9-2021

Agricultural Carbon Markets: How Might They Work?

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September 26th, 2021

Acknowledgements

Thank you to Dr. Lilyan Fulginiti and Dr. Richard Perrin for their guidance, assistance, and mentorship on this literature review project.

Thank you to UNL's UCARE (Undergraduate Creative Activities and Research Experience) program for generously providing funding for the research.

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Introduction

<u>Climate Change</u>

Since the Earth was formed, its climate has varied drastically (Ghil 2002). Periods of warming and cooling have occurred as slow processes over millions of years, but within the last 150 years anthropogenic activity has resulted in a much faster warming than ever measured before (USGCRP 2017). Due to our reliance on fossil fuels and other carbon-intensive activities, Earth now has a "carbon budget" (Le Quere et al 2018) defined as the remaining amount of carbon dioxide our collective society can emit before a tipping point of 1.5°C warming. The lifespan of this budget is not long in comparison to the rate at which we are transitioning towards carbon neutrality, and any action we can take to extend the budget is critical to avoiding the worst effects of global climate change. Soil sequestration of organic carbon is one solution to drawing down levels of atmospheric carbon dioxide (Lal 2004) that has the potential to be greatly increased.

Soil Sequestration and the Carbon Cycle

While some industrial sectors are focused on creating mechanical methods of capturing carbon from the air, a natural method already exists: plants. The global carbon cycle is repeated every year as plants start to grow in the spring and throughout the summer and then become dormant or die in the fall and winter (Post et al 1990). In order to grow, plants perform photosynthesis to store sugars and produce energy. One of the main inputs in this process is carbon dioxide, which the plants gather from the air. As most plants grow, the carbon that was stored as sugar is used to produce biomass, making up a majority of the plant's structures. Part of the biomass of the plant will be located under the soil in the form of stems or roots (Sokol et al 2018). When the plant eventually dies, the biomass in the soil is decomposed and turned into soil organic carbon (SOC). If the soil is not disturbed, this carbon will remain in the ground for hundreds of years before re-entering the atmospheric pool.

The study of soil sequestration to mitigate climate change is based on this concept. In the United States alone, over 897 million acres (about twice the area of Alaska) of land are farmed annually (USDA-NASS 2020), but only about 140 million of these acres are enrolled in federal farm conservation programs (USDA-NASS 2017). Regenerative agricultural practices such as no-till, cover crops, crop rotation, and limited application of chemical fertilizer are often a requirement of these programs and have the result of increasing soil carbon sequestration rates. While 140 million acre is a large area (about the size of New York and California combined) there still exists potential to store more carbon in our soils.

Increasing Soil Carbon Sequestration with Economic Incentives

Besides carbon sequestration, there are many benefits to practicing regenerative agriculture, such as increased biodiversity, reduced runoff, minimized soil erosion, and improved ecosystem resilience (White 2020). There might also be costs, including potential initial costs such as the purchase of new equipment or greater time spent working (Manley et al 2005). A farmer's job includes risk assessment; they must use data and prior knowledge to make decisions for what and how much to plant, how much fertilizer to apply, how much to irrigate, etc. (Selvaraju 2012). For this reason, most farmers tend to prefer to use methods of farming that are familiar and reliable and are hesitant to switch to something new. Poor implementation of a new practice could result in a loss of income that the farmer and his or her family is counting on. Therefore, regenerative agricultural practices are often incentivized by the government to encourage farmers to adopt them. The results of these practices are a net benefit to society, so the government justifies the taxpayer expense.

Incentives do not always come from governments, however. Producers can be enticed to farm using carbon sequestering methods if they can accurately quantify and then sell the amount of carbon dioxide that has been sequestered as a carbon offset credit. In this way, the free market works to internalize a negative externality (carbon dioxide emissions) by making the externality a commodity that has value (Varadarajan 2020). Demand also must exist for the market to sustain itself. If there is great demand from consumers and businesses to offset carbon intensive activities such as flying in a plane, the price paid to farmers per ton of carbon dioxide sequestered will be higher and more producers will be likely to use sequestration techniques. Conversely, if demand is not high, prices will be low and a small number of farmers will put in the time and effort required to sequester carbon (Gale 1955).

If private enterprise can so easily provide a solution to the problem, why hasn't it? Carbon markets have existed and failed in the past, and some are still operating today. The United States' main carbon market, the Chicago Climate Exchange, failed in 2011 after collapsed demand (Sabbaghi and Sabbaghi, 2016) and other factors that will be discussed later. More recently, several private firms have begun to contract with farmers to sequester an agreed upon amount of carbon dioxide, then sell those carbon credits by the ton to consumers.

For a modern agricultural carbon market to work, we need to understand why past markets have failed and the dynamics of supply and demand for soil-sequestered carbon. This report and literature review will provide information on how current and future agricultural carbon markets can succeed and the tools necessary for fair, accurate, and effective transactions to take place in the market.

Guiding Research Questions

The work for this research began with a single question: How can an agricultural carbon market work? After doing preliminary research on the subject, five additional questions were proposed to supplement the main question. Each of the sections in this literature review will be centered around answering one of the five supplementary questions.

How can an agricultural carbon market work?

- Why have past agricultural carbon markets failed?
- What challenges do agricultural carbon markets face?
- How can an agricultural carbon market be sustained in the long term?
- Are agricultural carbon markets effective at sequestering carbon?
- Are agricultural carbon markets equitable?

Goals of this Report

Climate change is a pressing issue that requires immediate action, and a carbon market predicated on regenerative agriculture is a potentially important solution. Information related to the factors of supply, demand, verification, and measurement of an agricultural carbon market is critical to the successful and long-term function of the market. The purpose of this report is to answer the research questions outlined in greater detail below. The findings of this report will be made public and aim to serve those who want to participate in or aid the market including farmers, agricultural commodity boards, government officials, and carbon offset consumers.

What are agricultural carbon offset payment programs?

