Alternative Policy Designs to Help Farmers Select Profitable Conservation Practices

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Abstract

Voluntary private carbon initiatives (VPCIs) promote the implementation of agricultural conservation practices that mitigate emissions of greenhouse gases (GHGs) via financial incentives to participating farmers. Simultaneously, an array of public policies supports the adoption of conservation practices through technical and financial assistance. This article explores the potential impact of different policy designs on cover crops and no-till adoption in the United States, under alternative additionality requirements for carbon crediting, when farmers voluntarily choose to participate in VPCIs only when it is profitable for them. The baseline is calibrated with actual adoption rate data by county and serves as benchmark for four scenarios: (1) financial and physical additionality required; (2) only physical additionality required and unrestricted EQIP payments; (3) only physical additionality required and HEL-limited EQIP payments; and (4) only physical additionality required and budget-limited EQIP payments under reverse auction in HEL-acres. Incremental adoption rates and farmers' net returns are highest in Scenario 2; incremental adoption rates are lowest in Scenario 1; and farmers' net returns are lowest in Scenarios 1 and 4. The required EQIP funding for Scenario 2 makes it unfeasible. Scenarios 3 and 4 result in lower incremental adoption of conservation practices but also lower average EQIP payments per unit of GHG emissions reduction and higher EQIP cost-effectiveness in mitigating GHGs than Scenario 2.

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Voluntary government-sponsored conservation programs provide financial and technical assistance to U.S. farmers to help them select and implement agricultural conservation practices with potential to improve the operation's bottom line and the environment. Cover crops and no-till are well-known to have many environmental benefits, such as improving soil health, reducing soil erosion, and retaining excess fertilizer runoff to waterways (Sanchez et al., 2019; Blanco-Canqui and Ruis, 2020; Franklin and Bergtold, 2020; Magdoff and van Es, 2021). In addition, these practices have the potential to capture carbon dioxide (CO_2) and store it as soil organic carbon (SOC) (Powlson et al. 2014; Poeplau and Don 2015; Spotorno et al. 2024; Moraes et al. 2025).

Potential benefits to producers' farms (improved soil health, reduced input costs), and their environmental-oriented attitudes can induce the adoption of conservation practices (Andrews et al. 2013; Plastina et al. 2020; Wang et al. 2021). However, many studies have documented that implementation expenses and negative net returns to conservation practices can hinder the adoption of conservation practices, while receiving cost-share payments increases the likelihood of conservation practice adoption (Lichtenberg, 2004; Plastina et al. 2018; Lee and McCann 2019; Plastina et al. 2020; Maher et al., 2023). The federal government has made substantial investments through the Natural Resources Conservation Service (NRCS) to promote the adoption of conservation practices on working lands. A major NRCS program supporting new adoption of conservation practices on working lands is the Environmental Quality Incentive Program (EQIP), which offers a cost-share payment of up to 75% of the NRCS estimated cost to agricultural producers. In fiscal years 2017–2022, EQIP expended $504.8 million (9.1% of total

EQIP payment) in promoting cover crops and $37.0 million (0.7% of total EQIP payment) in promoting no-till (Environmental Working Group (EWG), 2025). However, according to the Census of Agriculture, the percentage of area in cover crops and no-till to total cropland in 2022 were 4.7% and 27.5%, respectively, merely 0.8 and 1.2 percentage points above their 2017 levels (USDA-NASS, 2019, 2024).

The ability of conservation practices to potentially reduce greenhouse gases (GHGs) in the atmosphere led to the rise of voluntary private carbon initiatives (VPCIs) that offer farmers contracts to implement practices that generate carbon credits, in exchange for monetary payment. VPCIs later sell carbon credits to intermediaries or end users in search of reducing their environmental footprint. Currently, farmers are offered between $30 and $45 per ton of carbon dioxide equivalent (CO_2e) reduced or sequestered by implementing eligible conservation practices.[1] Importantly, farmers are mostly allowed to collect payments from a VPCI and government conservation programs for the same practices on the same field and year (i.e., 'stacking' payments) as long as the governmental payments are not directly tied to the carbon impact of the practice (Plastina et al., 2024a). Financially stacking payments allows producers to offset adoption cost and increases the likelihood of practices' adoptions.

Plastina et al. (2024b) estimated the potential new adoption of cover crops and no-till and their impacts on total GHG emissions under the assumption that all croplands are eligible to receive financial support through EQIP plus a carbon payment from VPCIs when the practices

[1] This price information is obtained from publicly available data from each initiative's website as of May 27, 2025, although some initiatives do not disclose this information. In addition, carbon prices for some initiatives, such as Carbon by Indigo, vary based on the market. Carbon by Indigo (https://app.indigoag.com/programs/how-much-can-i-earn-carbon-farming) estimates carbon price of US$45/$tCO_2e$. Nutrien's Sustainable Nitrogen Outcomes Program (https://info.nutrienagsolutions.com/sno) and Cargill's RegenConnect (https://www.cargillag.com/grow-sustainably/regenconnect) offers US$35/$tCO_2e$. Truterra Carbon Program (https://admin.truterraag.com/Truterraag/media/TTDocuments/25-1-TT-carbon-Tech-sheet_VFL112624.pdf) provides an incentive of US$30/$tCO_2e$.

are implemented. Under a carbon payment of \$15/metric ton of CO_2e (tCO_2e), their simulation suggests that an additional 43.4 million acres would be in cover crops and 194.7 million acres would be in no-till, while farmers' net returns would increase by \$0.68 billion and \$1.24 billion, respectively. The present article extends the work of Plastina et al. (2024b) by relaxing one of the assumptions behind the simulation, namely that of an infinitely elastic supply of EQIP cost-share payments. Instead, we propose two approaches to reflect budgetary limitations to EQIP: (i) capping the cropland area eligible for EQIP payment only to highly erodible lands (HELs)[2] in each county, and (ii) capping the EQIP budget for new cover crop and no-till adoption at twice its size. Additionally, we explore the effects of implementing a costless reverse auction of EQIP contracts through NRCS offers heterogenous EQIP payment rates in amounts equal to each farmer's break-even practice implementation cost.

Data

Since our methodological approach is limited by data availability, it seems relevant to describe the existing data before proceeding with our model description: the agronomic data consist of area in conservation practices and total cropland area by county and is sourced from the 2022 Census of Agriculture (USDA-NASS, 2024); the economic data consist of additional costs to implement conservation practices (compared to production systems excluding those practices) from NRCS (USDA-NRCS, 2023); and the GHG effects from agronomic practices are derived from COMET Planner (Swan et al., 2022).

[2] Highly erodible land (HEL) is the land that can erode at an excessive rate because of soil properties, leading to long-term decreased productivity. More detail on HEL determination can be found at https://www.nrcs.usda.gov/resources/guides-and-instructions/highly-erodible-land-determinations.

The current adoption rates of no-till and cover crops at the county level are computed as cropland acres in each of those practices divided by the total harvested cropland, both obtained from the 2022 Census of Agriculture (USDA-NASS, 2024). The average cover crop adoption rate is 5.6% of total cropland, ranging from 0.01% to 63.2% across all counties, while no-till adoption rate averages 21.5% of total cropland, from 0.1% to 93.8%, as shown in Table 1.

[Table 1 Here]

The state-specific implementation costs of cover crops and no-till are obtained from the 2023-level cost estimated by NRCS (USDA-NRCS, 2023), along with EQIP payment rate per acre. As reported in Table 1, planting single-species cover crops is estimated to cost $77.36–$87.35/acre, while adopting no-till costs $18.63–$26.54/acre. The EQIP payment rates are estimated to range from $24.52/acre in North Dakota to $74.12/acre in North Carolina for cover crops and from $11.09/acre in Iowa to $20.14/acre in North Carolina for no-till. While EQIP payment rates are equal to 75% of the state-specific estimated cost in most states, the payment in North Carolina covers 90% of the estimated costs for cover crops and no-till, as high-priority practices. On the other hand, Arkansas and Iowa farmers would receive EQIP payment rates at 60% and 50% of their respective costs for both practices. Other states that provide different EQIP payment rates for cover crops include Nebraska (55%), Minnesota and South Dakota (40%), and North Dakota (30%).

The estimates of GHG reduction potential from no-till and cover crops are acquired from the COMET-Planner tool (Swan et al. 2022), which is publicly available on http://comet-planner.com/. In this study, we focus on the GHG reduction potential from (a) planting non-legume cover crops, for cover crops; and (b) shifting from conventional tillage to no-till, for no-till. The mean, minimum, and maximum potential GHG reductions by county and irrigation practice are aggregated into a weighted county-average, with weights equal to the share of irrigated and non-irrigated acres obtained from the 2022 Census of Agriculture. When no county data on irrigated area are available, all cropland in the county is assumed to be non-irrigated. If the reported irrigated area exceeds total county cropland, all acres in the county are considered as irrigated. The weighted average, minimum, and maximum GHG reduction potential from conservation practices are reported in Table 1.

Crop production on highly erodible lands (HELs) is highly susceptible to losing productivity if used in conventional cropping practices, so conserving and improving these types of areas is important for farmers and the environment. The number of HELs at the county level is based on the 1997 data from the National Resources Inventory (NRI) (USDA-NRCS, 2017). Due to the lack of county-level data in the recent HEL data, the 1997 dataset is used after a comparison between the number of HELs in the contiguous states in 2017 (109.06 million acres) and in 1997 (108.39 million acres) indicated a relatively small difference (USDA-NRCS, 2017) and suggesting that the number of HELs is stable over time. In 2017, 109 million acres of croplands in the contiguous United States were classified as HELs, accounting for 27.6% of total cropland in that year. The number of acres in no-till alone was 103.6 million in 2017 (USDA-NASS, 2019), which was lower than the total number of HELs in 1997. Overall, at least 26 million acres were available for further adoption, calculated from HEL acres minus adopted acres at the county level. Hence, we use the number of HELs to limit the number of cropland eligible for EQIP participation.

Methodological Approach

This article extends the work of Plastina et al. (2024b) by relaxing the assumptions that all farm operations are eligible to participate in EQIP and that the federal budget for the EQIP cost-share payments adjusts to service all qualifying farms. In reality, only a portion of the EQIP applications is accepted annually due to limited funding. This study explores two methods to incorporate limits to EQIP eligibility into the model: (i) using the number of HELs in each county; and (ii) increasing the EQIP budget for each practice by an amount equal to the annual average budget over 2017–2022.

According to Plastina et al. (2024b) and Cameron-Harp et al. (2024), a flat rate of carbon payment per acre may result in negative regional carbon reductions and cost ineffectiveness. Hence, this study only focuses on carbon payments per outcome at a rate of \$30/tCO_2e and analyzes the economic and environmental impacts of allowing farmers to stack payments from EQIP and VPCIs in exchange for implementing conservation practices on additional acres. The economic and environmental impacts are measured with respect to a baseline scenario calibrated in the absence of carbon payments and observed adoption rates with EQIP support. The relationship between total acres in a conservation practice and total acres classified as HEL is explicitly modeled in the model baseline and all scenarios.

