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Modeling, analysis, and evaluation of a carbon tax policy based on the emission factor

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ABSTRACT

This paper studies a tax policy based on the emission factor, which is used as an intensity measure. Specifically, the paper models a situation where policy makers set a limit on the production emission factor of a regulated industry and require firms to pay tax if they exceed that target. The efficiency of the policy is evaluated against other existing environmental policies using a social welfare mathematical programming model. A case study is built within the context of the cement industry and is used to carry out the analysis. The results show that the intensity-based carbon tax achieves the highest consumers' surplus and production quantities and the lowest prices. The policy is found to be effective in reducing CO_2 emissions with little impact on social welfare.

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1. Introduction

In response to growing concerns about the negative impacts of GHG emissions, market-based environmental policies such as a carbon tax and a cap-and-trade system have emerged (Ramseur & Parker, 2009; Stavins, 2003). In general, the tax policy provides price stability, but the primary concern is the uncertainty of the emission level. Thus, the government is interested in estimating the tax rate that achieves the reduction target. In the literature, the proposed tax rates range from \$30/tonne of Carbon (tC) to \$400 or more (Cline, 2006; Nordhaus, 1993; Pizer, 2002). On the other hand, the cap-and-trade program can hold the emission level at a predetermined target but the cost of the program is uncertain. Given the uncertainty surrounding economic growth, setting a cap on total emissions will limit the economic developments and increase the reduction costs if the economic growth is higher than expected (Herzog, Baumert, & Pershing, 2006). Moreover, provided that the number of permits is fixed and the policy is inflexible in supplying additional allowances, the permit price is likely to fluctuate. For instance, in the European Union's Emissions Trading Scheme, carbon permit price has fluctuated from €30/tC in 2008 to €8/tC in 2009 (Ramseur & Parker, 2009).

A variation of the cap-and-trade policy that sets a limit on the emission intensity, measured in emissions per dollars or unit of output, is proposed in several countries such as Argentina, Canada, the United Kingdom, and United States to overcome some of the limitations of the absolute cap-and-trade system (Herzog et al., 2006). Throughout this paper, we use the terms intensity and emission factor interchangeably to refer to CO_2 emissions per unit produced. Arguably, the intensity-based cap-and-trade policy can accommodate future economic growth, reduce cost uncertainty, encourage the involvement of developing countries in climate change prevention, and provide incentives to improve energy efficiency and to use less carbon-intensive fuels (Herzog et al., 2006; Jotzo & Pezzey, 2007; Pizer, 2005). However, a major criticism for the policy is the uncertainty of the resulting emission level (Rivers & Jaccard, 2010).

Although one of the key drivers behind adopting the intensity cap-and-trade policy is to reduce cost uncertainty, the effect of the policy on cost uncertainty is found to be ambiguous and depends on some parameter values such as the correlation between emissions and GDP (Dudek & Golub, 2003; Marschinski & Edenhofer, 2010; Newell & Pizer, 2008; Pizer, 2005; Webster, Sue Wing, & Jakobovits, 2010). On the other hand, the carbon tax is argued to provide predictable costs and is found to be preferable to quantity instruments (e.g., cap and trade) for GHG mitigation (Jotzo & Pezzey, 2007; Newell & Pizer, 2008; Pizer, 2002; Weitzman, 1974). However, most of the work on the intensity regulations has focused on the intensity cap-and-trade policy with almost no attention paid to an intensity-based carbon tax. To utilize the advantages of the carbon tax and the intensity targets, this work models and analyzes a carbon tax scheme based on the production emission factor, which is used as an intensity measure. Specifically, we study a carbon tax scheme where policy makers set a target emission factor for a specific industry and tax firms if

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they exceed that limit. The key concept behind such a policy is to induce high emitters to reduce their emission factors while alleviating the burden on low emitters. The policy aims to provide firms with an incentive to invest in new technologies while allowing them more flexibility to comply in case of unexpectedly high internal mitigation costs.

In the existing literature, there is very little work that focuses on models that can aid decision makers in investigating the impacts of the intensity-based tax on regulated sectors or specific products. Therefore, this paper proposes a social-welfare maximizing model that can serve as a tool to evaluate the economic and environmental impacts of the intensity-based carbon tax. In particular, the paper examines the effects of different tax rates on the industry-specific emission factors, overall emissions, product price, productions, consumers' and producers' surpluses, and social welfare. Moreover, to evaluate the effectiveness of the policy, the paper compares the outcomes of the intensity-based tax policy to those of other existing environmental policies; namely, carbon tax imposed on overall emissions, cap-and-trade systems, and mandatory caps using a case study that is built within the context of the cement industry. The intensity-based tax policy is found to have several advantages over other environmental policies: (1) it provides the lowest market price and the highest consumers' surplus and production quantity; (2) effectively reduces CO_2 emissions with low impact on social welfare; and (3) it provides a stable price for carbon credits which protects firms from unexpectedly high costs. Although policies allowing for carbon trading have a slightly higher social welfare, trading might not occur due to the uncertainty surrounding the price of carbon credits. Therefore, the system will transform to just mandatory caps which have more negative impacts on the industry.