Many people have heard the term “goods” before, likely in reference to products or services in the marketplace. Not as many are familiar with the concept of an economic “bad”- the opposite of an economic good. While goods provide the consumer with utility in the form of greater satisfaction, economic bads detract from our utility and cause less satisfaction (Turvey 2000). As is well established by climate science, the release of carbon dioxide from anthropogenic activities is an economic bad (Li et al 2019). Additional carbon dioxide (a greenhouse gas) in our atmosphere causes more heat to be trapped on Earth, resulting in a myriad of negative effects for the global population (Tol 2009). Therefore, consumers who desire to lessen the effects of climate change value less atmospheric greenhouse gases. While consumers will pay to have a greater amount of goods, they will also pay to have a lesser amount of bads- think paying for a trash disposal service. The actions of a single individual are relatively insignificant, but the collective action resulting from a carbon market can potentially be enough to make a dent in the amount of carbon dioxide in our atmosphere. This concept is fundamental to the operation of carbon offset payment programs.

In a carbon market, consumers exchange money for the rights to claim a carbon offset, which is an agreed upon amount of carbon dioxide that is either not emitted where it otherwise would be or sequestered directly from the air into a non-atmospheric form (Lovell and Liverman 2010). A carbon offset is an example of a credence good, which is a good that gives the consumer satisfaction due to its qualities, even though the consumer cannot experience them. While the consumer’s life is not directly made better by the transaction, they recognize the severity of the climate crisis and gain utility from the knowledge that they are decreasing the amount of carbon dioxide emitted. The consumer’s money is transferred to a marketplace institution that facilitates transactions of carbon offsets between buyers and sellers, then passed on to the seller of the carbon offset. Many of the sellers in the carbon offset market are farmers who are actively sequestering carbon dioxide in their ground through regenerative farming practices (Giller et al 2021), and the payment they receive helps cover any costs associated with the change of farming method.

The institution that facilitates carbon offset transactions is important for two reasons. First, carbon dioxide offsets are dissimilar to the purchase of other products. The consumer does not receive a physical product as they would if they went to the store and bought something, and they also do not receive a service. Instead, they receive confirmation that a measured amount of carbon dioxide has been sequestered on their behalf (Liu et al 2015). For the confirmation to be legitimate, it must be verified. This requires accurate methods of measuring soil organic carbon (SOC), which will be discussed later in the literature review. A carbon market institution can standardize the verification and measurement methods, ensuring every carbon offset is equally valuable (Haya et al 2020).

Second, the market is more efficient when there is an entity that handles the transactions between buyers and sellers. It would be inefficient for every buyer to individually contact a seller that they were interested in purchasing carbon credits from and arrange for their own measurement and verification costs (Bessy and Chauvin 2013). Some larger farming operations might have thousands of metric tons to sell and arranging sales that might be a few tons at a time would be both time consuming and expensive for the farm operation. Conversely, the consumer might desire to purchase more metric tons at once than any one producer could provide. For example, Microsoft has purchased 1.3 million metric tons of carbon dioxide emissions offsets in 2021 through the company TruTerra (Watson 2021). As there is not an agricultural operation producing anywhere near this amount, Microsoft would have had to expend time and money procuring smaller amounts of offsets. Without the intermediary, the volume of carbon offset transactions would decrease as the transaction cost would be higher, reducing quantity demanded.

Even though the product may be unlike those in a traditional market, carbon markets are still governed by the same economic principles of supply and demand. Given consumer demand exists for offsets and agricultural producers are willing to invest in producing them, as well as an entity to facilitate transactions, the result should be a net negative amount of atmospheric carbon. But how effective are agricultural carbon offset programs?

Are agricultural carbon markets effective?

When tackling an issue as large as climate change, no one solution will solve the problem. Rather, a combination of solutions involving decreasing the amount of carbon emissions now and sequestering atmospheric carbon to extend the carbon budget will be used. Frequently touted as a cost-effective solution (Osborne 2015), the commodification of carbon dioxide has potential to offset a substantial portion of global climate emissions. However, critics say that the market simply moves money around without keeping carbon dioxide out of the air (Gilbertson 2017). This section will explore the variables that determine how much carbon dioxide agricultural carbon markets sequester.

<u>Voluntary vs Regulatory</u>

Debate among economists and scientists about the way a carbon market should (or should not) be regulated has existed since their genesis. A regulatory carbon market arises when a governing body either imposes a tax on carbon emissions or imposes limits on carbon dioxide emissions (Schillie n.d.). If the regulations allow pollution permits to be tradable, polluters who face high pollution reduction costs will buy permits from polluters who face low pollution reduction costs. Prices for the permits are established based on the buyer's willingness to pay and the seller's pollution abatement costs. Like how cryptocurrencies derive their value based on a finite amount of the currency being available, each emissions credit has value because it gives its holder the ability to emit carbon dioxide when only a set amount can be emitted (Fang et al 2017).

The opposite of a regulatory approach to market governance is a voluntary one. In a voluntary carbon market, there is no emissions cap ((Schillie n.d.), so for the buyers each credit's value comes from consumer demand and the utility it can provide. Buyers in a voluntary carbon market might be motivated by wanting to claim low-carbon or carbon-free status. The market is also largely unregulated, resulting in a possible difference in standards. This type of market can cover multiple sectors of the economy since no regulation is involved targeting specific sectors. Any carbon offset or sequestration credit (both offset and credit refer to the same thing and can be used interchangeably) can be priced and sold in the carbon marketplace, no matter the industry it came from. One benefit of this type of market structure is that there is no cap to the amount of carbon dioxide that can be sequestered (Corbera et al 2009). If supply and demand push the equilibrium quantity above where the cap would be if the market were government regulated, the voluntary market is more successful than the regulated one at sequestering carbon.

Another advantage the voluntary market has is that it fosters innovation (Guigon 2010). In response to the questionable results of the Kyoto Protocol's Clean Development Mechanism (CDM), standards in the North American voluntary market were developed to determine how much carbon was being sequestered beyond normal rates- a concept known as additionality (Michaelowa et al 2019). Also, because there is less regulation and compliance guidelines, more entities are free to enter and exit the market. Regulated markets can sometimes have the unintended effect of keeping some producers out because they lack technical or financial capital (Guigon 2010). In a voluntary agricultural carbon market, any producer is free to participate if their carbon offsets meet the standard put forth by the market for a particular offset. This effect helps keep smaller producers on the same footing as the larger corporations.