The model baseline assumes that conservation practice adoption occurs in the absence of carbon markets, and eligibility for EQIP participation is limited to HELs. In the alternative scenarios, we explore how the interactions between two types of limitations to EQIP participation and two different types of additionality requirements imposed by VPCIs on eligible acres affect model results. We consider HEL and budgetary restrictions as the two types of limitations to EQIP participation, and physical and financial additionality as the two types of eligibility requirements for VPCIs. Physical additionality means that only acres where the selected conservation practice had not been implemented are eligible to participate in VPCIs. Financial additionality means that those acres that have received financial support through EQIP to implement the selected practice are not eligible to participate in VPCIs.

Four scenarios are evaluated with respect to the baseline: (i) full additionality required, where both physical and financial additionality are required to participate in VPCIs; (ii) physical additionality required and unrestricted EQIP payments, where carbon payments from VPCIs and EQIP payments are available to all physically additional acres; (iii) physical additionality required and HEL-limited EQIP payments, where carbon payments from VPCIs are offered on all physically additional acres, but EQIP payments are restricted to HELs; (iv) physical additionality required and budget-limited EQIP payments under reverse auction, where carbon payments from VPCIs are offered on all additional acres, and reverse-auctioned EQIP payments are available for physically additional acres until budget exhaustion.

Baseline Scenario: No Carbon Payment and Cost-Share Support for Existing Adopters

Consider a county j with A_j acres of cropland, the agronomic appropriateness (θ_{ji}) for each acre i determines the acre-specific private benefits from conservation practices, such as reduced soil erosion, improved soil water holding capacity, reduced weed and pest pressures, and cash crop yield change. Same as in Plastina et al. (2024b), θ_{ji} is assumed to be uniformly distributed: $\theta_{ji} \sim U[0,1], \forall j$ and is perfectly known by producers during the decision-making process, and adoption decisions are made on a per-acre basis. This baseline further restricts the total number of acres receiving EQIP payment to not exceed the number of HEL-acres in the county. All acres in conservation practices are assumed to receive EQIP cost-share payments in the baseline. In the absence of specific information on HEL-designated areas, this study assumes that acres with high agronomic parameter values θ_{ji} are HELs.

Producers are assumed to decide whether to adopt a conservation practice based solely on their net returns. The net return function (π_{ji}^{B}) for acre i in county j, shown as the green line in Figures 1a and 1b, is assumed to be as follows:

$$\pi_{ji}^{B} = \begin{cases} -C_j + EQIP_j + \lambda_j\theta_{ji} & \text{if } EQIP_j + \lambda_j\theta_{ji} \geq C_j \text{ and } \theta_{ji} > 1 - H_j \\ -C_j + \lambda_j\theta_{ji} & \text{if } \lambda_j\theta_{ji} \geq C_j \text{ and } \theta_{ji} \leq 1 - H_j \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where C_j and $EQIP_j$ indicate the county-specific implementation cost of the conservation practice under analysis and the EQIP payment per acre, respectively; λ_j denotes a county-specific marginal agronomic private benefit from the selected practice, and H_j represents the county-specific share of HEL-acres in total cropland.

Figure 1a illustrates the case when the current adoption rate of a conservation practice is lower than the HEL-rate in county j, so all acres implementing the conservation practice receive EQIP payments. In this set up, some EQIP-eligible acres do not participate in EQIP. All acres with $\theta_{ji} \geq \theta_j^0$ adopt the practice, where $\theta_j^0 = \frac{C_j - EQIP_j}{\lambda_j}$ and the adoption rate is: $A_j^A = (1 - \theta_j^0) < (1 - H_j)$. In order to calibrate the parameters of this baseline, we use publicly available data on C_j, $EQIP_j$, A_j^A, and H_j, and set $\lambda_j = \frac{C_j - EQIP_j}{(1 - A_j^A)}$. The magnitude $A_j^N = \theta_j^0$ is a non-adoption rate, indicating additional implementation potential.

Figure 1b exhibits the case when the current adoption rate is greater than the HEL-rate, resulting in all HEL-acres receiving EQIP cost-share payments and some adopting acres not receiving EQIP payments. In Figure 1b, $\theta_j^0 = C_j/\lambda_j$ and $A_j^A > (1 - H_j)$. The calibration of this baseline requires setting $\lambda_j = \frac{C_j}{(1-A_j^A)}$.

Denoting A_j as the total cropland acres in the county, the total net returns to farmers for conservation practice implementation (Π_j^B) are the summation of the value below the green line and above the zero line or $A_j \int_{\theta_{ji}=\theta_j^0}^{1} \pi_{ji}^B d\theta_{ji}$.

[Figure 1 Here]

Scenario 1: Full Additionality Required

For all scenarios in this study, the VPCIs and producers are assumed to have full information on the actual amount of carbon reduction potential from the conservation practice for each acre and offer a carbon payment of $\$p$ = \$30 per tCO_2e at the time of contract signing. In this scenario, VPCIs are assumed to require both financial and physical additionality in carbon credits generation. In our methodological framework, physical additionality is a stronger requirement than financial additionality, because in some counties the area with a selected practice can exceed the HEL and EQIP area (Figure 1b).

Farmers operating acres not using the selected conservation practice in the baseline scenario ($\theta_{ji} < \theta_j^0$) maximize the following net returns function:

$$\pi_{ji}^1 = \begin{cases} -C_j + \lambda_j\theta_{ji} + py_{ji} & \text{if } \lambda_j\theta_{ji} + py_{ji} \geq C_j \text{ and } \theta_{ji} < \theta_j^0 \\ 0 & \text{otherwise for } \theta_{ji} < \theta_j^0 \end{cases} \quad (2)$$

where p denotes a carbon price and y_{ji} is the annual amount of GHG emission reduction from the practice for acre i in county j. The latter variable is simulated as a random draw from a county-specific triangular distribution of GHG reductions calibrated using the minimum, maximum, and mean GHG effects from the COMET-Planner model.

While new adopters cannot participate in EQIP due to the VPCIs' restriction, existing adopters still receive EQIP cost-share payment as in the baseline model. New practice adoption might occur over non-contiguous acres in the θ-space, highlighted in blue on the horizontal axis of Figures 2a and 2b. The total net returns to farmers from new adoption in county j, $\Pi_j^1 = A_j \int_{\theta_{ji}:\pi_{ji}^1 \geq 0}^{\theta_j^0} \pi_{ji}^1 d\theta_{ji}$, is represented by the shaded area above the zero line and below the line of net returns function π_{ji}^1. The acres with new practice adoption generate a total carbon reduction equal to $A_j \int_{\theta_{ji}:\pi_{ji}^1 \geq 0}^{\theta_j^0} \int y_{ji}\, dy d\theta_{ji}$; farmers receive total carbon payments from VPCIs amounting to $A_j p \int_{\theta_{ji}:\pi_{ji}^1 \geq 0}^{\theta_j^0} \int y_{ji} dy\, d\theta_{ji}$.

[Figure 2 Here]

Scenario 2: Physical Additionality Required and Unrestricted EQIP Payments

This scenario assumes that all newly adopted acres will receive cost-share support from EQIP, regardless of HEL acres in the county, same as in Plastina et al. (2024b). VPCIs allow participants to stack their carbon payment with payment for environmental impact from cover crops and no-till and there is no EQIP budget limit for new practice adoption. Hence, potential adopters can receive payments from both EQIP and a VPCI if they decide to adopt the practice. For acres without the selected conservation practice in the baseline, with $\theta_{ji} < \theta_j^0$, farmers' adoption decision relies on the following equation:

$$\pi_{ji}^2 = \begin{cases} -C_j + EQIP_j + \lambda_j \theta_{ji} + p y_{ji} & \text{if } EQIP_j + \lambda_j \theta_{ji} + p y_{ji} \geq C_j \text{ and } \theta_{ji} < \theta_j^0 \\ 0 & \text{otherwise for } \theta_{ji} < \theta_j^0 \end{cases} \quad (3)$$

This scenario is illustrated in Figures 3a and 3b. The total net returns to farmers from new adoption for county j is $\Pi_j^2 = A_j \int_{\theta_{ji}:\pi_{ji}^2 \geq 0}^{\theta_j^0} \pi_{ji}^2 d\theta_{ji}$. Likewise, the total GHG emission reductions from newly adopted acres, and their payments from EQIP and VPCIs are calculated as

$A_j \int_{\theta_{ji}:\pi_{ji}^2 \geq 0}^{\theta_j^0} \int y_{ji} dy d\theta_{ji}$, $A_j EQIP_j \int_{\theta_{ji}:\pi_{ji}^2 \geq 0}^{\theta_j^0} d\theta_{ji}$, and $A_j p \int_{\theta_{ji}:\pi_{ji}^2 \geq 0}^{\theta_j^0} \int y_{ji} dy d\theta_{ji}$, respectively

[Figure 3 Here]

Scenario 3: Physical Additionality Required and HEL-Limited EQIP Payments

In practice, EQIP funding is limited, thus EQIP payment cannot be offered for every new adopter. This scenario assumes that EQIP eligibility is limited only to HEL-acres. Hence, only acres characterized by $\theta_{ji} \in \left(1 - H_j, \theta_j^0\right)$ are eligible for EQIP payments. The carbon payment from VPCIs is assumed to be available for all new adopters. For $\theta_{ji} < \theta_j^0$, farmers will make their decision based on equation (4):

$$\pi_{ji}^3 = \begin{cases} -C_j + EQIP_j + \lambda_j \theta_{ji} + p y_{ji} & \text{if } EQIP_j + \lambda_j \theta_{ji} + p y_{ji} \geq C_j \text{ and } \theta_j^0 > \theta_{ji} > 1 - H_j \\ -C_j + \lambda_j \theta_{ji} + p y_{ji} & \text{if } \lambda_j \theta_{ji} + p y_{ji} \geq C_j \text{ and } \theta_{ji} \leq \theta_j^0 \leq 1 - H_j \\ 0 & \text{otherwise for } \theta_{ji} < \theta_j^0 \end{cases} \quad (4)$$

Figures 4a and 4b illustrate this scenario for the cases when the baseline adoption rate is lower than the HEL-rate, and when the baseline adoption rate is greater than HEL rate, respectively. It should be worth noting that in the case of baseline adoption rate exceeding HEL rate (Figure 4b), the adoption decision would be identical to the scenario 1 under the same condition (Figure 2b), because no extra EQIP funding is available in that county. Farmers' net returns from newly adopted acres $\Pi_j^3 = A_j \int_{\theta_{ji}:\pi_{ji}^3 \geq 0}^{\theta_j^0} \pi_{ji}^3 d\theta_{ji}$, are shown as the shaded area above zero line in Figures 4a and 4b. For each county j, the total GHG emission reductions from new practice adoption, the cost-share payment from EQIP, and carbon payment from VPCIs are calculated as

$A_j \int_{\theta_{ji}:\pi_{ji}^3 \geq 0}^{\theta_j^0} \int y_{ji} dy d\theta_{ji}$, $A_j EQIP_j \int_{\theta_{ji}:\pi_{ji}^3 \geq 0}^{\theta_j^0} d\theta_{ji}$, and $A_j p \int_{\theta_{ji}:\pi_{ji}^3 \geq 0}^{\theta_j^0} \int y_{ji} dy d\theta_{ji}$, respectively.

