reducing fertiliser.

Figure 6: Motivations by practice across programs



*Notes: Farmers could select up to three motivations. Percentages therefore total greater than 100%.

Figure 7: Barriers by practice across programs



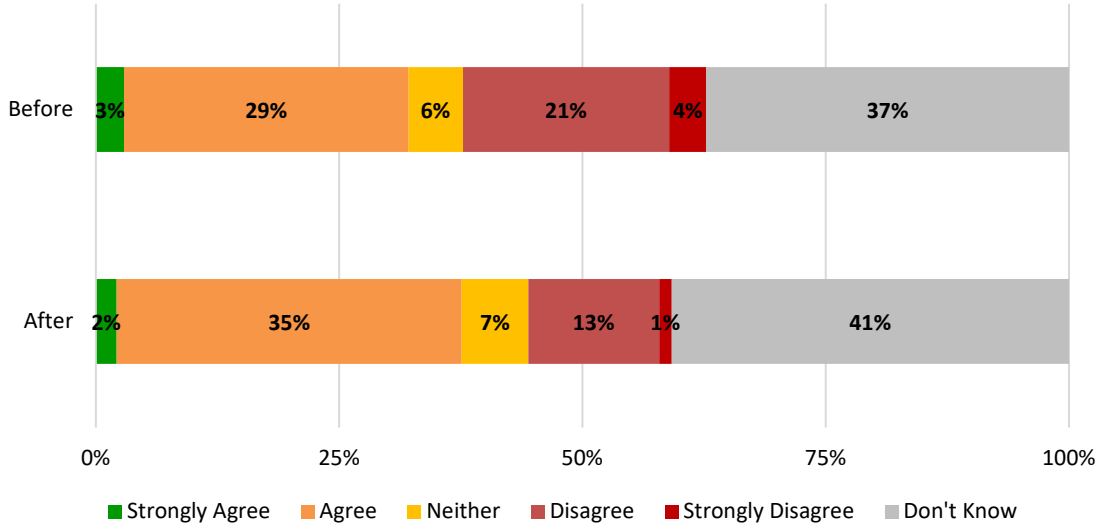
*Note: Farmers could select up to three barriers. Percentages therefore total greater than 100%.

Social drivers

Initially, perceptions of what others were doing, gathered from the social monitoring surveys, were not positive (Figure 5). However, after receiving support, farmers were significantly more likely to report positive perceptions of what others were doing compared to before (Wilcoxon signed-rank test: $W = 464.5$, $p < .001$). Over a third of farmers reported that they did not know whether most farmers in their local area and industry had adopted the same farming practice.

The behavioural insights research indicated that, for the broader farming community, social influences, particularly social norms and trusted local networks, are more powerful drivers of practice adoption than government regulations or technical information alone. This was further confirmed during the workshops, which identified shed meetings and farm tours as powerful settings for establishing and reinforcing social norms around farm practices. Extension officers consistently emphasised that, when farmers hear from other farmers, the message resonates more strongly than expert advice.

Figure 8: Level of agreement to "most farmers in my local area and industry have adopted this farming practice"



These findings reflect the social dimension of diffusion (Rogers 2003) and align with research showing that farmers are more likely to adopt practices when they perceive that similar others have done so (Dessart et al. 2019; Liu et al. 2018). The significant shift in perceived social norms among participants, alongside the large proportion who did not know what others were doing, points to both an opportunity and a limitation: programs can shift norms among those they reach, but a substantial share of farmers lack the social information that would support adoption.

Program design factors shaping adoption

The workshops, on-ground verification and financial incentives evaluation identified several factors as key to the regional programs' successful engagement and practice adoption. Across all four workshops, local relationships and trust emerged as the most frequently cited success factor. The programs leveraged established relationships between farmers and advisors, and participants emphasised that relationship building required time and that local representation increased trust and credibility. The on-ground verification found that including agribusiness, industry and research institutions in the traditional pool of delivery providers engaged farmers who had not previously participated in voluntary government programs.

A one-on-one, tailored approach to extension was consistently emphasised as more effective than group approaches, with participants highlighting that individualised extension allowed advice to be tailored to specific farmer situations and aspirations. Peer-to-peer learning from farmers already implementing improved practices was deemed more influential than external expert advice, whether occurring organically or through delivery provider facilitation. Linked to this, both the workshops and on-ground verification found that, with rigorous technical oversight and effective communication of results back to participants, local farmer-led water quality monitoring components were valuable for building farmer trust and supporting extension.

