Design of an Emissions Trading Market

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Abstract

The steep rise in carbon emissions has led many policymakers to attempt to implement market-based approaches to limit industrial pollution. Theoretical work in mechanism design is essential to ensure the efficacy of such approaches. This paper focuses upon a carbon emissions trading market (or cap-and-trade), a mechanism with significant promise in carbon economics. We isolate several primary problems in the field: allocation, buying, selling, and exchange. For each problem, we consider the variety of theoretical work on mechanisms to potentially solve each. Deeper understanding of the benefits and costs of these different approaches can help design a holistic, effective cap-and-trade approach to ensure a cleaner planetary future.

1 Motivation

Economists have come to a general consensus that market-based approaches more cost-effectively reduce pollution in certain sectors than command-and-control regulation. This assumes that creating prices in the market to reduce pollution can help coordinate actors' behavior. Such prices can be determined by the market (endogenously) or through tax rates on pollution (exogenously). In either scenario, every participant in the market will have an equal marginal cost to reduce pollution. Note that this cost depends upon the prices produced by the market: the optimal amount of pollution reduction occurs when its marginal benefit equals the marginal cost. Thus, if those do not accurately represent the marginal cost of pollution reduction, a market-based approach may no longer be cost-effective (Hitaj and Stocking, 2014).

Numerous market-based approaches have been proposed by academics and policymakers. For instance, the Kyoto Protocol allows for three types of mechanisms: Joint Implementation, Clean Development Mechanism, and Emissions Trading. This paper will focus on analysis of the third. This approach, also called cap and trade, strikes at the hart of this cost/benefit quandary. A central authority, usually the government, sets a limit–or *cap*–on the amount of some pollutant that can be emitted. This limit is allocated or sold by the central authority to firms through emissions permits, which represent the right to emit a specific volume of a specific pollution. Subsequently, firms trade their permits on secondary markets. Membership in the market requires that firms hold a number of permits equivalent to their emissions; the total number of permits cannot exceed the cap. Thus, if a firm needs to increase their volume of emissions, it must buy permits from those who require fewer permits in a transfer referred to as a "trade." Effectively, the buyer is paying for polluting, while the seller is rewarded through reducing emissions. This generates a price on emissions, which tells firms whether they should reduce emissions or buy allowances on the market. As both the cap and the number of allowances reduce over time, the price of greenhouse gases theoretically rises and creates a continuous incentive for firms to reduce emissions. Thus, those who can most cheaply reduce their emissions clearly benefit from doing so.

It then becomes clear that cap-and-trade's success relies upon an efficient marketplace for trading emissions allowances. Such theoretical methods have demonstrated their efficacy in similar environmental applications. For example, the Environmental Protection Agency's Acid Rain Program, legislated under the 1990 Clean Air Act Amendments, has contributed to reductions in sulfur dioxide and spawned subsequent programs in other pollution markets (Hitaj and Stocking, 2014). The European Union's Emission Trading Scheme, the biggest emissions trading scheme in the world, is a major pillar of EU climate policy and demonstrates the positive benefits of the cap-and-trade approach. It is important to note that many of its benefits slowly came to fruition because of poor initial implementation. This only highlights the critical need for appropriate market design and oversight. The inclusion of oversight is an important concern for design, as a carbon market is intimately connected to markets for other energy resources. Unless directly addressed, the potential exists to manipulate these other markets. Moreover, the government creates both demand and supply in this market: it mandates that regulated entities participate, and it determines the (limited) supply of emissions allowances.

Thus, approaches from market design are particularly apt, as the conditions of the market heavily determine its chances for success. A well-designed policy should prevent excessively high prices and extreme price volatility and should include oversight provisions to prevent market manipulation, irresponsible risk-taking, and similar common problems in the market. In this paper, we review the variety of existing proposed solutions from mechanism exchange.

2 Further Background

Before delving into the variety of specific proposed mechanisms, we will address inherent difficulties in a cap-and-trade scheme. Every such mechanism begins with the initial allocation of caps: after choosing the reduction target, allowances must be distributed across emitters. Initial allocation determines who starts with wha and thus significantly impacts subsequent trades between emitters. Currently, there are two main approaches for allocation: auctioning allowances and handing out free allowances to emitters (Arava et al 2012).

The first follows the format of a typical auction: the governing body sells permits to the highest bidders. This has several benefits. First, it furthers the market principle of polluters paying for their emissions. Second, it treats all agents the same; there are no penalties for emitters who later join the market. Third, the governor can reinvest revenue into other environmental initiatives. The major drawback is that the government's gain is the utility companies' loss: emitters do not wish to pay for previously free pollution rights, and they will likely divert the lost funding from technology to reduce emissions into more profitable efforts. This auction-based approach has been utilized in the EU ETS and the regional Greenhouse Gas Initiative, the first mandatory cap-and-trade system in North America. Though neither initiative saw all permits auctioned at first, both saw above 85 percent of allowances auctioned—a high level of success.