[Figure 4 Here]

Scenario 4: Physical Additionality Required and Budget-Limited EQIP Payments Under Reverse Auction in HEL-Acres

In addition to HEL restrictions, this scenario assumes that the annual budget caps for EQIP payments on new practice adoption beyond the baseline. Total EQIP payments ranged from $816.3 billion in fiscal year 2017 to $992.0 billion in fiscal year 2022 (EWG, 2025). Over this 6-year period, planting cover crops was the practice that received most financial support, totaling $504.8 billion, while total payments for no-till amounted to $37.0 billion. In line with the average annual payments over 2017-2022, the extra EQIP budget for new cover crops and no-till adoption is assumed to be capped at $85.3 million and $4.9 million, respectively. This is essentially equivalent to assuming a doubling in the EQIP budget for the selected practices.

Under the assumption of perfect information of the GHG impact of the adoption on each acre, this scenario allows NRCS to offer different EQIP payment rates to each acre ($EQIP_{ji}$). EQIP payments would be provided only up to the break-even point (zero profit) necessary for farmers to adopt the practice. The additional EQIP budget will prioritize new adopters with the highest joint values of $\{\theta_{ji}, y_{ji}\}$, and the EQIP payments will be allocated in descending order of $\{\theta_{ji}, y_{ji}\}$, until the budget is exhausted.

Farmers' maximization process is shown in equation (5), as follows:

$$\pi_{ji}^4 = \begin{cases} -C_j + EQIP_{ji} + \lambda_j\theta_{ji} + py_{ji} & \text{if } EQIP_{ji} + \lambda_j\theta_{ji} + py_{ji} \geq C_j \text{ and } \theta_j^0 > \theta_{ji} > 1 - H_j \\ -C_j + \lambda_j\theta_{ji} + py_{ji} & \text{if } \lambda_j\theta_{ji} + py_{ji} \geq C_j \text{ and } \theta_{ji} \leq \theta_j^0 \leq 1 - H_j \\ 0 & \text{otherwise for } \theta_{ji} < \theta_j^0 \end{cases} \quad (5)$$

$$\text{such that} \qquad \sum_j \sum_{\theta_{ji}|\pi_{ji}^4 \geq 0}^{\theta_j^0} EQIP_{ji} \leq CAP.$$

Unlike other scenario, $EQIP_{ji}$ is an acre-specific EQIP payment rate and CAP denotes the total budget cap for additional practice adoption under EQIP at the national level. For county j, the total GHG emission reductions from new practice adoption, and carbon payment from VPCIs are $A_j \int_{\theta_{ji}:\pi_{ji}^4 \geq 0}^{\theta_j^0} \int y_{ji} dy d\theta_{ji}$ and $A_j p \int_{\theta_{ji}:\pi_{ji}^4 \geq 0}^{\theta_j^0} \int y_{ji} dy d\theta_{ji}$, respectively. Meanwhile, the total EQIP payment for each county is computed as $A_j \int_{\theta_{ji}:\pi_{ji}^4 \geq 0}^{\theta_j^0} EQIP_{ji} d\theta_{ji}$, while farmers' net returns to practice adoption would be close to null for all newly adopted acres ($\Pi_j^4 = A_j \int_{\theta_{ji}:\pi_{ji}^4 \geq 0}^{\theta_j^0} \pi_{ji}^4 d\theta_{ji}$ is approximately 0).

Simulated Results

Scenario 1: Full Additionality Required

When no EQIP payment is offered to any new adopters of cover crops and no-till, farmers can only receive the carbon payment of \$30/tCO_2e under perfect and symmetric information (i.e., as the GHG impact from the practice adoption is known by farmers and a VPCI at the time of contract signing). Table 2 reports the simulation results for all scenarios at the national level. Scenario 1 would result in an additional 8.3 million acres (2% increase) in cover crops and an additional 95.7 million acres (25% increase) in no-till. The new cover-crop adoption would translate into a 5.2 million tCO_2e reduction of GHG emissions and a \$77.8 million increase (an average of \$9.33/acre among participating farmers) in total net returns to farmers. Similarly, the new no-till adoption would generate \$727 million (an average of \$7.60/acre) in farmers' net returns to participating farmers and reduce GHG emissions by 51.3 million tCO_2e. The carbon market size, calculated by total GHG emissions reduction times the carbon price of \$30 per tCO_2e, would be \$156 million for cover crops and \$1.54 billion for no-till.

At the state level, the additional acres in cover crops are concentrated in Louisiana (16.4% of total cropland), Florida (16%), Arkansas (14.7%), and Mississippi (14.5%), as shown in Figure5a. Likewise, the new adoption of no-till would mainly occur in Arkansas (69.8%), Louisiana (62.8%), Florida (53.7%), and Mississippi (52.5%) (Figure 5b). These outcomes suggest high net returns per acre in these states, possibly due to relatively high GHG emissions reduction potential and relatively low implementation costs. While private carbon payments can partially offset the adoption costs of cover crops and no-till, they are insufficient without additional source of financial support to incentivize wider adoption in some major crop producing states, such as Texas (14% increase) and Kansas (17% increase).

[Figure 5 Here]

Scenario 2: Physical Additionality Required and Unrestricted EQIP Payments

In this scenario, farmers are allowed to participate in both VPCI and EQIP under the assumption of no EQIP budget limit. All newly adopted acres can receive EQIP cost-share payments on top of the private carbon payment. This scenario corresponds to the payment-per-output case in Plastina et al. (2024b). The simulated results in Table 2 show a 127.4 million cover crops acre increase (34% of total cropland acres) and a 262.3 million no-till acre increase (69% of total cropland acres). In the exchange of additional implementation of cover crops and no-till, U.S. farmers would receive a total of $2.4 billion (an average of $18.55/acre among participating farmers) and $3.6 billion (an average of $13.84/acre among participating farmers) of net returns, respectively. New cover crops acres would reduce 48.6 million tCO_2e of GHG emissions, while new no-till acres would account for 105.1 million tCO_2e of GHG emissions reductions. Corresponding to high adoption rates, the size of the carbon market is estimated at $1.46 billion for cover crops and 3.15 billion for no-till.

Figures 6a and 6b illustrate the spatial differences in additional acres in cover crops and no-till. The top 4 states with the highest percentage of new cover crops acre are Louisiana (89%), North Carolina (85%), Florida (83%), and Mississippi (82%). In comparison to scenario 1, the states with additional area in cover crops are North Carolina (77%), followed by Louisiana (72%), partly due to the higher cost-share payment rate in North Carolina. In scenario 2, Montana (6%), Washington (7%), and Nevada (8%) are the states with the lowest proportion of new cover crop areas, due to relatively low GHG impact from cover crops. The top states with additional no-till area as a percentage of total cropland are Maine, Massachusetts, California, New Hampshire, and Minnesota with the adoption rate of 92%–93%.

[Figure 6 Here]

This scenario would provide the highest new adoption rates of both cover crops and no-till. However, the additional $7.3 billion and $4.2 billion in annual EQIP payments required to support these new cover crops ($57.13/acre) and no-till ($16.08/acre) acres. The total budget over the 5-year contract period for these practices would be equivalent to about 9.5 times the EQIP budget for fiscal year 2025 (USDA, n.d.). The huge budgetary requirements to expand EQIP to those levels make this scenario highly improbable.

Scenario 3: Physical Additionality Required and HEL-Limited EQIP Payments

Due to the EQIP limitation to HELs, the total acres in cover crops or no-till supported through EQIP are capped at 100.6 million and 103.4 million acres, respectively. The disparity in HEL acres between both practices is due to the difference in data availability affecting the total number of counties included in the model. Given the current cover crops acres, the potential new adoption with EQIP payments is limited to 85.0 million acres, lower than the total additional acres projected in scenario 2. Similarly, the total new no-till acres are capped at $40.8 million acres, over 200 million acres less than the newly adopted acres in the previous scenario. The availability of acres in EQIP at the county level are shown in Figures 7a for cover crops and 7b for no-till.

[Figure 7 Here]

At the national level, the simulation indicates that an additional 42.5 million acres (11% of total cropland) would go into cover crops, of which 80% would receive EQIP payments, as reported in Table 2. New acres in no-till amount to 130.0 million (34% of total croplands), while only 29% of those acres would be able to participate in EQIP. These results suggest that producers are more likely to adopt no-till than cover crops due to lower adoption cost of no-till and higher GHG impact potential.

These newly enrolled EQIP acres would cost an extra $2 billion ($58.21/acre) and $617 million ($16.35/acre) of annual EQIP funding for cover crops and no-till, respectively, or 23 times and 125 times of the average annual EQIP payments of $85.3 million for planting cover crops and $4.9 million for no-till over 2017–2022. The total GHG emissions reduction is estimated to reach 77.9 million tCO_2e (16 million from cover crops and 61.9 million from no-till), translating into a $2.3 billion agricultural carbon market. Amid the high EQIP funding and large carbon market size, the total net returns to farmers are $295 million for cover cropped area (an average of $6.94/acre among participating farmers) and $1.04 billion for no-till area (an average of $8.01/acre among participating farmers).

The results of newly adopted acres for each county in this scenario are displayed in Figure 8. Unlike the previous two scenarios, the top four states with the highest percentage changes in cover crops acres are Kentucky (33%), Tennessee (31%), Missouri (29%), and

Mississippi (27%). Although Arizona, Colorado, and New Mexico are the states with the most EQIP availability, these states only have new adoption rates ranging from 9%–24%, possibly due to low GHG emissions reduction potential at the weighted averages of 0.02–0.12 tCO_2e. At the state level, the percentage of new cover crops acres in EQIP range from 8% (Florida) to 100% (CO, ID, MT, NV, NM, PA, and VT). For no-till, the top four states with the largest shares of newly adopted acres are Arkansas (70%), Louisiana (64%), Massachusetts (63%), and Mississippi (58%). However, only 1% of newly adopted acres in Arkansas, 4% in Louisiana, and 16% in Mississippi would participate in EQIP due to the HEL restrictions. Meanwhile, the states with the highest share of additional acres in EQIP to adopted acres are those that have relatively high EQIP availability, such as New Mexico (99%) and Colorado (98%).

[Figure 8 Here]

Scenario 4: Physical Additionality Required and Budget-Limited EQIP Payments Under Reverse Auction in HEL-Acres

In addition to capping EQIP participation by HELs, this scenario assumes that the annual EQIP budget for new cover crops and no-till acres are $85.3 million and $4.9 million, respectively. The additional funding would be equivalent to $426.6 million and $24.6 million over the 5-year contract period, accounting for 7.5% of total EQIP budget in fiscal year 2025. Furthermore, NRCS offers variable payment rates per acre designed to provide the minimum amount necessary to incentivize farmers to adopt conservation practices, given full information on their net returns.

The simulations indicate that the new national areas adopted cover crops and no-till are 21 million acres (6% of total cropland) and 105 million acres (28% of total cropland). Of which

60% of newly cover crops adopted acres (12.7 million acres) are participating in EQIP, while only 9% of newly no-till adopted acres (9.3 million acres) would receive EQIP payment. With the cap on total annual EQIP payment, the average EQIP payment rates for participating acres are $6.73 per acre for cover crops and $0.53 per acre for no-till, significantly lower than the normal EQIP payment rates of both practices.