Upon initial contact, delivery providers attributed effective engagement to a focus on productivity and profitability benefits rather than environmental or water quality messaging. A financial incentive scheme was used in three of the five programs. Its evaluation demonstrated that financial incentives accelerated practice adoption by approximately three years compared with extension-only approaches. Notably, 92 to 100 per cent of incentive recipients rated future practice maintenance as easy. The key conditions that made the scheme effective, as identified by James et al. (in press), were flexibility in the regional delivery model to address regional-

specific challenges; measurable practice adoption linked to water quality improvement as a key assessment criterion; a minimum 50 per cent farmer cash co-contribution to ensure commitment; integration of incentives with extension support over a substantial period to build technical capacity for sustained use; and an onsite review by an independent advisor to validate farm practices prior to final payments.

Barriers to enduring adoption beyond the individual

The key barriers to engagement and enduring practice adoption were identified through the workshops, on-ground verification and financial incentives evaluation. They operated at two levels: barriers a program might address directly, and barriers that are system wide.

At the program level, the poor reach of communication for opportunities offered through government-funded programs was an ongoing barrier to wider engagement. Some farmers visited during the on-ground verification stated they were largely unaware of available opportunities, or that the support they were receiving came from a government-funded program. This was corroborated by the behavioural insights research, which found that many farmers in the broader community did not know about Reef water quality programs. Extension support for adopting emerging technologies such as variable rate fertiliser application, soil variability mapping, drone technology and automated irrigation was highly desired, but low farmer digital literacy presented a barrier to precision agriculture and the use of digital recording platforms, often compounded by limited data availability and connectivity. On-ground verification confirmed farmer interest in digital platforms, but farmers acknowledged the need for ongoing support to incorporate such systems into their management. In the terms of the COM-B model, these are capability and opportunity barriers respectively.

At the system level, insufficient agronomic expertise and low workforce retention emerged as fundamental barriers across all regions. The shortage left staff with insufficient time to dedicate to farmers, caused a lack of continuity as turnover disrupted farmer-advisor relationships, and created geographic gaps in service provision. Workshop participants attributed workforce shortages to the sugar industry's inability to compete with other agricultural sectors for graduates, the perceived unattractiveness of regional locations, and limited career development opportunities.

> [We] cannot get enough suitably qualified people in roles [there is a] shortage of qualified people across industry (Lower Herbert, Delivery Provider).

Contradictory advice from resellers was consistently raised as a challenge in all workshops, particularly regarding pesticide products. Resellers exercise considerable influence through their regular contact with farmers and their ability to provide immediate solutions during time-critical periods. Workshop participants considered that many resellers may not fully understand pesticide toxicity or the importance of avoiding nutrient runoff and rarely participated in water quality activities when invited.

> We saw some issues last year when fertiliser prices were really high. Resellers offering all nitrogen products and [Nitrogen] budgets blown out of water by taking resellers' advice without consulting agronomists (Mulgrave Russell, Delivery Provider).

That said, it was also acknowledged that while this represented the majority, some resellers wanted to "do the right thing" and had joined the regional programs as delivery providers promoting messages consistent with improved practices. Given the limited control over how resellers operate, the group agreed the most practical solution was to help farmers become better at evaluating advice themselves.

Across all regions, participants reported that further reductions in fertiliser application rates were unlikely and unrealistic, as traditional fertiliser reduction approaches have reached practical limits. Participants identified that the forward focus should be on improving nitrogen uptake through alternative approaches such as soil health improvement, reducing yield constraints, precision agriculture and whole-farm system optimisation.

Finally, participants in all workshops converged on the view that the sugar industry's historical payment of mandatory levies, and decades of agronomy support funded through Reef programs, have created an expectation that advice will be free. This constrains the development of commercial advisory services and limits farmers' interest in fee-for-service models.

> Free advice to growers makes it harder for consultant agronomists (Lower Herbert, Delivery Provider).

Workshop participants also consistently cited a mismatch between program timeframes and crop cycles: sugarcane production cycles typically spanning five to seven years from planting through multiple ratoons, yet most programs operated on two-to-three-year funding cycles. This provides no opportunity for programs to support growers through a whole cycle, and the variety of

circumstances they may experience. The absence of post-program support emerged as a key factor in reversal, with multiple extension officers reporting that farmers reverted to familiar practices when technical assistance ceased.