In considering the potential effectiveness of a particular offset market, it is imperative that the perspective of the farmer-suppliers be considered as well as that of the buyers. An overwhelming majority of farmers prefer a voluntary approach to carbon markets over a regulatory one (Kitchens 2020; Center for Climate and Energy Solutions 2021; Schattenberg 2021). Reasons for this include a general dislike of government constraints that limit their ability to do what they think is best for their crop. In a voluntary market, farmers choose to participate in the marketplace and make changes in the way they farm, whereas regulatory market conditions might force them to make changes they don't want to. Carbon sequestration credit producers are also concerned about the increasing amount of market power wielded by agricultural product buyers and the possibility of losing market share to large companies. Voluntary markets allow small producers to participate in the same market as the corporations, whereas if a compliance market were to be put in place they might not be able to participate due to possible economies of scale in meeting regulatory requirements.

Overall, the existing literature shows that the benefits of regulatory and voluntary carbon markets are mixed. Voluntary markets may have a credibility problem. The lesser standards for offsets produce credits that won't last as long, and the variability in verification services reduces the amount of standardization. However, there is a downside to regulatory markets as well. Basic supply and demand show the same thing: when a tax or restriction is placed on the market, price increases and quantity demanded decreases, resulting in a deadweight loss and a less efficient market (Hausman 1981). There is not enough evidence to definitively say whether one type of market structure is better than the other, so the effectiveness of a carbon market will depend heavily on other factors.

Regional vs Global

The scope of agricultural carbon markets is another determinant of their efficacy. Regional markets have the potential to be specialized and better serve producers locally, but global markets give access to remote producers and people in places where a regional carbon market does not exist (Michaelowa 2011). Due to the scale at which global markets operate, they are less likely to be regulated as well. Perhaps the most well-known global carbon market is the Kyoto Protocol's Clean Development Mechanism (CDM) that allowed the trading of carbon credits internationally and aimed to promote sustainable development in rural communities. Unfortunately, the CDM failed to deliver on most of its promises (Subbarao and Lloyd 2011) and the legitimacy of its credits was called into question.

In a 2017 research paper, NYU Professor of Environmental Studies Jessica F. Green argues that linking regional carbon markets into a larger conglomerate ultimately makes them less effective. Green's reasoning is that the more governments there are trying to regulate a carbon market, the more volatile prices can be within the market (Green 2017). She notes that if it were possible to create one central, global carbon bank the stability of the market would likely be enough to promote trade and expansion, but the difference in standards and currencies simply make the idea unattainable. Contrarily, in a 2010 research paper Fankhauser and Hepburn argue that the linking of carbon markets provides flexibility in the market, which helps to reduce compliance costs producers face. They also note that in a more traditional product market, the higher the number of buyers and sellers the greater the stability of the market (Fankhauser and Hepburn 2010) (Lanzi et al 2012). While the combining of regional markets for other products often produces favorable results, carbon credits are not like other products. As it stands right now, the existing literature is not clear on which geographic approach produces the most effective results for carbon sequestration.

Effectiveness of Agricultural Carbon Markets

When reviewing the existing literature surrounding meaningful carbon dioxide sequestration because of carbon market policies, scientists make cases for and against the practice. It is widely recognized as a cost-effective solution to the climate crisis (Boyce 2018) due to classic economic reasoning. When faced with a negative externality, consumers choose the cheapest way to internalize the externality, enabling society to efficiently allocate resources to the problem (Yin and Lawphongpanich 2006). This leads to "picking the low-hanging fruit" first and quickly decreasing atmospheric carbon dioxide in the most efficient way. In this section, the effectiveness of a carbon market depends on the market's ability to sequester the maximum amount of carbon dioxide, disregarding cost.

As discussed before, implementation of a carbon market often leads to an increase in innovation in response. The United States' cap and trade system for sulfur dioxide emissions is a fitting example of this phenomenon. According to a research paper from 2000, this program caused rapid technological innovation to occur within the first 10 years of its use (Burtraw 2000), enabling power plants to cut back on sulfur dioxide emissions even more. Data from the European Union's Emissions Trading Scheme (ETS) supports this concept further. The ETS is a compliance carbon offset market resulting from emissions caps on carbon dioxide. It involves members of the European Union in a cap-and-trade system, and many of its carbon credits come from agriculture. After the commodification of carbon dioxide in the EU, patents regarding "low carbon technologies" increased (Calel and Dechezlepretre 2016). We could expect a similar jumpstart to U.S. funding and research if American carbon markets grew to a place of prominence in our agricultural and resource economies.

Carbon markets have another advantage over other types of emissions reduction policies. Anyone is welcome to participate in a carbon market, resulting in greater equity (Stavins 2008). Carbon taxes usually regulate large industrial centers and power plants, excluding individuals to some extent (although the tax might get passed on in some capacity to the consumer). However, in a carbon market any individual is free to offset his or her personal emissions directly through the purchase of carbon credits.

Most of the critical literature on voluntary carbon markets focuses on the fact that when implemented alone, they will not sequester enough atmospheric carbon to keep Earth's warming below a tipping point of 1.5°C (Kuhns and Shaw 2018). This is true, and the fact is climate change is a global problem with many necessary solutions. An agricultural carbon market will be most effective when used in conjunction with other forms of carbon dioxide emission reduction and sequestration. Carbon taxes and cap and trade are two other useful tools which will be discussed in the next section.

Other Methods of Reducing Emissions

<u>Carbon Tax</u>

A tax on carbon is one government way of dealing with carbon emissions directly. The economic reasoning supporting a carbon tax is that carbon dioxide is a pollutant that creates a decrease in social welfare, so raising the cost of emitting a metric ton of carbon should decrease the quantity that is emitted (Metcalf 2019). If a government is considering implementing a carbon tax, they commission research to find the optimal price of the tax so that an effective amount of carbon dioxide will not be emitted when it otherwise would be. Supporters of a carbon tax argue that the tax keeps fossil fuels in the ground, which is one of the most effective ways to minimize the release of carbon in the first place (Van der Ploeg and Withagen 2014). They also say it is the most cost effective at bringing down emissions levels (Lin and Li n.d.). Proposed ideas for the revenue generated from a carbon tax include reinvesting the funds into renewable energy research, a rebate to the American taxpayer, or a combination of both.