These new practice adoptions would reduce GHG emissions by a total of 64.5 million tCO_2e, 9.1 million from cover crops and 55.4 million from no-till, translating into $1.94 billion of carbon market flows. In turn, farmers would earn total net returns of $77.8 million for cover crops and $727 million for no-till, which are the net returns to those who would adopt the practices without EQIP payment (but with carbon payment) in scenario 1.

At the finer level, the top four states with the largest percentage increase in cover crop acres are Florida (29% of state's cropland), Louisiana (26%), Arkansas (25%), and Mississippi (22%). On the other hand, Nevada, New Mexico, and Vermont would have no change in cover crops areas. For no-till, the top four states with largest new adopted areas are Arkansas (73%), Louisiana (66%), Florida (57%), and Mississippi (56%). These states are consistent with the results in scenario 1, mainly due to high proportions of newly adopted acres without EQIP payments. Meanwhile, Minnesota, North Dakota, and South Dakota gain the most cover crop acres under EQIP, ranging from 1.1 million to 1.3 million acres (6%–8% of each state's cropland). The top states with largest no-till areas with EQIP support would be Iowa, Illinois, and Minnesota, accounting for only 0.7–0.9 million acres (3% of each state's cropland). The average EQIP payment rates per acre at the state level range from $6.51 (Pennsylvania) to $7.00 (Arkansas) for cover crops and from $0.52 (Arkansas) to $0.57 (Colorado) for no-till.

[Figure 9 Here]

Discussion and Policy Implementations

The simulations show that a large number of acres (25% of total U.S. cropland) would adopt no-till without federal financial support if farmers can receive the carbon payment of \$30/tCO_2e from the private sector. In contrast, a small proportion (2%) would adopt cover crops under the same conditions. These outcomes suggest that the cost-share payment is more necessary to incentivize cover crops adoption than no-till due to higher implementation costs and lower GHG impact potential. However, this study ignores the social value of the environmental benefits from the selected conservation practices, such as nutrient runoff mitigation and weed suppression.

Introducing HEL restrictions to EQIP participation would possibly reduce the implementation of conservation practices; however, it would provide a more cost-effective approach to reducing GHG emissions (scenario 2 vs. scenario 3)—\$150 vs. \$124 per tCO_2e for cover crops and \$40 vs. \$10 per tCO_2e for no-till. These outcomes occur because scenario 2 offers EQIP support to all physically additional acres, while conservation practices would be adopted on some acres even without the cost-share payment in the presence of carbon payments. The tradeoff between the environmental impact and federal funding for the practices should be considered when policymakers aim to increase the use of agricultural conservation practices. The additional EQIP budget may be used in other approaches for the same purpose, such as increasing forest areas and carbon capture technologies.

While heterogeneous cost-share payment rates per acre in scenario 4 would encourage the most additional conservation practice adoptions given limited budgets, NRCS has information on neither actual producers' implementation costs per acre, acre-specific private benefits, nor actual GHG impact from practices that are crucial to compute their net returns from practice adoption. However, despite its unfeasibility, scenario 3 suggests that a state-level recalibration of EQIP cost-share payment rates (lowering rates for states that are more likely to adopt the practices without EQIP support and increasing rates in states that are less likely to adopt them) might incentivize higher adoption rates at the national level.

Research Limitations

This study explores how additionality requirements by VPCIs and EQIP eligibility interact with conservation practice adoption with a simple methodological approach limited by data availability. Several caveats apply to our findings. The model is static, and while it can be argued that results represent steady-states under certain assumptions, the market dynamics associated with large-scale changes in agricultural practices such as increasing seed, equipment, and farm labor costs due to higher demand, as well as initial crop yield losses, are critical and should be explored in extensions of this research.

The simulated results with HEL restrictions are overly optimistic because the restrictions are not sufficient to limit program participation relative to the actual budget and EQIP acceptance rate. In scenario 3, the extra EQIP payments over a 5-year period for cover crops and no-till would cost 164% and 51% of total EQIP budget for fiscal year 2025, respectively.

The major caveat is the assumption of the perfect information on the GHG impact from the conservation practices. In practice, the uncertainty in GHG impact from practice adoption can reduce farmers' willingness-to-adopt if they are risk-averse impact, while VPCIs and federal agency do not certainly have this information. In addition, only one type of carbon payment is offered for each scenario, while private carbon payments are simultaneously offered at different rates and through an array of heterogeneous contracts. Due to high search costs, farmers may not participate in VPCIs because they simply are not willing to incur those search costs, even if net returns after search costs (unknown to them before implementing the search) are positive. Importantly, decisions are made under uncertainty and asymmetric information. Risk aversion to implementing new practices, entering into new types of contracts for carbon (different from the well-known and standardized contracts in commodity production), and relying on an unknown technology to measure carbon output, would result in much lower adoption rates than the ones presented in this study, and a much smaller market for agricultural carbon credits.

Conclusions

Cover crops and no-till have been widely supported by government-sponsored conservation programs and VPCIs as practices that provide environmental benefits and have the potential to reduce GHG emissions. Hence, federal conservation programs, such as EQIP, have offered cost-share payments to farmers who voluntarily choose to adopt these practices. In addition, most VPCIs in the United States compensate participating farmers for using cover crops and no-till as a method to mitigate climate change.

This study uses a highly stylized economic model of heterogenous farms calibrated with county-level data to simulate the changes in adoption rate, total EQIP costs, and net returns to farmers under four policy designs: (i) full additionality required; (ii) physical additionality required and unrestricted EQIP payments; (iii) physical additionality required and HEL-limited EQIP payments; and (iv) physical additionality required and budget-limited EQIP payments under reverse auction in HEL-acres.

Using the EQIP payment rates and estimated adoption costs in 2023 from USDA-NRCS (2023) and a carbon payment of \$30/tCO_2e, the results show that U.S. cover crops acres would increase by 2%–34%, from its 2022 level. The increase in cover crops adoption is lowest in full additionality required scenario and largest when EQIP participation is unlimited in scenario 2. Imposing HEL restrictions to limit EQIP participation in scenario 3, additional area in cover crops would be 11% of total cropland, costing almost $2 billion in additional EQIP funding. The average net returns per acre captured by participating farmers would be $6.94, lower than the $18.55 in scenario 2, while the EQIP cost per one tCO_2e emissions reduction is more cost effective. On top of the HEL restrictions, heterogeneous EQIP payment rates to bring farmers to their break-even points with limited budgets in scenario 4 would reduce the increase in cover crops area to 6% of total cropland. This method would cap the total annual EQIP payment to $85.3 million for new cover crop adoption, while it would provide the most cost-effective in terms of total cost per one tCO_2e of emissions reduction and the lowest net returns to farmers.

The results for no-till are consistent with the results for cover crops. However, we found a substantial additional adopted area (25% of total cropland) under scenario 1, resulting from lower adoption costs and higher GHG impact potential. Scenario 2 would increase additional no-till acres by 69% of total cropland. Adding HEL restrictions in scenario 3 would only increase adopted acres by 34%, reducing the annual EQIP funding from $4.2 billion to $617 million. Under the heterogeneous EQIP rates and limited budget in scenario 4, no-till acres would increase by 28% of total cropland with $4.9 billion of annual EQIP expenses.

Spatial differences in adoption rates are found, mainly due to the variation in GHG impact potential, estimated costs, and EQIP payment rates. Louisiana, Arkansas, Mississippi, and Florida are more likely to adopt cover crops and no-till without EQIP support due to high GHG emissions reduction potential from the conservation practices. Meanwhile, high cost-share payment rates can help encourage wider adoption in the states with moderate GHG impact potential.

Since allowing farmers to stack payments from government programs and VPCIs (i.e., requiring only physical additionality but not financial additionality) incentivizes adoption of conservation practices, but public funding for those government programs is limited, higher cost-share payment rates for areas with relatively higher environmental benefits could increase the cost-effectiveness of taxpayers' dollars.

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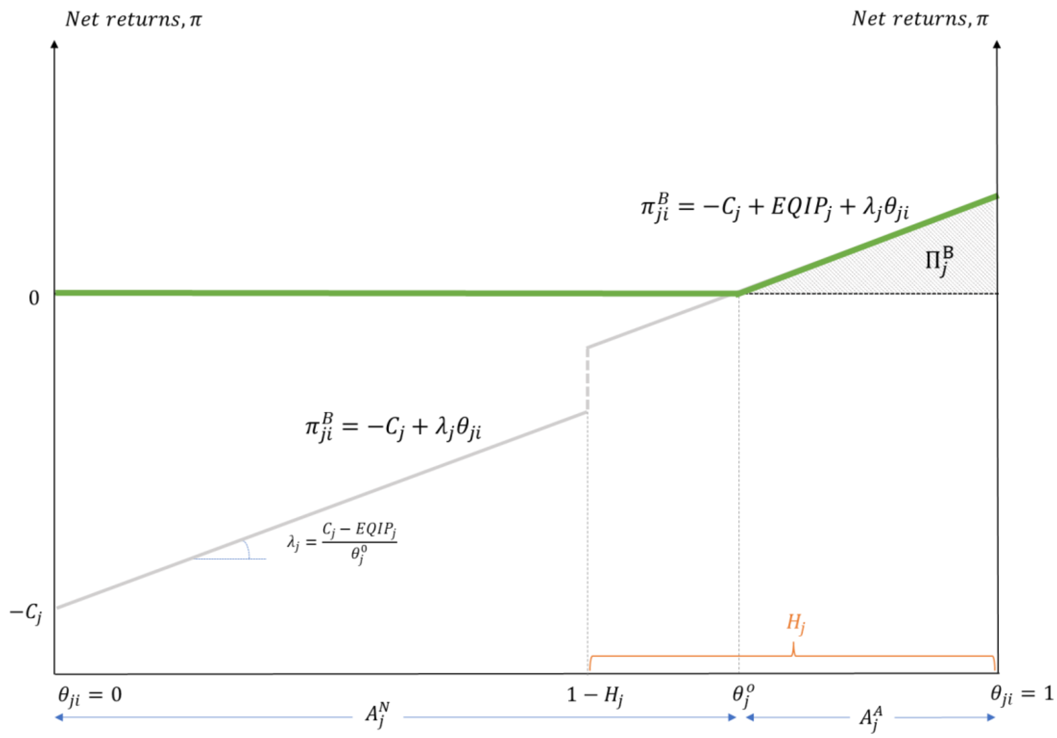
Table 1. Statistics of variables used in the simulated models

