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An intertemporal carbon emissions trading system with cap adjustment and path control

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A B S T R A C T

Cap adjustment with shocks and cost-effectiveness in cap-and-trade system has been an area of concern for regulators. By a simple two-period model of such system with banking and borrowing, we examine how emission reduction technological changes affect the cap in three cases (i.e. pure flow externality, pure stock externality and mixed externality), and identify the efficiency properties in such system with banking and borrowing. We show that the effects of technological changes on cap are negative in both pure flow and pure stock externality cases. In the mixed externality case, the effects are uncertain, which depend on the decayed rate of CO_2 stock, the discounted rate and functions of marginal abatement costs and marginal damage. In general cases, the social optimum is not attainable via the cap-and-trade system, since firms sub-optimally distribute emissions across periods. In a particular case if the ratio of marginal damage in Period 1 to the discounted marginal damage in Period 2 is exactly equal to the decayed rate, the decentralized emissions of firms will lead to the social optimum. Finally, a hybrid quantity-price policy is proposed to rectify the paths of firms to be socially desirable with an effective quantity control.

1. Introduction

Cap-and-trade system has been used for decades as a cost-effective means to control emissions, and they appear to be the primary systems to control CO_2 emissions in some areas, such as the European Union emission trading scheme (EU ETS) and the China's carbon trading pilots. However, in recent years numerous significant issues related to cap-and-trade system have emerged in practice, which have been well documented in the literature. One of these issues is how to adjust the emission cap in such system with dynamic setting (banking and borrowing). The shocks such as technological changes of emissions abatement, economic situations and energy demand variation may impact the efficiency of the existing instruments in carbon market. The EU ETS is suffering the unexpected over-supply of emission permits. This leads to further complications such as carbon price collapsing, thin trading and low incentive on investment of cleaner production. In fact, the cap setting is a key part in the cap-and-trade system. In theory, strict policies in cap stringency may push up carbon price, and thereby increase the abatement costs of firms (Jiang et al., 2016). In contrast, slack ones may lead to excessive emissions and increase the environmental damage. This study will particularly shed light on the dynamic relationship between the technological change and the cap, which will be beneficial to lay down a reasonable cap instrument such that the volatility of permits demand induced by technological change can be alleviated.

Furthermore, rather than being interested in benefits of the cap-and-trade system with dynamic setting, the regulators are more concerned with how to achieve social efficiency, namely minimizing the social costs, which consists of two conflictive targets: emissions abatement costs and environmental damage costs due to global warming. As a result, the regulators will face a trade-off between emissions abatement costs and damage costs. However, the purpose of private agents in such system is to achieve emissions abatement costs efficiency (Martins et al., 2011) without considering environmental damage, which means that the decentralized paths of private agents do not necessarily imply social efficiency. Thus, another purpose in this study is to examine how decentralized paths deviate from socially desirable one. It will be essential for the regulators to understand the efficiency properties in such

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system with banking and borrowing.

To address the over-supply of permits in the EU ETS, Market Stability Reserve (MSR) system is proposed. If the number of banked permits in carbon market is above the threshold, the number of planned permits available for the subsequent auctions will be reduced. Otherwise, more permits will be planned and added into subsequent auctions (European Union, 2015). The purpose of MSR is therefore to keep balance of the demand and supply of permits at least temporally. However, Salant (2016) argues that MSR is essentially an ex-post intervention by regulators that will create inefficiencies as the cap is achieved at high costs and deteriorates misallocations. Indeed, the carbon price was highly responsive to unanticipated administrative interventions, which is verified by Koch et al. (2016). They assess the carbon price response to 29 administrative announcements from EU ETS by the event study model, and they further argue that an automatic mechanism once for all will be better than intervention on and off. Several studies evaluate MSR efficacy and argue that it is not an ideal automatic stabilizer (Fell, 2016; Holt and Shobe, 2016). Fell (2016) uses stochastic dynamic model to evaluate the efficacy of three instruments aiming at reducing over allocation in EU ETS. These instruments include MSR, price collar, and permit reduction policies. Their simulation results show that price collar reduces over supply of permits (just as MSR does) with lower price variation and abatement costs, and both MSR and price collar perform better than permit reduction policies. Holt and Shobe (2016) run an actual human experiment and show that MSR prevents agents from maintaining their preferred level of banking price such that carbon price variation is increased. Moreover, Kollenberg and Taschini (2016) propose a novel approach in which the cap is adjusted in response to shocks, which is measured by “adjustment rate”. The cap is adjusted from pure quantity instrument to pure price instrument at the policy spectrum. For pure quantity instrument, the cap is never adjusted. For pure price instrument, the cap is perfectly adjusted in response to shocks and remains carbon price fixed. As a result, the relaxation of cap stringency makes the mechanism more responsive to supply-demand imbalance, with lower costs of firms’ adjusting strategies to shocks. The optimal adjustment rate is presented in both risk-neutrality and risk-aversion cases. Although these models have been elaborated from the perspective of carbon price stabilization and cost-effectiveness, they do not involve any analysis of environmental damage and technological changes in regulators’ problems.