Any solution comes with drawbacks, however. One of the main criticisms of carbon taxes is that they unfairly distribute the tax burden over income levels (Williams III et al 2015). It is considered a regressive tax because low-income persons would pay a larger fraction of their income in the tax than would higher income persons. This decreases the tax burden for an individual the higher their income level is, and some economists claim that a carbon tax would have this effect. It may also be politically difficult to implement, depending on the public's perception of what will be done with the tax revenue (Gevrek and Uyduranoglu 2015). Still, these issues are ones that can be overcome for a carbon tax to be implemented and work alongside agricultural carbon markets synergistically.

Cap and Trade

Cap and trade is frequently mentioned in conjunction with carbon markets. The term is used to refer to when a government sets a limit on the amount of a pollutant that can be released over a set time period (the "cap") and then distributes emissions permits to firms in the affected industries (Stavins 2008). Each firm can then decide to either reduce their own emissions and sell their excess permits (if any) or continue to emit at the same level and buy permits from other firms to comply with the policy. This results in efficient use of resources by industry as the cheapest methods of reducing emissions are employed first (Chen et al 2020). Proponents of a cap and trade system argue it is beneficial for this reason as well as its ability to put a hard cap on the amount of annual emissions, providing a degree of certainty (Kaufman 2016).

Critics of cap and trade claim energy producers and other carbon intensive industries are too hard hit by the policy (Curtis 2014) and the technology for low carbon operations does not exist yet. However, this first criticism seems to be directed at the EPA's Nitrous NOx Budget Trading Program and not at any carbon cap and trade program. As shown by the effect of the U.S. government putting a cap on sulfur dioxide emissions, innovation flourishes in response to efforts to curb pollution. Others argue that there exists a "rebound effect" that limits the gains in emissions cuts received by increasing efficiency due to consumer behavior (Jarke-Neuert and Perino 2020). While there may be some drawbacks economically, multiple governments have employed cap and trade programs with success (Wood 2018), and again is a tool in the overall need to lower carbon emissions.

Summary

As discussed in the introduction, global climate change is too large a problem to require just one solution. Evidence from both voluntary and regulatory carbon market performance shows that they are effective at sequestering (in the case of agriculture) and keeping carbon dioxide from being released (in the form of offsets), while the polices of a carbon tax and cap and trade help by setting emissions caps and regulating heavy carbon industries. The degree to which each is employed around the world will vary by region, but all three are valid solutions to help stop anthropogenic climate change. A report by the World Resources Institute finds that as long as these policies are well designed, most critics' claims are no longer supported by evidence (Kaufman 2016). Several voluntary carbon markets have existed in the past or still exist today, and the next section will focus on the successes and failures of each.

History of Programs That Provide Carbon Offset Payments to Farmers

The concept of a carbon market that trades offsets generated by agriculture is not a novel one. Earlier markets, such as the Chicago Climate Exchange (CCX), linked large and small scale producers and consumers to trade 680 million metric ton credits throughout the course of its operation (CCX 2010). Even before the CCX was the Kyoto Protocol's Clean Development Mechanism, which aimed to encourage investment from "developed" countries into emissions offset projects in "developing" ones. Later, the European Emissions Trading System was founded and still trades credits today. What were the successes and failures that led these markets to where they are now?

The Chicago Climate Exchange

The most prominent American carbon market, the Chicago Climate Exchange, began trading in 2003 as a voluntary market for six different greenhouse gases (Clark 2005). CCX sought large businesses and governing entities as consumers and garnered carbon offsets from agricultural producers, mainly the forestry sector (Streck et al 2009). Members could then purchase CCX offsets to comply with the commitments they had made to CCX, described below.

There were two initial phases to the CCX. In phase I, members of the Chicago Climate Exchange made a legally binding commitment to decrease their emissions by 1% every year between 2003 and 2006 (Clark 2005). Each member's baseline emissions were calculated by taking the average of the respective entity's emissions between 1998 and 2001, and the changes in emissions levels were found by comparing current emissions output (minus credits) against the baseline emissions number. Phase II occurred from 2006 through 2010 and required members to achieve emissions levels 6% below their baseline value by 2010. Members had the option of either reducing their own physical emissions (by decreasing production or upgrading to lower carbon technologies) or purchasing carbon offsets through the exchange. Carbon offsets could only be used to fulfill up to 50% of each member's reduction obligation, however. Participation in Phase I was not required to participate in Phase II, although the emissions reductions requirements remained unchanged at 6% below baseline for all Phase II members.

Offsets purchased by members were verified by an approved third-party service to maintain the integrity of the system and give the offsets their value. Objective verification is a necessary component of carbon markets; without it the market would have less price stability and fail to sequester the reported amount of pollutant (Moura Costa et al 1999). To sell offsets on the Chicago Climate Exchange, each offset producer was required to hire their own verification service from a selection of CCX approved firms for an annual verification inspection (De Pinto et al 2010). The offset market was wide in scope. As of 2007, 82 million tons of offsets were generated in just the three years prior from 9,000 farmers on 16 million acres (about the area of South Carolina) of land. Most of these projects were within the United States, but about a quarter were internationally located. To participate in the Chicago Climate Exchange, each offset producer had to prove their method of generating offsets met the requirements for additionality. Their method could not already be required by law and was required to be an "uncommon" practice within their industrial sector. Applications from offset producers were reviewed by an offsets committee within CCX to ensure their project would provide quality emissions offsets, and if approved the measured and verified amount of offsets would be sold on the CCX market.

Companies and municipalities that participated in the CCX did so voluntarily, which is partly what caused the market to eventually fail. While the commitments to reducing emissions were legally binding, supply simply outstripped demand. Up to 50% of CCX offsets could be used to satisfy the emissions reduction targets, but as of 2007 only 15% of reductions achieved under the CCX program came from offsets. Members joined for the opportunity to advertise their "green" stewardship to consumers or out of a sense of social responsibility, but no laws existed requiring heavy polluters to account for their carbon emissions. It appears that when the fiscal crisis of 2008 hit, companies simply lost interest in their own carbon footprint and instead redirected their efforts towards keeping their stock price from plummeting. After Phase II ended in 2010, the Chicago Climate Exchange was no longer trading emissions credits (Spaargaren and Mol 2013) due to lack of demand.