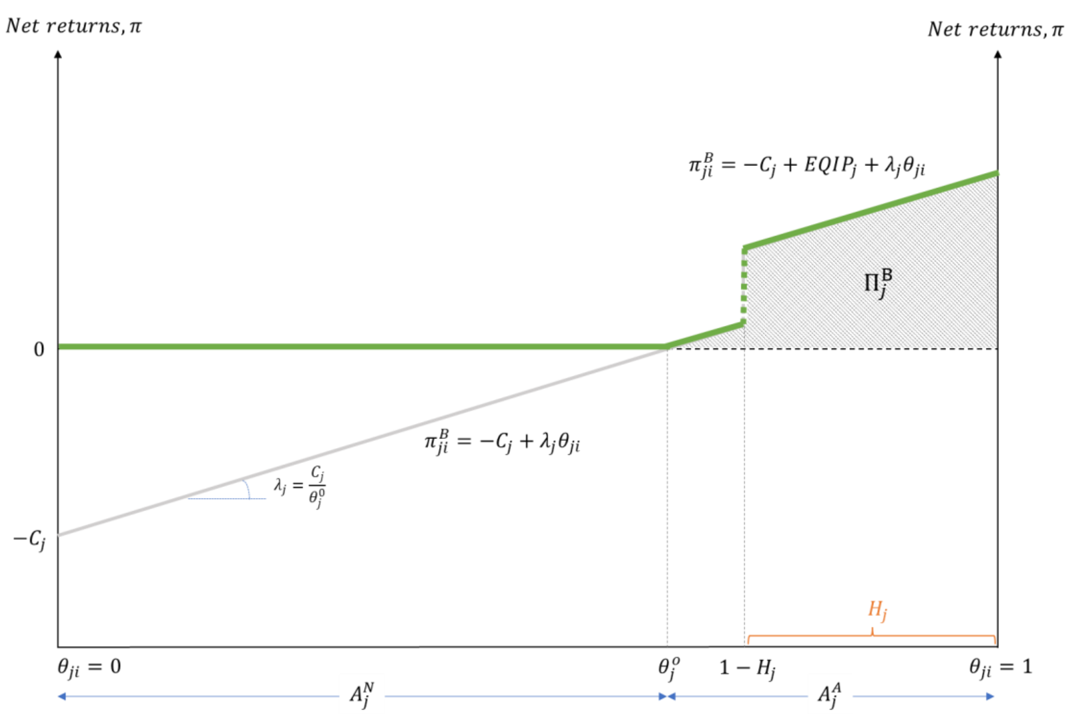
Variable	Mean	SD	Min	Max	Obs.
Cover crop adoption rate (%)	5.6	6.1	0.01	63.2	2,882
No-till adoption rate (%)	21.5	19.4	0.1	93.8	2,923
HEL rate (%)	29.3	30.0	0	100.0	3,042
EQIP payment rate for cover crops ($/ac)	58.14	9.34	24.52	74.12	3,042
Cover crop adoption cost ($/ac)	81.71	1.41	77.36	87.35	3,042
Average GHG reduction potential from cover crops (CO_2e/ac)	0.23	0.19	-0.07	1.36	3,028
Minimum GHG reduction potential from cover crops (CO_2e/ac)	-0.06	0.12	-1.04	0.20	3,028
Maximum GHG reduction potential from cover crops (CO_2e/ac)	0.66	0.43	0.05	1.99	3,028
EQIP payment rate for no-till ($/ac)	16.39	1.59	11.09	20.14	3,042
No-till adoption cost ($/ac)	22.04	1.15	18.63	26.54	3,042
Average GHG reduction potential from no-till (CO_2e/ac)	0.41	0.15	0.04	0.79	3,028
Minimum GHG reduction potential from no-till (CO_2e/ac)	0.02	0.10	-0.50	0.54	3,028
Maximum GHG reduction potential from no-till (CO_2e/ac)	0.82	0.26	0.28	1.44	3,028

Table 2. Summary of simulated results at the national level for cover crops and no-till, all scenarios.

Scenario	Additional acres adopted ('000 acres)	% of additional acres	Additional acres in EQIP ('000 acres)	Additional acres without EQIP ('000 acres)	Additional CO_2e reduction ('000 tCO_2e)	Carbon market size (million $)	Total additional EQIP payments (million $)	Additional net returns to farmers (million $)
Cover Crops								
1. full additionality required	8,334.29	2%	-	8,334.29	5,194.70	155.84	-	77.79
2. physical additionality required and unrestricted EQIP payments	127,414.97	34%	127,414.97	-	48,572.52	1,457.18	7,279.16	2,363.31
3. physical additionality required and HEL-limited EQIP payments	42,505.56	11%	34,172.08	8,333.48	16,013.52	480.41	1,989.01	294.94
4. physical additionality required and budget-limited EQIP payments under reverse auction in HEL-acres	21,013.30	6%	12,679.02	8,334.29	9,087.60	272.63	85.33	77.79
No-Till								
1. full additionality required	95,690.66	25%	-	95,690.66	51,325.77	1,539.77	-	727.06
2. physical additionality required and unrestricted EQIP payments	262,275.58	69%	262,275.58	-	105,110.02	3,153.30	4,217.29	3,630.58
3. physical additionality required and HEL-limited EQIP payments	130,034.26	34%	37,738.96	92,295.30	61,855.91	1,855.68	617.05	1,041.36
4. physical additionality required and budget-limited EQIP payments under reverse auction in HEL-acres	105,040.73	28%	9,350.08	95,690.66	55,457.21	1,663.72	4.92	727.06