> Most farmers need to grow to fourth or fifth ratoon so need at least a 7-year project (Tully-Johnstone, Delivery Provider).
>
> it is not reasonable to expect long-term sustainability of the practices that are implemented in short-term projects (Project lead, Tully Johnstone Program)
>
> Practice change is good news but too young, want to see it extended to seven or eight years (Mackay Whitsunday, Delivery Provider).

Discussion

This evaluation provides the first documented spatial examination of practice endurance across successive Reef water quality programs. The finding that 26 per cent of RTP enrolled land had previously received support, combined with evidence of practice reversal identified through follow-up investigation, suggests that adoption cannot be assumed to endure over time. While the regional programs achieved substantial participation, the evidence shows that practice adoption from Reef water quality programs cannot be assumed to endure, and that there are fundamental misalignments between the design of current funded programs and the conditions necessary for enduring change. We discuss the implications under five headings: the endurance gap and its measurement, why reversal occurs, the role of social norms, what programs should retain, and what requires action beyond programs.

The endurance gap: adoption does not imply permanence

Progress towards water quality targets is measured through the Paddock to Reef program. Until now, practice reversal was recognised as a problem, but its identification rested on anecdotal evidence and its prevalence was unclear. The spatial overlay analysis reported here moves discussion of practice reversal beyond anecdotal observations by demonstrating substantial overlap between successive programs and identifying multiple instances of reversal through follow-up investigation. This finding contributes to a growing international literature documenting the discontinuance of conservation practices (Sawadgo & Plastina 2022; Pathak et al. 2024), and, to our knowledge, is the first to quantify it spatially across successive government-funded programs in an Australian context.

The finding has a direct measurement implication. Coggan et al. (2021) described practices as transitional and in flux rather than fixed, yet measurement of practice adoption and water quality improvement through Paddock to Reef continues to assume permanence. Two actions follow. First, Paddock to Reef needs to change the way management practice adoption is reported so that it does not assume permanence. Second, additional effort is needed to minimise reversal. Some of the drivers of reversal lie within the reach of programs, but others are system-wide and require action at the level of policy, industry, commerce and workforce.

Why reversal occurs: a multi-level interpretation

The drivers of reversal reported by farmers and extension officers map onto the three forms set out in the conceptual framework, and they operate at different levels. Volitional reversal, where farmers revert because a practice was still being trialled or did not deliver sufficient relative advantage, is consistent with Rogers' (2003) disenchantment discontinuance and with Pannell et al.'s (2006) account of adoption as contingent on perceived private benefit. This form is, in principle, addressable through program design: by supporting practices through a full learning cycle, and by prioritising practices with demonstrable relative advantage. Structural reversal, driven by change of ownership, workforce loss or the cessation of support, is largely beyond the influence of any single program and points to system-level conditions. Apparent reversal, arising from practices reported while still in trial, is a measurement issue that reinforces the case for changing how Paddock to Reef records adoption.

Elevating social norms for adoption that endures

While regulatory compliance and economic benefit are the key motivations for participation, peer influence, social norms and trusted networks are key enablers of sustained adoption in the broader agricultural community. The literature supports the critical role of social norms in agricultural practice adoption (Liu et al. 2018; Dessart et al. 2019). The implication is that programs need to consider not just individual behaviour change but community-level norm transformation. This evaluation found that programs tend to positively influence social norms among participants, but the challenge lies in extending that influence beyond direct participants. Even well-funded programs that achieve substantial adoption, such as the RTP, will tend to change practice only

among participating farmers if prevailing social norms do not support the practices, and even that adoption is not guaranteed to endure.

Strategies to elevate social norms were initiated and tested in the regional programs and could continue in future programs. In the Mackay Whitsunday regional program, a communication and behaviour change campaign, CaneRise, designed around the COM-B model, aimed to elevate social norms to underpin practice adoption over the medium to long term (CaneRise Mackay Whitsunday n.d.). It supports peer-driven knowledge networks, celebrates local champions and facilitates peer-to-peer learning. While it is too early to detect its impact on social norms, it has achieved community-wide reach and represents a promising step. It is now continued through the Queensland Government's Queensland Reef Water Quality Program. Insights into the most influential social networks for shifting social norms are described by Cruz and Guerrero (in press).

What programs should retain

Several design factors that worked well are consistent with the extension literature and could be maintained. Local relationships and trust, the most cited success factor, reinforce extension scholarship emphasising trusted relationships in facilitating change (Coutts et al. 2005). One-on-one tailored approaches proved more effective than group methods, reflecting the contextual nature of agricultural decision-making and Pannell et al.'s (2006) emphasis on compatibility with the individual farming system. Economic messaging was more effective than environmental messaging for initial engagement, aligning with research on farmers' primary economic motivations (Prokopy et al. 2019), though the evaluation also found that, once engaged, farmers can come to appreciate broader benefits, indicating scope to broaden motivations over time.