The Kyoto Protocol's Clean Development Mechanism

Created as a piece of the Kyoto Protocol in 1997, the Clean Development Mechanism (CDM) was an offset tool that could be used to meet the carbon emission limits set on each participating country (Barrett 1998). Pioneering the field of carbon offset markets, the CDM faced many challenges over the course of its operation. Its main component involved the funding of emissions reductions projects in lower-income countries by higher-income countries so that the higher income-countries could claim the carbon offsets produced by the project. The market was advertised as a solution to climate change as well as economic stimulus for lower-income countries and thus attracted many supporters (Gillenwater and Seres 2011). A key feature was the flexibility of the mechanism- it allowed countries time to develop and implement low-carbon technologies while funding carbon emissions reductions in lower cost regions of the world (Grubb et al 2010).

Additionality was a major challenge for the Clean Development Mechanism. The scientists behind the CDM worked at creating an extensive set of guidelines and rules to determine if proposed projects would have occurred without the influence of the CDM (Greiner and Michaelowa 2003), and thus they knew that to be effective the mechanism had to be reliable and trustworthy. An Executive Board issued the final decision after discussion about a project, and once approved the offset could be sold in the marketplace. Verification costs also proved to be greater than expected, leading to high transaction costs in the market (Joshi 2012).

The CDM hits its peak in 2008 after being linked with the EU's Emissions Trading System which created a broader marketplace and encouraged participation (Michaelowa et al 2019). However, this occurred at the same time as the global fiscal crisis, leading to the same outcome as the Chicago Climate Exchange. By linking the CDM and ETS, there was simply an oversupply of credits at a time when demand was dropping. The price of a credit subsequently decreased as well (Green 2017) to the point where the market was not a worthwhile endeavor for producers. Today, the CDM still maintains active sequestration projects but does not have anywhere near the level of activity it contained thirteen years ago.

<u>The European Union's Emissions Trading System</u>

In response to new commitments set by the European Union on the amount of carbon dioxide emitted annually, the Emissions Trading System (ETS) was developed (European Commission 2021). Instead of relying on individuals' voluntary inclinations to purchase carbon offsets like the Chicago Climate Exchange, the system set a cap on the amount of emissions to ensure its targets were met. The cap was to be decreased every year, eventually drawing emissions down to a more sustainable number. This cap and trade method is touted as economically efficient because it will result in the least-costly emissions reductions happening first (Mandell 2008). It also allows for flexibility in the industry for polluters who may not be able to immediately reduce their carbon footprint. If the technology is not readily available but could be developed within a feasible amount of time, firms can choose to buy allowances from the ETS market until they can reduce their own carbon emissions.

Along with the CCX and CDM, the ETS was dramatically affected by the 2008 financial crisis. From 2008-2012, a backlog of credits piled up as extremely limited demand left prices low. However, the European Union commission overseeing the function of the ETS market produced a solution that enabled the system to survive. They introduced a measure that postponed the auctioning off of 900 million carbon credits until 2019 (European Commission 2017). Supply was artificially reduced as a result, which coincided with slowly increasing demand as the world's economies recovered. Prices began to return to pre-recession levels, and the commission was careful to maintain a sustainable balance of credits in the market so as to not force the price to be too high or too low. This solution, called the Market Stability Reserve, serves as an important lesson for carbon markets. The supply of credits in a marketplace can be reduced by temporarily banking credits to ensure prices remain high enough to incentivize production of credits by future projects (Kreibich and Hermwille 2021). Otherwise, trading will come to a halt and the market will have a tough time recovering.

Summary

The three historical carbon markets listed above offer a wealth of information for us to learn from. A multitude of literature has been written discussing aspects of each market, and the modern markets are remarkably similar in some ways. The ETS is notably the only market out of these three that is still trading a high volume of credits today, due to their Market Stability Reserve action. While a similar policy could not be enacted in a voluntary market due to the absence of a single governing body, the individual private marketplaces could adopt policies that restrict the number of new credits if supply within that marketplace gets too high. This would help to ensure that voluntary carbon markets of the present are sustainable in the long term.

Status of Current Programs and Proposals for Carbon Offset Payments to Farmers

Nori

Founded in the fall of 2017, Nori began as a business plan entry in the "ConsenSys Blockchain for Social Impact Hackathon" (Nori 2021). After winning the competition, the business plan was turned into a real company and has been growing quickly. Nori's goal is to enlist agricultural producers to supply carbon offsets through change of practices, then sell those offsets on their own voluntary carbon market (Thompson et al 2021). One crucial aspect of running a successful carbon offset market is having well defined methodology: policies and specific verification methods that are standardized across all suppliers so that each carbon offset credit has equal value. Nori provides this information with their "Croplands Methodology" document, which explains the eligibility of crop types, additionality, length of the project, and the lifecycle of one of their offset credits.

Nori's carbon offsets are called "Nori Removal Tonnes" (NRT) and are equivalent to one metric ton of carbon removed from the atmosphere. Currently, Nori bases their offsets on the standard of how likely the carbon is to stay in the ground for at least 10 years (Nori 2020). When an NRT is sold, Nori assigns it a score reflecting the likelihood of the carbon meeting this longevity standard. The supplier of the NRT is then paid accordingly. By using a scoring system for longevity, the marketplace innately encourages suppliers to use quality carbon sequestration practices and continue carbon storage into the future.

Similar to the cryptocurrency market, Nori uses blockchain technology to keep track of and verify transactions made in their marketplace (Donnelly 2020). Each NRT produced by one of their suppliers is turned into a token which enables it to be tracked via blockchain (Chen 2018). Consumers of Nori's credits can instantly and securely purchase and receive NRTs, removing costly and time-consuming human-based security actions (Woo et al 2020). Currently each NRT is sold for $15 plus a 15% transaction fee for Nori's marketplace services, and the supplier of the NRT receives the full $15 purchase price. Once an NRT token is sold, it is immediately retired from the marketplace and cannot be sold further (Nori 2020). These combined practices ensure proper carbon accounting for credits sold by Nori and bar any double counting of offsets.