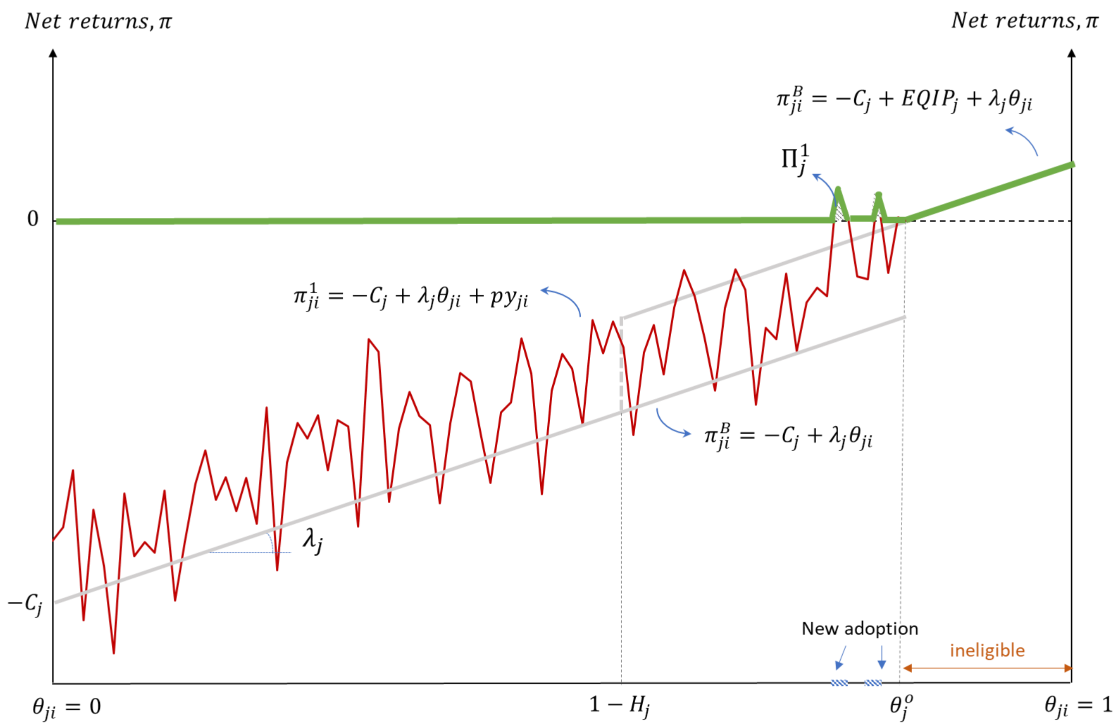


Panel a. The case of the adoption rate < HEL rate

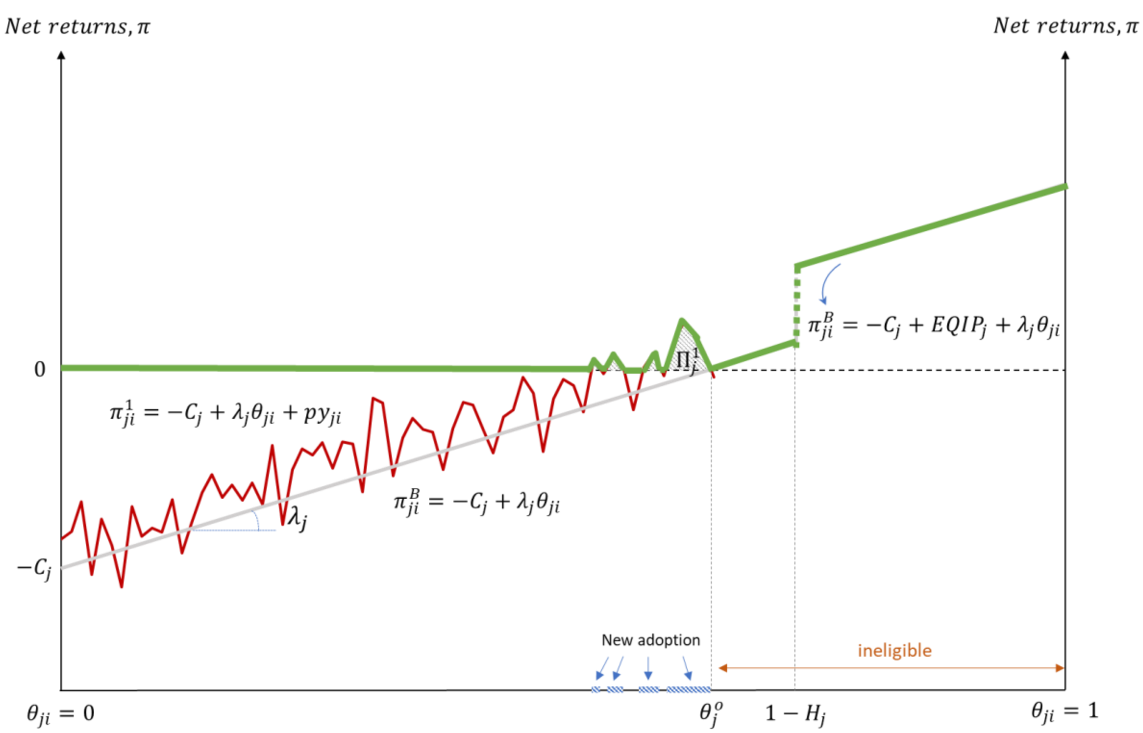


Panel b. The case of the adoption rate > HEL rate

Figure 1. Farmers' adoption decision under the baseline scenario

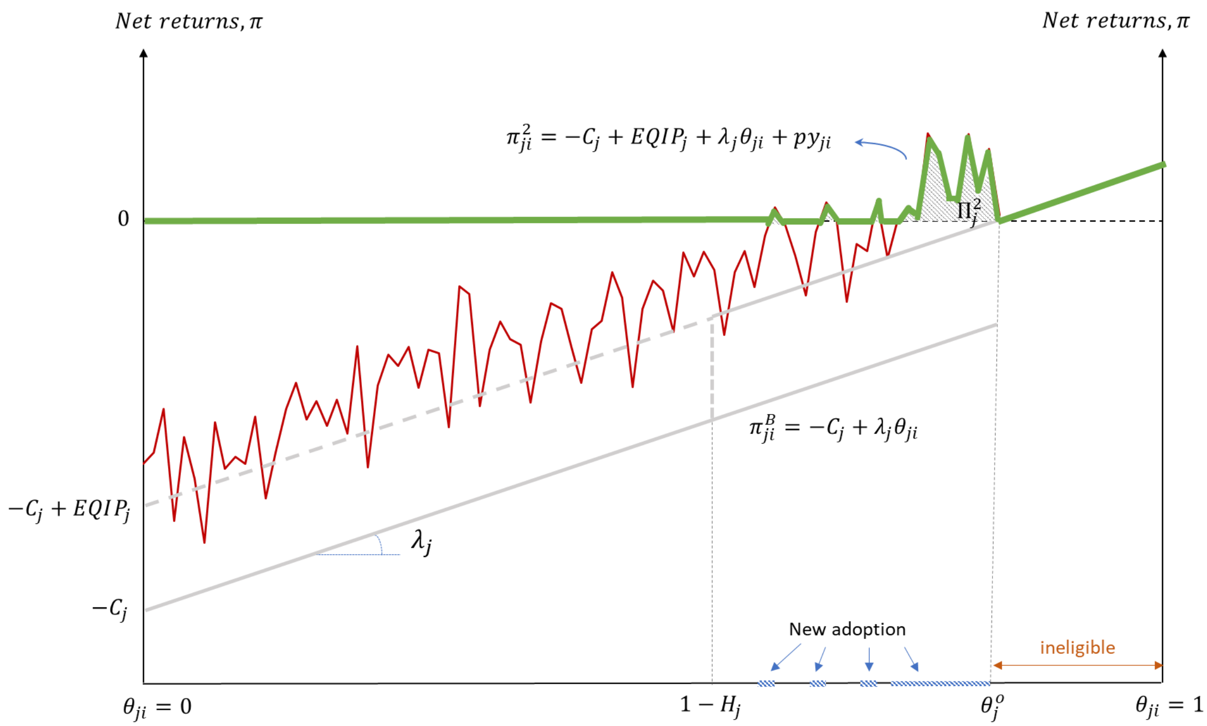


Panel a. The case of the adoption rate < HEL rate

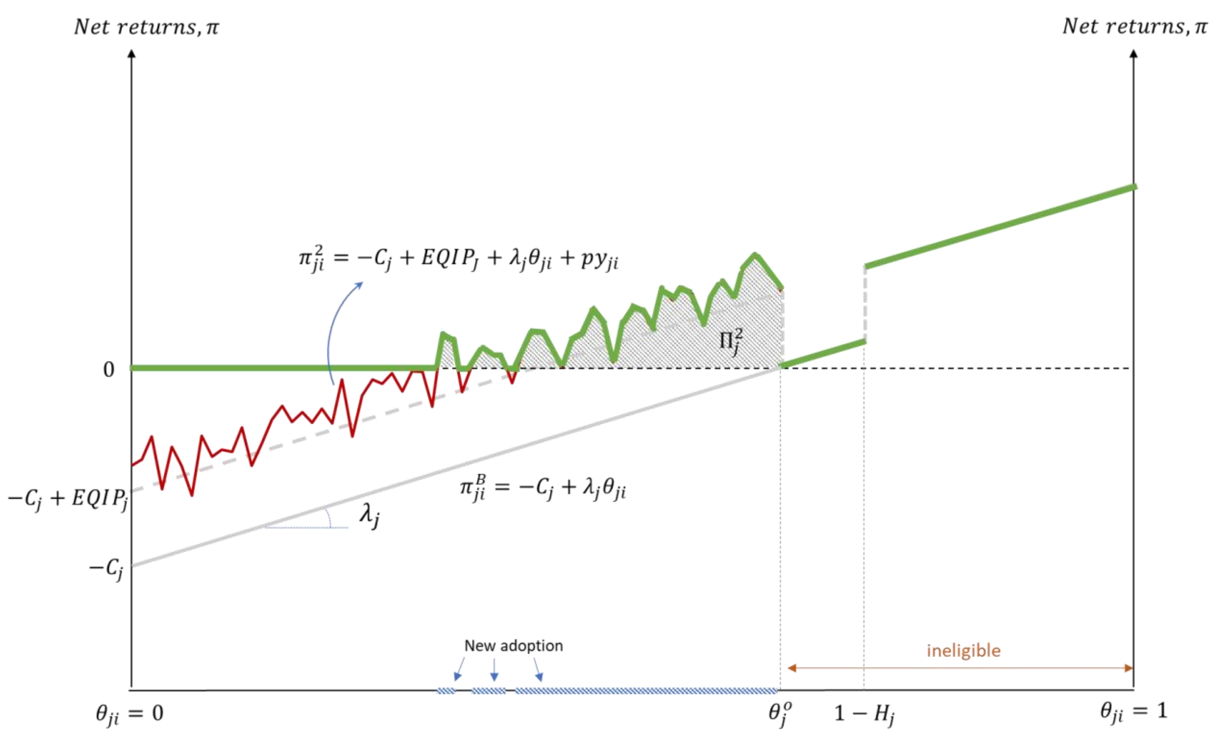


Panel b. The case of the adoption rate > HEL rate

Figure 2. Farmers' decision-making on adopting a conservation practice under scenario 1.

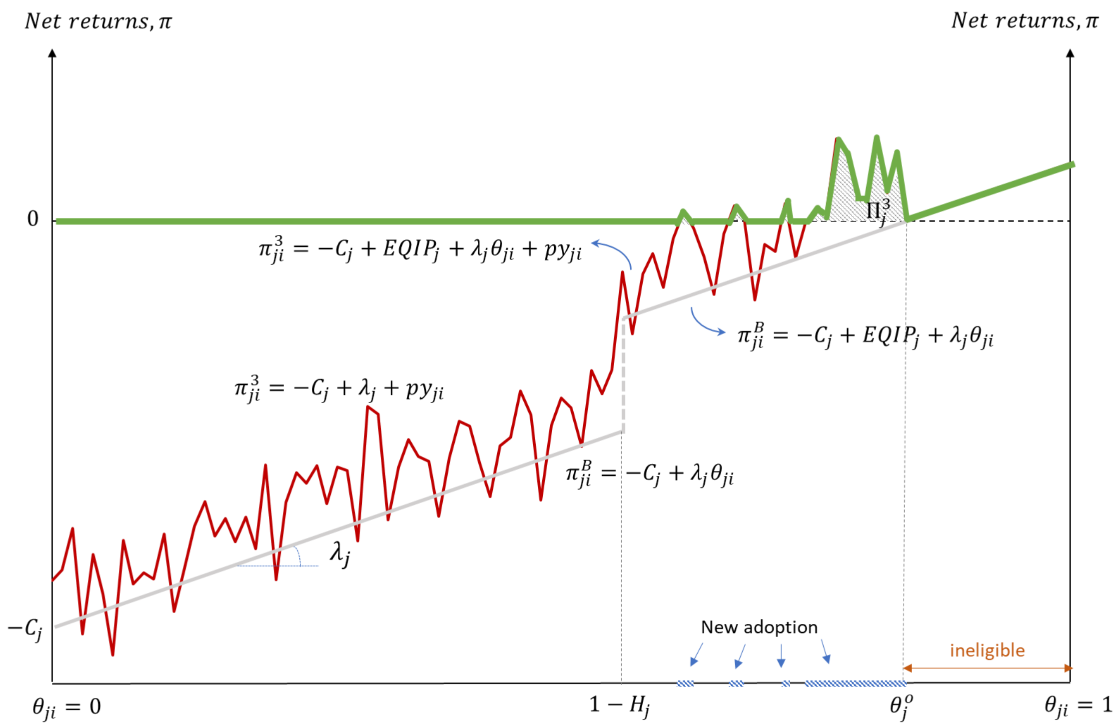


Panel a. The case of the current adoption rate < HEL rate

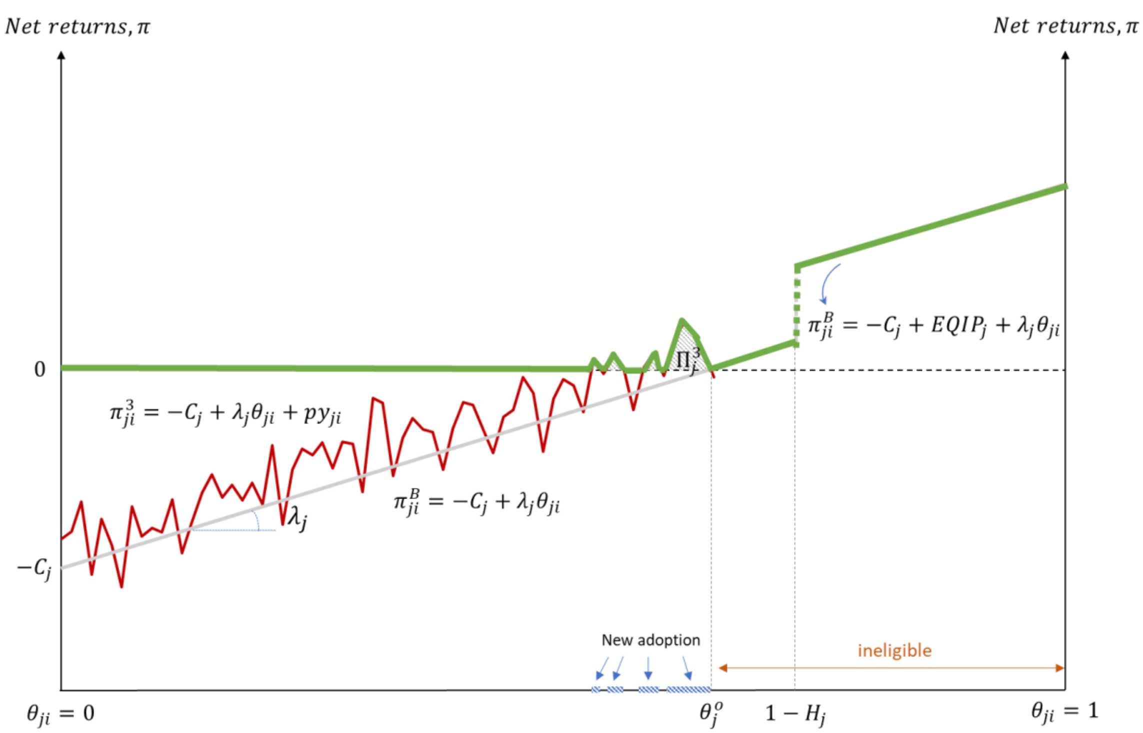


Panel b. The case of the current adoption rate > HEL rate

Figure 3. Farmers' decision-making on adopting a conservation practice under scenario 2.