The efficiency of tradable permit market in dynamic setting without environmental externality has been thoroughly investigated in framework of competitive market (Cronshaw and Kruse, 1996; Rubin, 1996; Schennach, 2000; Maeda, 2004; Newell et al., 2005; Feng and Zhao, 2006; Fell et al., 2012; Stranlund et al., 2014; Chaton et al., 2015) and market power (Hagem and Westskog, 1998, 2008; Liski and Montero, 2006, 2011; Montero, 2009). One of the important results is that the decentralized solutions generated by the dynamically competitive market can achieve emissions reduction goal at the least costs. Hagem and Westskog (1998) examine the market power in the intertemporal trading market by two-period model. They show that both banking and borrowing system and durable system incur cost inefficiency, as the former makes suboptimal abatement across firms, while the latter makes suboptimal abatement across periods. Their follow-up study (Hagem and Westskog, 2008) further demonstrates that market power results in inefficient allocation of permits across periods provided that the market allows banking but rules out borrowing. Liski and Montero (2006) extend to analyze the impacts of the spot trading, stock trading, and forward trading on market power in presence of banking. They prove that the firm with market power can credibly manipulates the spot market, while it can be alleviated in the forward trading market. If firm receives a stock allocation in a dynamic model, a large seller can extend its market power sufficiently but a large buyer has great difficulties in exercising market power (Montero, 2009; Liski and Montero, 2011).

Kling and Rubin (1997) show that the tradable permit market with banking and borrowing does not necessarily harvest efficiency in presence of pollutions externality. Because firms tend to sub-optimally discharge more in early period and less in the future in case of pure flow externality.[1] A modified banking system is therefore proposed to incentivize firms to behave in consistent with social optimum. Based on the work of Kling and Rubin (1997), Leiby and Rubin (2001) show that social optimum can be achieved by setting correct cap and specifying correct intertemporal trading ratio for firms. The optimal intertemporal trading rate equals the ratio of current marginal stock damage to the discounted value of marginal stock damage. Both studies consider an adequate discounted rate across periods to induce firms to behave as social optimum. However, a quantity policy for emissions control will be invalid as such policy may result in an unfixed cap, because it is difficult to ensure that the total amount of banking is exactly offset by that of borrowing in the intertemporal trading system.

Following Hagem and Westskog (1998), we conduct the analysis by a simple two-period model in three cases (i.e. pure flow externality, pure stock externality and mixed externality). The proposed model allows analyzing the dynamic technology effects in a simple way. The static framework (single-period) is powerless to cope with this and multi-period model will be complicated unnecessarily. The findings show that the cap decreases with technological changes in both cases of pure flow and stock externality. In the mixed externality case, the effects of technological changes on cap are uncertain, which depends on the decayed rate, discounted rate, and the slope of marginal abatement costs of firms in Period 1 and the marginal damage in two periods. A hybrid quantity-price policy is proposed for three cases and expected to motivate the emissions of firms to move to a socially desirable state with an effective quantity control. In addition, we specify an application of the proposed model by numerical analysis. Compares with the existing studies, the main contribution of our study is twofold. Firstly, our study examines how emission reduction technological changes affect optimal cap in three cases. Secondly, the socially desirable paths and firms’ decentralized paths are identified in a more general framework, and a hybrid quantity-price policy is proposed to rectify the emission paths of firms to be socially desirable.

The rest of the paper is organized as follows. Section 2 proposes a model of cap-and-trade system with banking and borrowing, which considers technological change and environmental damage in three cases. Section 3 analyses how the technological changes affects socially desirable emission across periods and optimal emission. The decentralized paths of firms in cap-and-trade system with banking and borrowing are identified and compared with social optimum in Section 4. A hybrid quantity-price policy is proposed in Section 5. Section 6 proposes a numerical analysis and the final section concludes.

2. Framework

There are N firms in the cap-and-trade system, and they discharge CO_2 in production process. $C^{ij}(e_{ij}, \mu_j)$ denotes the function of emission abatement costs of firm i in period j, where e_{ij} is CO_2 emission. The abatement costs will be quite large if CO_2 emissions are zero: $C^{ij}(0, \mu_j) = +\infty$. μ_j denotes the basic technological level of emissions reduction in period j and $\mu_j > 0$, which is homogeneous across firms but probably heterogeneous across time, since the basic technology is assumed to transfer rapidly among firms and advance potentially over

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[1] Pure flow externality means that the pre-existing pollution stock in atmosphere can be decayed completely and the environmental damage is only related to the current emissions. Pure stock externality means that the pollution stock cannot be decayed at all and the damage depends on the cumulative emissions. Mixed externality means that the pollution stock can be partially decayed and the damage depends on both the decayed stock and the current emissions.