The finding that many farmers remain unaware of program opportunities, combined with evidence from the overlaps analysis that the same cohorts participate repeatedly, suggests communication failures rather than a lack of interest. Expanding delivery provider networks, particularly to industry-based organisations, effectively reached previously unengaged farmers, and the overlaps analysis itself offers a practical tool for selecting farms not represented in previous programs. The financial incentives evaluation (Eberhard 2024) demonstrated that well-structured incentives can accelerate adoption by around three years while achieving high maintenance confidence, although not all Reef incentive schemes have been effective (Eberhard et al. 2021); the conditions identified by James et al. (in press) distinguish effective schemes.

What requires action beyond programs

Several barriers require interventions beyond the design of any single program. Traditional fertiliser reduction has reached practical limits, a conclusion validated in the literature (Thorburn et al. 2017). Future nitrogen reduction requires alternative approaches such as addressing yield constraints, improving soil health and integrating precision agriculture, which in turn require different support mechanisms and longer timeframes. A current limitation is that tools such as the P2R Projector and the Paddock to Reef program cannot easily represent the water quality benefits of improved nitrogen use efficiency, so that delivery providers cannot readily demonstrate the benefit of these practices even where it exists (P2R Projector n.d.; Truii 2024).

The recognition that not all water quality-beneficial practices provide sufficient relative advantage to farmers highlights a fundamental challenge for voluntary adoption. For practices such as improved pesticide management, or nutrient management in the Lower Burdekin, sustained adoption may require external motivation, including regulatory compliance, as a maintenance mechanism. The consistent mismatch between program duration and crop cycles is a critical finding for program design: future programs might align engagement with agricultural cycles rather than funding cycles, supported by research showing that agricultural innovations require multiple seasons for farmers to develop confidence and adapt practices (Pannell et al. 2006), and that learning about relative advantage occurs over multiple cycles, particularly for complex practices (Kuehne et al. 2017).

The tension between government support and industry dependency on free services raises a further challenge. While government funding effectively accelerates adoption, it creates expectations for continued support that are difficult to sustain. Future programs might explore gradual transitions from public funding to commercially viable support, and co-funded approaches that increase farmer investment over time. Workforce shortages affect both delivery capacity and post-program sustainability and require coordinated policy responses addressing education, regional development and industry transformation (ABARES 2019); initiatives such as the Queensland Farmers' Federation Agricultural Extension Work Placement Program have effectively added to the extension workforce in Reef regions and could be maintained (Bickle et al. 2024). Contradictory reseller advice, identified as undermining program gains, has been addressed in other agricultural contexts through coordination of commercial organisations, standardisation of

information sources, knowledge management platforms, and training and certification of staff (Lamm et al. 2020; Staudacher et al. 2021; Wuepper et al. 2021).

Limitations

As noted in the Methods, the extent of practice reversal was not quantified, owing to gaps in previous data. The overlap analysis used Commonwealth-funded program data only and therefore likely understates the true extent of overlap and reversal. Data for the Lower Burdekin catchments were unavailable for the overlap analysis. The social monitoring survey response rate of 38 per cent, and the reliance on self-reported intentions to continue practices, mean these findings should be read as indicative rather than definitive. These constraints temper, but do not overturn, the central finding that adoption cannot be assumed to endure.

Conclusion

This evaluation demonstrates that whilst significant practice adoption can be achieved through well-designed agricultural extension programs, sustaining these improvements requires addressing social, economic, and institutional factors that extend beyond program boundaries. The identification of practice reversal alongside substantial overlap between successive programs suggests that adoption cannot be assumed to endure and highlights the need for greater attention to long-term practice maintenance. Insights into the factors supporting and undermining sustained adoption, provide a foundation for developing more effective approaches to agricultural practice adoption in sugarcane.

Interpreted through established frameworks of adoption, discontinuance and behaviour change, the findings suggest that enduring practice adoption may require a shift in how agricultural extension programs are conceived and delivered: from short-term, project-based approaches towards longer-term, system-oriented interventions that align with crop cycles, elevate social norms beyond direct participants, and prioritise practices with demonstrable relative advantage. It also requires a change in how practice adoption is measured, so that it no longer assumes permanence. Implementing such approaches will require coordinated action across policy, industry, commerce and workforce.

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