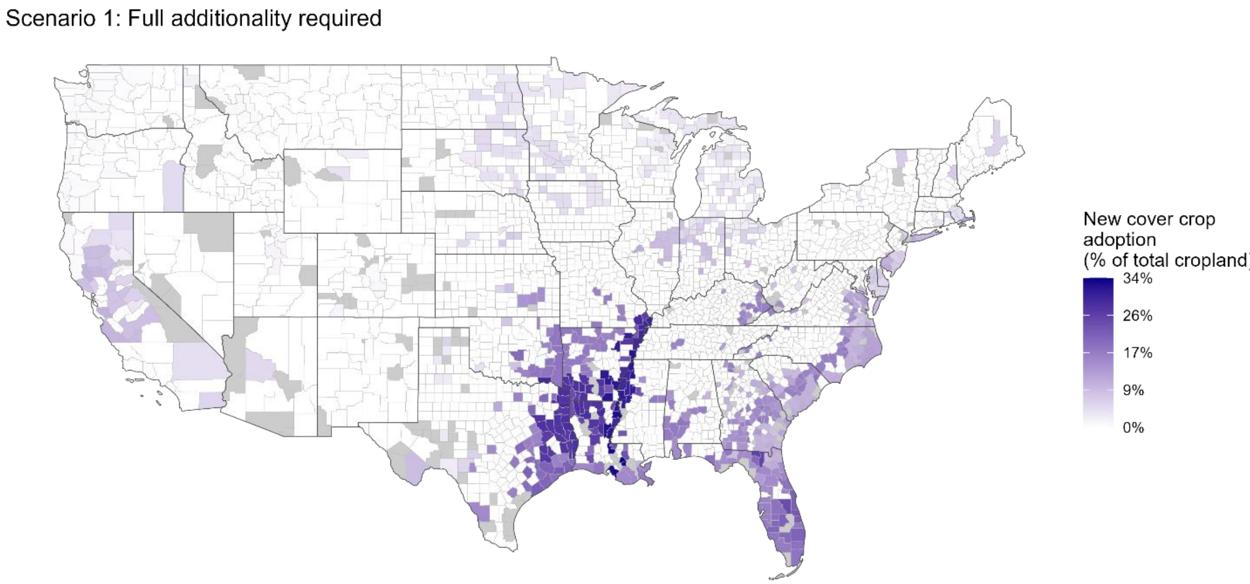


Panel a. The case of the current adoption rate < HEL rate

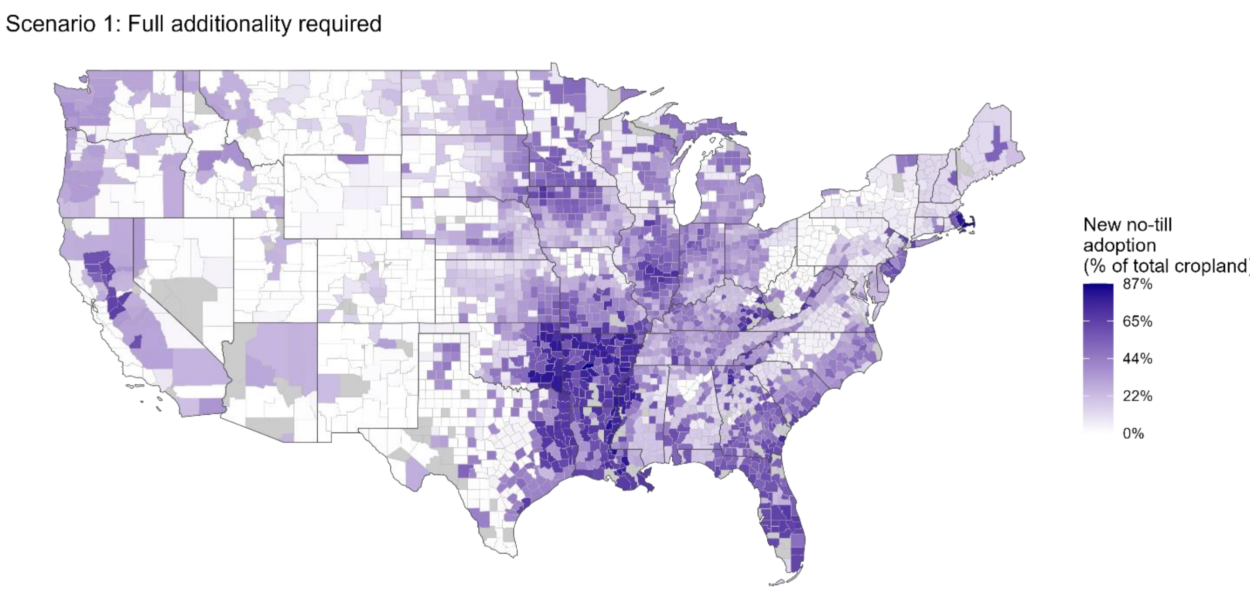


Panel b. The case of the current adoption rate > HEL rate

Figure 4. Farmers' decision-making on adopting a conservation practice under scenario 3.

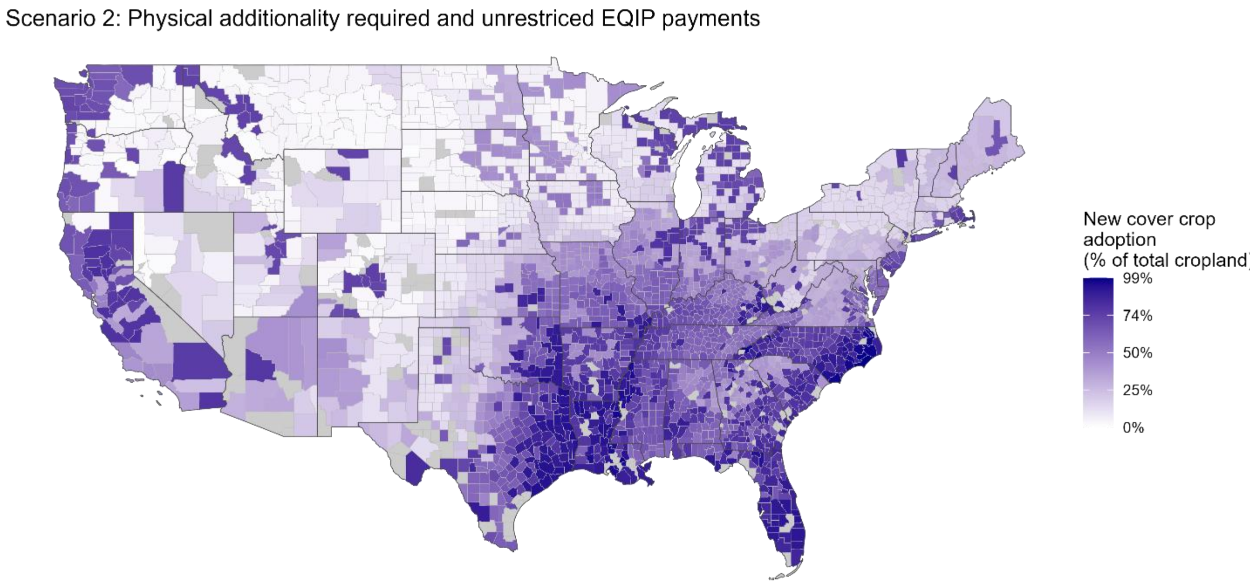


Panel a. The share of additional cover crops adoption to total cropland within the county

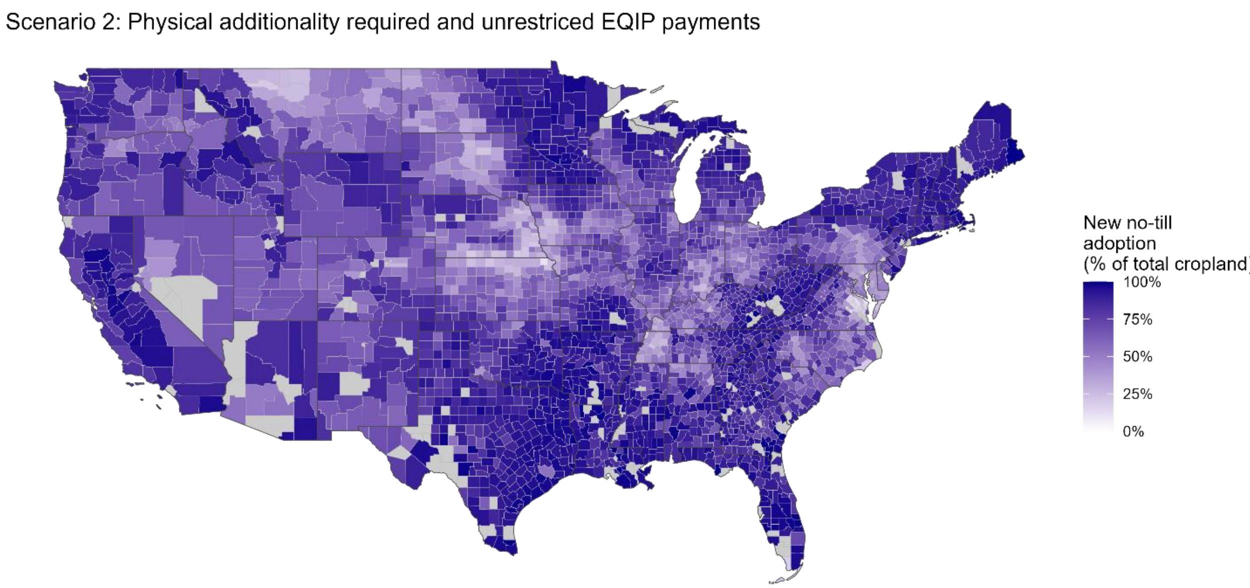


Panel b. The share of additional no-till adoption to total cropland within the county

Figure 5. The percentage of additional acres in cover crops and no-till under scenario 1.

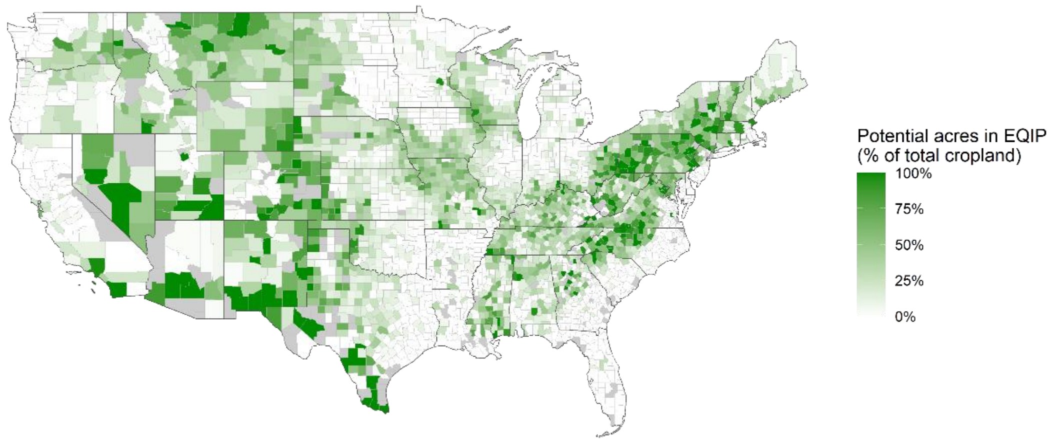


Panel a. The share of additional cover crops adoption to total cropland within the county

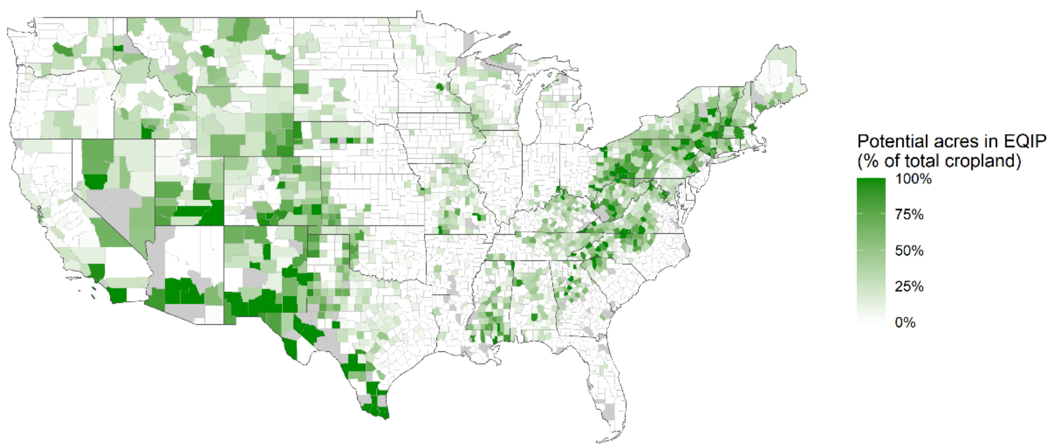


Panel b. The share of additional no-till adoption to total cropland within the county

Figure 6. The percentage of additional acres in cover crops and no-till under scenario 2.