Indigo Ag

Indigo Ag is a more recent participant in the carbon offsets industry. They began seeking out farmers in early 2021 to provide carbon sequestration credits by practicing regenerative agriculture (Spratt et al 2021). The company's approach is centered around the farmer. Indigo works with farmers to determine the amount of land enrolled in the program, then it is up to the farmer to make changes in the way they farm and send that data to Indigo. The farmer continues to collect and send data to Indigo over the course of the year, and Indigo takes a physical soil sample from selected acres (Indigo 2021). After receiving a farmer's annual data and the results of the soil samples, Indigo calculates the amount of carbon dioxide that has been sequestered and sends the number to Verra, an independent verification firm. They verify the amount of carbon sequestered with their Verified Carbon Standard (VCS) (Verra 2021), and Indigo is then free to market and sell the carbon credits. Once the credits sell, the producer receives payment for their sequestration efforts.

For agricultural producers who register acres with Indigo right now, a potential credit price of $15 per ton is advertised. Indigo notes that as the market expands, this price is subject to change in response to supply and demand. Several large companies have signed contracts with Indigo already, promising to purchase carbon offsets at a price of $20 per ton (Indigo 2021). The difference between the consumer purchase price and the payment the producer receives goes towards verification of the credits and the upkeep of the marketplace. By aggregating carbon credits to be sold to consumers on the voluntary market, transaction costs between parties are minimized (Wang et al 2021) and theoretically more credits should be exchanged as a result.

The Indigo Carbon market program was created after the company's 2019 Terraton Initiative (Keenor et al 2021), a challenge to sequester one trillion tons of carbon dioxide in the world's soils and improve soil and atmospheric health as a result. Indigo encouraged individuals and teams to innovate and improve on existing technology for sequestration and verification of soil organic carbon, with rewards for the best ideas (UBC 2019). This is just one example of how the need for voluntary carbon markets sparks technological advancement and can result in more carbon dioxide sequestered.

Truterra

A third prominent U.S. voluntary carbon market is Truterra's TruCarbon program. Truterra is farmer-owned and operates Land O'Lakes' sustainability program, currently making TruCarbon the only farmer owned voluntary carbon market available (Boland et al 2020). Its process of generating carbon credits is very similar to those of Nori and Indigo Ag. First, the farmer registers acres with the TruCarbon program and implements one or more change of practices. Throughout the growing and harvesting season, data is collected and sent to Truterra and stratified soil samples are taken and tested after harvest. The stratified soil testing process divides soils into zones that are likely to have similar changes in SOC, and Truterra employs this method to save costs. Using the aggregated data and results from the soil sample tests, Truterra determines additionality and verifies the appropriate amount of carbon sequestered. After verification, the carbon credits go through certification against market standards then can be sold to buyers in the marketplace. Even after the credits are sold, the farmer must continue to provide information on how they are keeping up practices that retain the carbon in the soil (Truterra 2021).

A notable aspect of the TruCarbon program is the willingness to accept carbon sequestration that occurred up to five years ago (Thompson et al 2021). This "look back" policy is different from other modern voluntary carbon markets. Most programs require the registration of acres first, then implementation of the change of practice that satisfies additionality, but Trucarbon is unique in this way. However, as the carbon offset market continues to develop, the focus on higher quality credits that have proven additionality will likely be increased.

As a company that already conducts agricultural business outside of the voluntary carbon markets, Truterra has a valuable resource at its disposal. Data sharing and management are considered to be critical to the success of voluntary carbon markets (Amelung et al 2020). When producers can efficiently organize and send management data to the market aggregator, the quality and therefore marketability of the credits will be higher. Truterra has developed an "insights engine" to streamline the process of reporting additionality and continued stewardship practices. Some commercial bulk purchasers of carbon credits will find value in this additional layer of data when they can market their offsets as being maintained in the soil and have the data to support this claim (Cerri et al 2021).

Challenges Facing Modern Voluntary Carbon Markets

Supply and Demand

One of the main reasons the Chicago Climate Exchange failed is the lack of demand and overabundant supply. The fiscal crisis of 2008 shifted the world's focus from fixing the future to fixing the present, and demand ultimately dried up when companies were forced into survival mode. On the opposite end of the spectrum, between the Clean Development Mechanism, the Emissions Trading System, and the Chicago Climate Exchange there were simply too many sequestration projects verified and producing credits. This led to a large supply of credits with limited buyers (DiPerna 2018).

To maintain a balanced supply of carbon credits that meets demand, firms that are trying to create a carbon market should carefully research the economics of the industry and only register a predetermined number of acres. This will ensure that the price of their carbon offset certificates remains high enough to incentivize the production of more credits and provide producers with fair compensation. Legislation, such as the Growing Climate Solutions Act, focuses on issues surrounding a fair price for farmers to receive for credits and was passed in June of 2021 (US Senate Committee on Agriculture, Nutrition, and Forestry 2021).

As far as demand goes, much has happened in the eleven years since the end of the CCX. Climate education is now a fundamental part of the scientific curriculum in many school districts around the country (Schreiner et al 2008). Youth movements have begun to affect mainstream politics (O'Brien et al 2018), and the business world is finally seeing the problem for what it is and the opportunities that come with it (Bristow 2021). While still very divided on the issue of climate change politically, the majority of American society is concerned and desires immediate action. The purchase of millions of tons of offsets by Microsoft earlier this year speaks to how desirable the credits are, and other major US companies will soon be looking for similarly large-scale markets to purchase from. Individual consumers who are concerned about climate change will also bolster demand for credits as it has already become somewhat mainstream to offset emissions from flights and other carbon intensive activities.

Verification

Accurate verification of sequestered carbon gives the credits their value and ensures double counting does not occur. Unlike projects like REDD+, which deal with conservation of tropical ecosystems, a majority of carbon sequestration projects in the United States are agriculturally and agroforestry based. Verification standards are necessary to ensure quality offsets (Streck 2020). However, verification processes are time consuming and expensive.