Uner the second approach, each firm receives free allowances. There are two major approaches used to distribute (Arava et al 2012). In the first, grandfathering, emitters receive permits based on past emissions in a certain period. This lets them continue existing operations at no added cost, but expansion typically requires buying allowances. While this is cheaper for emitters and consumers, it disadvantages those who later join the market. In the second, benchmarking, a regulator assesses each firm's operations and estimates a "benchmark" level of pollution each should emit. The firm can then buy or sell permits depending upon their actual emissions versus the regulator assessment.

Another challenge is an accurate and verifiable method to monitor emissions. At the end of a predetermined period, every agent in the market can emit at most their allowances. Monitoring emissions is primarily a technological problem, whereas enforcement an economic one. There are three primary ways to enforce this limit. First, agents who fall short of allowances can be penalized. Second, agents who have leftover allowances can bank the leftovers for future periods. Finally, agents can be permitted to lend and borrow allowances in the case of a sudden spike in demand (Arava et al 2012).

3 Carbon Economics: Problems

With this understanding of the challenges facing a cap-and-trade scheme, we now examine problems in carbon economics faced by contemporary global industries. Here, we visit the framework for carbon planning proposed by Arava et al, 2012, which models a multinational corporation attempting to optimize their carbon footprint. In short, the paper constructs a framework for the case in which a company gets a cap, distributes it over its sub-units, and subsequently utilizes intelligent algorithms to optimize trading. Although the authors assign particular features to their model, we will use this model more generally. Specifically, we focus on four important problems in each step of emissions trading that fall under the said framework. These are carbon credit allocation, carbon credit buying, carbon credit selling, and carbon credit exchange. Though explicitly identified by Arava et al, a wide variety of literature in mechanism design discusses each of these. Let us consider each in turn.

Carbon Credit Allocation (CCA): As discussed, allocating the emissions cap between agents is important; carbon emissions must be less than or equal to this cap. Allocations must thus consider the difference in costs of reduction between agents, capacity of reduction of each agent, and similar policy issues dealing with equitable, efficient initial allocation.

Carbon Credit Buying (CCB): If an agent cannot reduce carbon emissions to the level of the cap, it can buy the required carbon credits in carbon exchanges. Alternative actions can also lead to the regulatory body increasing an agent's emission cap; for example, under the Kyoto protocol, agents may also invest in a clean development mechanism (CDM) and joint implementation (JI) projects (Bagchi et al, 2012). These are broadly characterized as offsets markets, which pay firms to reduce emissions rather than raise the costs of continued emission. In particular, CDM and JI generate allowances by financing emission reduction projects in other countries—hence "offsetting" their own emissions. In the event that agents cannot fall under a mandatory threshold, we must then motivate those sectors to reduce emissions. This gives rise to an interesting problem: the company must then first optimize internally and then determine its market behavior.

Carbon Credit Selling (CCS): Agents can earn revenue through selling surplus credits to those over the cap. Companies must thus optimally invest so as to maintain a surplus and its accompanying benefits.

Carbon Credit Exchange (CCE): CCB and CCS assume that buyers and sellers are interested in monetary exchange of carbon credits. This problem considers the trade of carbon credits, giving rise to problems modeled in the stock exchange literature.

Bagchi et al (2012) provide a general model of agents in the market that lends itself to a market design approach. Agents in the market are typically independent companies or their units. They hold private information (cost of reducing emissions, capacity of reduction, etc.) and may have no incentive to truthfully report their preferences. Thus, these four carbon economics problems above can be formulated as optimization problems with incomplete information involving strategic agents. To meet the goals of the market requires a system-wide solution that satisfies certain desirable properties—for instance, truthful reporting of private information and efficient allocation. In short, principles from market and mechanism design is a naural way of modeling and solving these problems.

4 Carbon Economics: Mechanisms

Each of the four problems discussed above has varying amounts of literature, reflecting the differential theoretical work in the various stages of carbon market design. We review each in turn.

Carbon credit allocation has the largest amount of recent literature. The same paper that first identified the four subproblems of carbon economics, by Arava et al., also describes in detail the carbon credit allocation problem. Here, it is important to note a general result from microeconomic theory. The key properties that need to be satisfied in the mechanism are dominant strategy incentive compatibility, strict budget balance, and allocative efficiency. Past work has shown that no mechanism can achieve all three simultaneously (Bagchi et al, 2013). A subsequent paper by Arava et al. further explores this problem for a global company wishing to reduce its carbon footprints. This places the further constraint of multiple internal divisions, each with its own cost curve for reduction, and subsequently develops a mechanism to allocate units of emission reduction to minimize total cost. Both papers utilize an appropriate model for the allocation but assume emitting agents are honest.