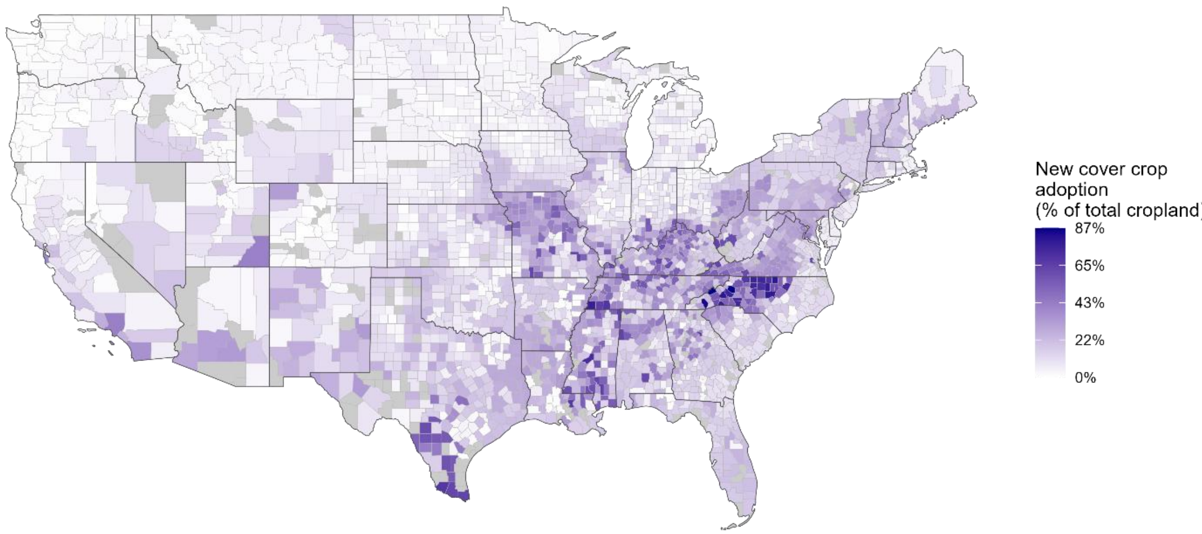
Panel a. Available additional acres in cover crops for participating in EQIP



Panel b. Available additional acres in no-till for participating in EQIP

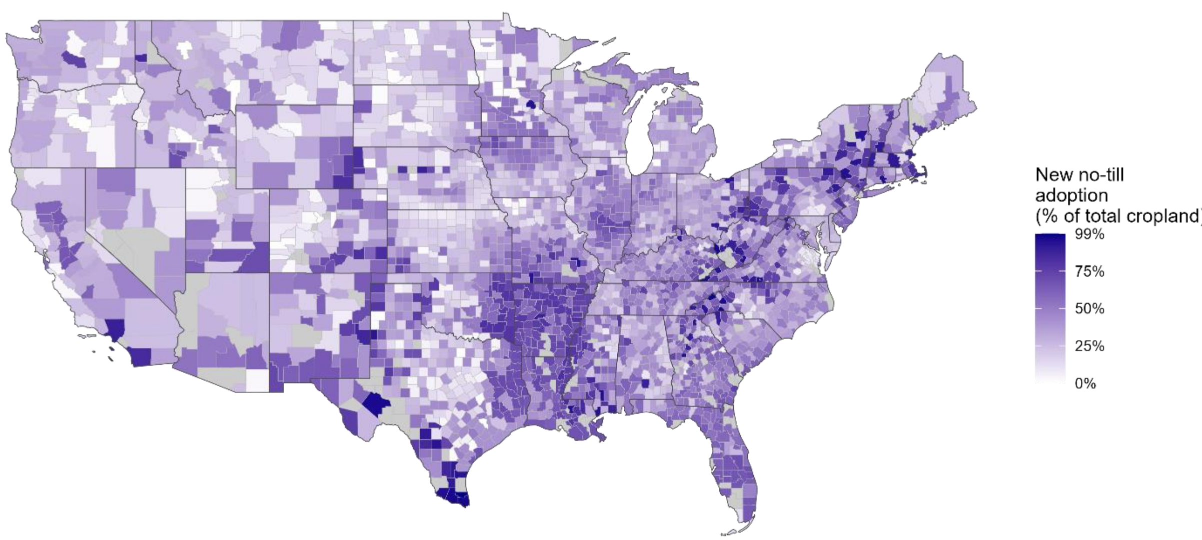
Figure 7. The percentage of acres available for EQIP to total cropland at the county level.

Scenario 3: Physical additionality required and HEL-limited EQIP payments



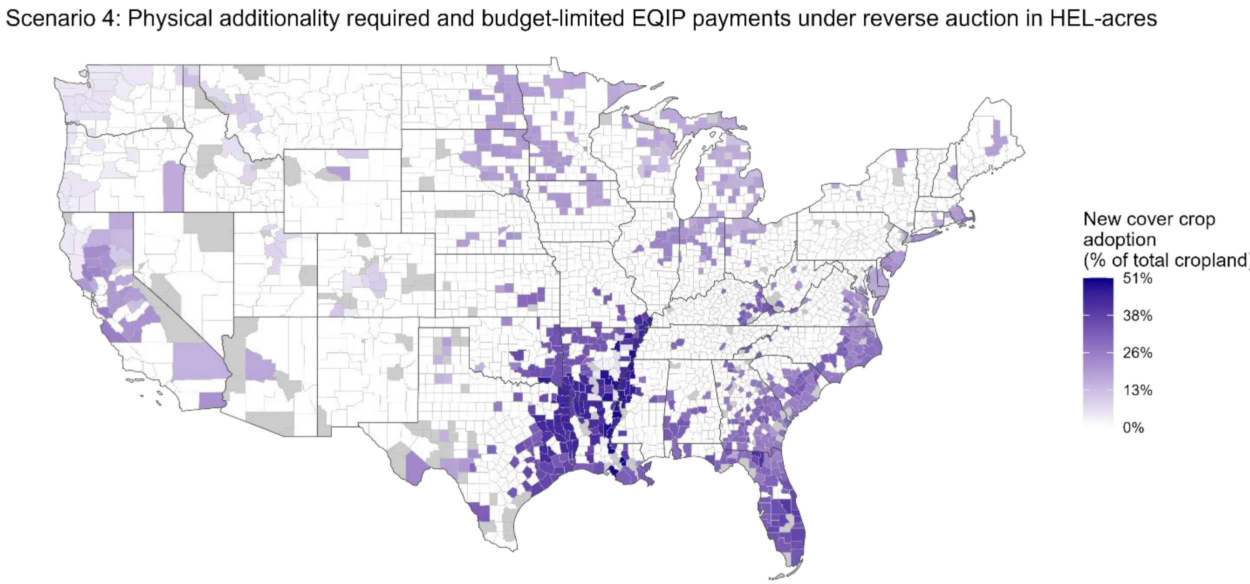
Panel a. The share of additional cover crops adoption to total cropland within the county

Scenario 3: Physical additionality required and HEL-limited EQIP payments

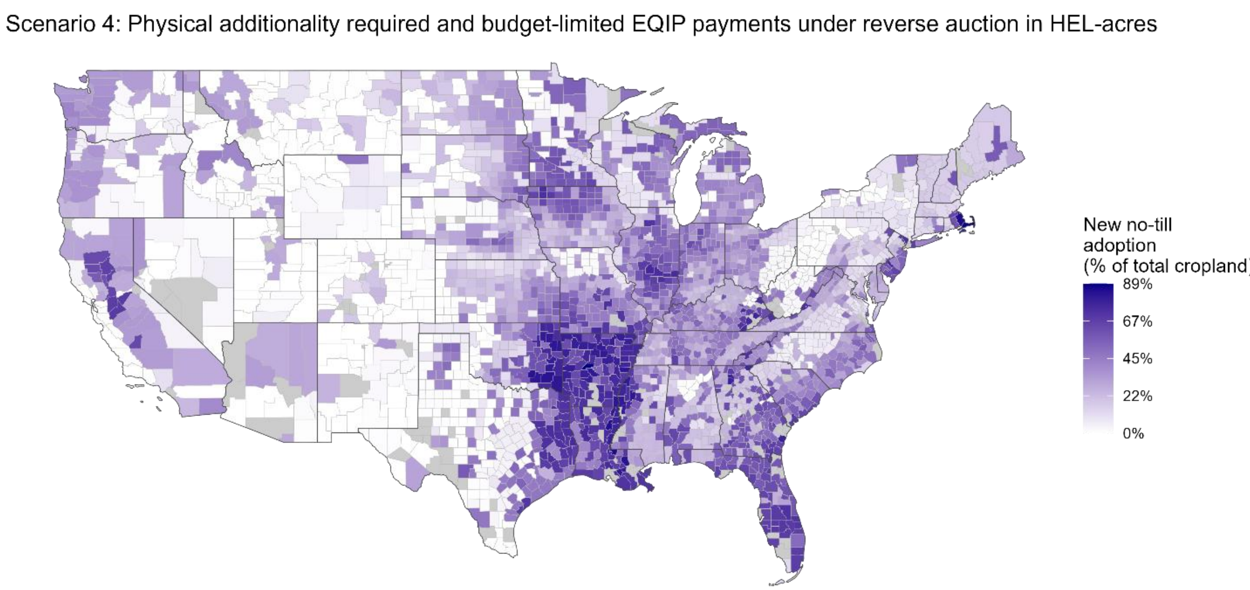


Panel b. The share of additional no-till adoption to total cropland within the county

Figure 8. The percentage of additional acres in cover crops and no-till under scenario 3.



Panel a. The share of additional cover crops adoption to total cropland within the county



Panel b. The share of additional no-till adoption to total cropland within the county

Figure 9. The percentage of additional acres in cover crops and no-till under scenario 4.