Innovation is lowering the cost of verification through adaptation of technologies like blockchain and will help make verified credits more attainable (Hua et al 2020). Blockchain also improves security in the carbon market as it precisely records every transaction associated with a specific credit, preventing credits being resold and the offset being claimed multiple times. Verification services such as the Greenhouse Gas Protocol and the Verra Verified Climate Standard offer the service to markets resulting from the need for standardized verification (Gifford 2020). To pay for verification, some markets (such as Nori) charge a service fee for every credit purchased. Nori's fee is only 10%, and since it is charged on top of the credit price the producer still receives full compensation for any extra costs. This type of policy incentivizes farmers to produce credits for a marketplace that covers verification costs and standardizes the credits sold in the marketplace.

Data Utilization

Each marketplace is different when it comes to data privacy. As there is no tangible physical product being exchanged during carbon sequestration, data sharing is key to creating and verifying the carbon credits (Amelung et al 2020). Market firms need to know how long the carbon has been in the soil, the density of carbon in the soil before and after the change of practice, and current management practices on the acres involved. Markets will have different requirements about data sharing regarding the type, frequency, and availability of the data, so farmers who are considering participating in the market should examine all aspects of the agreement made with the marketplace about data ownership (Brooks 2021).

Longevity of Offsets

To be effective in reducing carbon dioxide levels and preventing the worst effects of climate change, some degree of permanence must be established for the carbon sequestration credits in a marketplace. Agricultural carbon sequestration is unique in that the carbon that has been sequestered can be released again due to improper management. For example, a farmer could change from conventional till to no till and sell carbon credits for his or her land. However, if the land is then sold, or a lease expires, and a new operator manages that ground now they might not continue the same sequestration practices. Re-tilling of the ground would release most of the carbon from the previously sequestered offsets (McLauchlan 2006) and result in invalidation of the credits that had already been sold. For operators of family farms and land that has been held for generations, this will not pose much of an issue but 54% of cropland is rented land in the United States (USDA-ERS and USDA-NASS 2014). If a farmer who rents wants to participate in a carbon market, an agreement will have to be reached with the landlord about the longevity of the offsets. This might entail prevention of certain tillage practices on the land for a specified length of time.

Review of Literature Describing and Evaluating Voluntary Agricultural Carbon Markets

When researching the subject of voluntary agricultural carbon markets, extensive popular and scientific literature is available. However, there are major differences between the relevancy and helpfulness of the information in each category. The existing scientific literature covers most of the aspects of historical carbon markets (the Clean Development Mechanism, Chicago Climate Exchange, and Emissions Trading System) but contains very little information on modern markets. Nori, Indigo Ag, Truterra, and other newer markets have started their programs all within the last year or two (with some yet to begin) so there has not been a lot of time for research on these markets to occur. Additionally, it will be several years before data regarding price and volume of credits traded has built up and can be studied empirically for trends. However, the research that has been done on the CDM, CCX, and ETS is extensive and useful for studying how voluntary carbon markets can succeed. Scientists have studied and written about the factors that caused each market to succeed and fail, and these publications are of immense value to anyone looking to learn from the mistakes and triumphs of these past markets.

On the other side, popular literature has become increasingly engrossed with the subject of agricultural carbon credits since the beginning of 2021. The change of Presidential administration spurred this interest as the Biden administration is determined to find economical solutions to climate change. They have tasked the US Department of Agriculture with implementing a way for farmers to achieve net-zero greenhouse gas emissions from agricultural operations, and USDA is reported to be looking into the idea of a carbon bank to assist farmers and the voluntary markets. However, many of the popular articles about the rise of voluntary markets and how American agriculture can play a part are written with considerable skepticism towards the idea. The shutdown of the Chicago Climate Exchange in 2010 is still fresh in the agriculture industry's mind, and they understandably do not want to waste effort on a repeat market that might end the same way. The industry is also resistant to government intervention, so the idea of a federally run carbon bank is unappealing to some.

These perceptions are important to understanding agricultural carbon sequestration as popular articles written by agricultural publications are one of the main sources of information for ag producers. Public university extension services have also been providing information online about signing carbon credit production contracts with market firms, which is a vital source in the absence of scientific literature.

Popular Literature

Common Themes

Questions about measurement and verification are plentiful in popular articles written about ag carbon markets. Early adopters of carbon credit production have used a variety of methods to verify the amount sequestered, including drying soil samples in a battery powered oven before being sent to a lab (Wilcox 2021), the Verra Verified Carbon Standard (Maixner and Brasher 2020), and modeling the management practices of an operation (Schattenberg 2021). Ultimately, farmers want to know if the burden of verification is on them or the marketplace firm. If it is up to individual producers to provide verification, carbon sequestration looks a lot less appealing. Nori offers the choice of three different third-party verification services to farmers to avoid a conflict of interest (Nori 2021), whereas other market firms state they will use an independent verifier but do not specify who pays for the service.

Additionally, popular literature discusses how data will be used in modern carbon markets and what the data privacy rights of farmers are. The process of generating valid carbon credits hinges on producers submitting records on their planting schedule, management practices, and field boundaries to the market they are working with. Some firms have created proprietary software to enable farmers to efficiently report this information, but there are concerns about the accuracy of such tools undermining the credibility of carbon credits (Giles 2021). Most discussions focus on how integral data sharing is to the process, however. Because in-person verification services are expensive, the more data that can be sent over the internet the more profit there is for the farmer (Vogt 2021). To make it easier for farmers, Nori has partnered with Truterra to utilize data that has already been entered into Truterra's Insights Engine. If a producer already uses the insight engine software for farm management, Nori will look at the Truterra data at the farmer's request and provide an estimate as to how much the farmer could expect to earn from carbon sequestration (Successful Farming 2020). As the average age of American farmers is 57.5 (USDA-NASS 2017) the technology use and data imputation present a potential hurdle to overcome, so firms have a vested interest in making their reporting software as user-friendly as possible.

Another concern represented in many popular articles is the issue of voluntary versus compliance markets. As of August 2021, there is no compliance or non-voluntary market in the United States. Nori, IndigoAg, Truterra, CIBO, etcetera are all optional, voluntary, and privately run carbon markets. This issue is particularly important to the target producer demographic, American farmers (Colman et al 2021). Even the notion of regulatory markets is enough to turn off some potential carbon credit producers, so USDA and private firms working on carbon marketplaces have been careful to emphasize that the markets are completely voluntary (Morgan 2020). The agricultural industry generally favors a non-regulatory approach (Kitchens 2020), and the Biden administration appears to agree, so it does not look like the voluntary aspect of carbon offset markets will be changing anytime soon.