The aforementioned paper by Bagchi et al, 2012, also designs a mechanism to solve the same problem with the same constraint. It builds upon Arava et al's work through proposing mechanisms for strategic agents. Specifically, they propose a strategy-proof and allocative efficient reverse auction protocol for the initial allocation. To reduce subsequent budget imbalance, they also use redistribution mechanisms. They then propose a strategy-proof, allocative efficient forward auction protocol to further reduce the budget imbalance; however, the solution is still not strongly budget balanced. Both of these utilize a greedy algorithm that uses the cost curves of each participator to compute the optimal global allocation vector. This continued imbalance inevitably leaves surplus with the manager of the market—in this case, the global company—which means that its internal divisions are making extra payments beyond reduction cost. Lakshmi et al, 2012, attempt to fix this problem through sacrificing allocative efficiency for strict budget balance while maintaining strategy-proofness. Future work in this problem must focus on finding the optimal balance between these three properties through a mechanism that can effectively minimize global cost in the market.

The relevant literature regarding *carbon credit buying* can broadly be segmented into two parts. The first deals with mechanisms to buy and sell credits within a market. Since this is the same literature base as that of carbon credit selling, we will discuss it below. The second involves mechanism design for offsets markets, such as the Clean Development Mechanism and joint implementation. Theoretical work in this field centers on the trade-off between efficiency, cost-effectiveness, and emissions reductions. Concerns arise from a fundamental asymmetry in information: the regulator does not know firms' control costs and emissions levels. Resolving this entails selecting a common baseline for those who decide to opt into alternative markets. Choosing an optimal policy brings a classic trade-off between encouraging greater participation and increasing emissions from firms that opt-in but have emissions lower than the assigned baseline. A prominent recent theoretical work in this field, from Murray et al in 2012, tests a variety of offsets instruments through an adverse selection model; they assume that due to asymmetric information, the regulator must select a common baseline for firms opting into the program. They find that maximum welfare is achievable even with asymmetric information but requires a substantial transfer of rents from the regulated sector to the unregulated sector. A second-best outcome involves adjusting the baseline after delay and can generally prevent most of the aforementioned transfers, although welfare is not maximal (Murray et al, 2012). Future work in offsets markets must continue to study this central tradeoff and determine optimal baselines.

Next, we move on to discussing *carbon credit selling* mechanisms, which facilitate the buying and selling of carbon credits between agents on a market. Most literature about market design in carbon economics only cursorily considers this problem. This is not unexpected: after all, mechanism design for credit allocation attempts to minimize subsequent sale of permits. As a result, much of the theoretical work on this problem is covered by the discussion of allocation above. In the event that there is buying and selling, the agents in the market would likely behave in an expected manner. Thus, the theoretical work regarding carbon buying and selling specifically is minimal, as it is a combination of carbon credit allocation and more general work in microeconomic theory.

Finally, we will discuss *carbon credit exchange*. Theoretical work considers minimizing the discounted sum of social costs and the possibility of decentralizing through competitive permit markets (Hasegawa and Salant, 2014). Typically, this discusses banking and borrowing of credits, as these are the actual mechanisms of exchange in the carbon market. There is a variety of work done in this field; we will consider some of the more cited work, signifying their influence. Rubin (1996) extends a model of banking to borrowing (or not) and finds the necessary conditions for market equilibrium. By obtaining the growth path of equilibrium emissions for different approaches, he concludes that banking allows for less social damages when the cap decrease over time. This also highlights the importance of flexibility over time: firms reduce emissions sooner than without banking, because they save their reduction through permits for a more constrained future. Kling and Rubin (1997) also show that this does not make banking and borrowing in combination socially optimal, because lower emissions imply higher production costs for price-taking firms. Their proposed solution is to make borrowing more expensive. Subsequent work continues down this path to better understand equilibria, pricing, and properties of exchange in the market, both with and without accounting explicitly for pollution damages (Hasegawa and Salant, 2014).

5 Conclusions

The design of matching algorithms in emissions trading represents a fascinating intersection of theory and practice. Climate change is perhaps one of the few forces that is truly existential; if unchecked, it will indelibly alter the existence of every organism on Earth. Designing an efficient carbon market thus has real, significant ramifications for the energy future of the United States and the health of our planet. I found the diversity of situations involved in effective design fascinating. Unlike other models we have considered, the considered studies do not simply consider the design at one initial phase and simulate the subsequent behavior. Rather, while some degree of simulation is involved, most of the literature focused on theoretical models of different stages in the more general process. The necessity to consider four different stages typically led an individual work to either assume a certain future approach would be used and generate an appropriate theoretical approach for its stage. Moreover, some of the papers above cover both theoretical and simulation-based studies. This shows the experimental designs and results that accompany these theoretical analyses—a fascinating basis for further exploration of the material.

In terms of the subject matter itself, I have academic interests in both public economics and microeconomic theory, so I particularly enjoyed reading the variety of papers at their intersection. Moving forward, while I definitely enjoy theory, I want to get a better grasp of simulations and other methods in experimental economics. The environment is such a pressing issues that I felt that the sheer mass of theoretical limitations in each of these works almost made their results less applicable. If all these conditions need to be met, how do we know whether these findings can even matter? I feel like understanding experimental design better will allay most such concerns. Regardless, I really enjoyed the variety of problems discussed above, and I felt that they richened my view of both environmental economics and theory. I definitely came away with a deeper appreciation of the flexibility of theoretical approaches and their ability to deal with a variety of scenarios.

6 References

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