Because the concept of voluntary carbon markets is being utilized on a larger scale and the industry is growing rapidly, the market system can be overwhelming and complex to those who are unfamiliar with it (Rushforth et al 2021). Especially as the age of American farmers is older and many have been farming the same way for decades, rapid change to a new practice will not come easy. There are two things that can make this transition easier: accurate, easily digestible information from public university extension services and better reporting and measurement technology. University agricultural extension services can bridge the gap of information for farmers regarding voluntary carbon markets, especially regarding the concept of additionality which can be difficult to determine (Giles 2021). These services might already be familiar to farmers in their state and can act as a trusted source of reliable information. Technological innovation will also help with the problem. New measurement technologies offer faster, more effective testing than older methods, and streamlined reporting software makes reporting data take the minimal amount of time from a farmer's week (Maixner and Brasher 2020).

Topic Portrayal

Skepticism about the viability of voluntary carbon markets is prevalent throughout popular literature. The novelty of the concept and the eventual shutdown of the Chicago Climate Exchange have both contributed to farmers feeling hesitant to implement a change of practice and sell credits on a market. However, the key to convincing producers this is a worthwhile endeavor will be education and using data from the minority of farmers who have already begun selling carbon credits.

Scientific Literature

Answered Questions

Over a decade has passed since the Chicago Climate Exchange ceased carbon credit trading operations. In this time researchers have dug into the benefit to consumers (Gans and Hintermann

2013; Boulatoff et al 2013), the relationship between agricultural ecosystem services and marketability (Ribaudo et al 2010), the efficiency of informational exchange and data sharing (Sabbaghi and Sabbaghi 2016), and additionality requirements (Kollmuss et al 2008). The CCX, along with the European Union's Emissions Trading System and the Kyoto Protocol's Clean Development Mechanism have been covered extensively in the scientific literature. The information that is available is valuable to not only those who desire to run a voluntary carbon market but also potential producers in the market, consumers, banks, investors, and agricultural economists. While the Chicago Climate Exchange successfully traded hundreds of millions of credits over the course of its operation, it ultimately came to an end. More than a decade later, with the advantage of hindsight, multiple lessons (identified in the *Supply and Demand* section) can be learned from it that will provide for better markets in the future.

There also exists plenty of literature on the differences between voluntary carbon markets and other decarbonization mechanisms. An insightful paper by Jonathan D. Rubin explains how market forces automatically act to make the least cost emissions reductions first, leading to market efficiency (Rubin 1996). Scientists have also studied the relationship between cap and trade legislation and prices for carbon markets (Mizrach 2012) and the effectiveness of voluntary sequestration efforts with no government regulation (Yang 2006; Farleigh 2003). The existing literature covers the aspects of voluntary markets, cap and trade, and carbon taxes and is continuing to evolve as technology improves and policies are implemented.

Measurement of soil organic carbon (SOC) is vital to the functioning of any carbon sequestration activities, and the scientific literature that discusses accurate methods of measuring changes in SOC content is extensive. Scientists have written about the ability to measure SOC content directly (Yan et al 2011) and on a regional scale (Stevens et al 2010), and both will be used in modern carbon market systems. An article by Rattan Lal provides an in-depth look into the multiple factors that affect soil carbon content, including changes of management practices (Lal 2018). Uncertainty also exists in some methods of soil organic carbon content estimation (Ogle et al 2010), but the uncertainty can sometimes be accounted for in order to produce viable carbon credits anyway (Stockmann et al 2013). While measurement technologies and methods are continuously improving, soil carbon measurement is a subject that is pertinent to multiple fields, not just the voluntary carbon market. The literature will continue to evolve as well.

Gaps in the Literature

Few scientific articles have been published about the re-emergence of carbon markets within the past few years. Because these firms are so new, there has not been much literature written about them. Significant gaps exist around the levels of supply and demand for carbon offset credits in the present, which is pertinent information to the success of voluntary markets. Additionally, there is an aspect of competition that has not been present in historical carbon markets. Both producers and consumers of carbon offset credits have many choices on which market firm they want to sell to/buy from, which creates economic competition that has not been researched.

Modern data reporting technology is an area that is also lacking scientific literature. Most firms use similar but proprietary reporting technology, and it is of value to know how farmers use the software. Differences in ability to report information on the software are problems that would need to be addressed for the market to expand and provide all producers equal opportunity, but the potential differences cannot be dealt with if they are unknown. Also, the amount of data producers are required to report for different market firms is not public knowledge. If there were to be scientific or informative literature comparing the data requirements for each program producers would benefit from the additional information.

The final commonly overlooked issue regarding voluntary carbon markets is the equity associated with this strategy of decarbonization. In the world of carbon offsets, the term "equity" refers to ensuring groups who have been and will continue to be the most affected by climate change are supplied with resources that increase their resilience. A well-researched article titled *Carbon Pricing: Effectiveness and Equity* examines how the social cost of carbon relates to the price of carbon credits in modern markets (Boyce 2018), but other than this paper there is not much else. Equity is an important aspect of climate justice as the climate crisis affects everyone, and everyone deserves a chance to be part of the solution. Additional research on how the voluntary markets can be accessible to everyone would benefit policy makers and the firms running the trading platform by helping them make informed decisions on how best to ensure equity.

Conclusion

Voluntary carbon markets are one of many important tools we have to help reverse the consequences of the climate crisis. It is encouraging to see a resurgence of interest in the industry, although both consumers and producers require more information than is available to fully understand the benefits and potential drawbacks. Education can come from a variety of sources: popular articles, scientific literature, university extension services, etc. Every method of carbon sequestration and emissions reduction has pros and cons, and it is important to remember that these solutions can be used in concert with one another to meet emissions reductions goals. Regional differences, political atmospheres, and market systems will contribute to which methods are suitable for a specific area. But the baseline is this: consumers desire carbon dioxide sequestration credits, and agricultural producers have a way to potentially monetize their effort into producing the credits. The two groups just need to be connected.

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