This paper is organized as follows. Section 2 briefly reviews the related literature. Section 3 presents a nonlinear programming (NLP) formulation that maximizes social welfare under a carbon tax policy based on the emission factor and describes how to modify the proposed formulation to model other environmental policies. Section 4 details a case study built within the context of the cement industry. Section 5 discusses the results of the case study and provides policy recommendations. Section 6 summarizes the key findings and suggests some directions for future research.

2. Literature review

The literature on climate change control policies is rich with work that investigates the efficiency and the design issues associated with the intensity-based cap-and trade policy as well as with carbon tax and cap-and trade policies that target overall emissions. In this section, we briefly review some of this literature, paying particular attention to the work on intensity regulations. Aldy and Stavins (2012) review the experience of developed countries in implementing some market-based environmental policies—carbon taxes, cap-and-trade, clean energy standards, emission reduction credits, and fossil fuel subsidy reduction—to reduce CO_2 emissions and highlight the associated opportunities and challenges. Aldy and Pizer (2009) discuss six key policy elements—program scope, cost containment, use of offsets, revenues and allowance allocation, addressing competitiveness concerns, and research and development—in the context of designing U.S. climate change policy. Aldy, Barrett, and Stavins (2003) use six criteria including efficiency, equity, and flexibility to review the Kyoto Protocol and thirteen alternative approaches to the climate change problem. Anderson (2008) investigate the implications of absolute cap-and-trade and carbon tax policies on CO_2 emissions, energy consumption, economic performance, and competitiveness in the context of some of the European countries experiences. Metcalf (2009) use absolute cap-and-trade and carbon tax policies to discuss policy design issues such as scope, coverage, carbon capture, price, and policy integration. Metcalf and Weisbach (2008) consider three design issues: tax rates, tax base, and international trade concerns, that are related to carbon tax policies.

The work on intensity regulations has been mostly concerned with evaluating the performance of the intensity-based cap-and-trade policy under uncertainty. Jotzo and Pezzey (2007) find that optimal intensity targets reduce cost uncertainty, achieve higher expected welfare, and perform better than absolute targets. Ellerman and Sue Wing (2003) study the effect of the absolute and the intensity cap-and-trade policies on costs and emissions when the future GDP is uncertain. The analyses show that the reduction cost is uncertain under both policies because the uncertainty in GDP translates in either uncertainty in emission intensity or total emissions depending on the used policy. Sue Wing, Ellerman, and Song (2006) find that a small GDP variance and high correlation between emissions and GDP are required in order to favour intensity caps over absolute caps, a conclusion that is shared by Quirion (2005), Newell and Pizer (2008) and Webster et al. (2010). Pizer (2005) finds that the intensity cap-and-trade policy accommodates economic growth but not the best policy to handle cost uncertainty. Fischer and Springborn (2011) show that although the intensity targets allow for economic growth when compared to the tax and the cap policies, the carbon tax has the lowest welfare cost.

Bruneau and Renzetti (2009) find that targeting emission intensity would push Canadian companies to reduce their emission intensities; however, the overall emissions will be higher than 1990 levels. Rivers and Jaccard (2010) show that the emission-intensity policy could have less impact on the international competitiveness of the regulated entities if the environmental policies of other countries are less aggressive. Kuik and Mulder (2004) demonstrate that the intensity cap would avoid the negative effects on competitiveness, but it would not reduce emissions at the lowest cost. Dudek and Golub (2003) argue that the intensity targets have no advantages over the absolute targets based on some criteria including reducing cost uncertainty, ease of implementation, and providing incentive to innovate. These results are confirmed by Marschinski and Edenhofer (2010) who used similar criteria. Li and Lin (2013) employ a general equilibrium model to evaluate the potential impacts of several variations of energy and carbon tax policies to reduce China's carbon emissions. The authors compare the results of targeting absolute and carbon intensities and conclude that there would be significant differences in the economic and environmental effects among the studied environmental policies.

As shown from the literature review, models that investigate the design and the impact of the intensity-based carbon tax policy are few in the existing literature. This paper makes four main contributions: (1) modeling and analyzing an intensity-based carbon tax policy, (2) investigating the impact of the policy on regulated sectors using a social welfare maximization model that serves as a decision-support tool to find the tax rate, (3) comparing the intensity-based carbon tax policy with environmental policies targeting total emissions (absolute): carbon tax, cap-and-trade, and mandatory cap, and policies targeting emission factors: intensity cap and trade and mandatory cap on the emission factor, and (4) constructing a case study in the context of the cement industry.

3. Problem formulation

We consider a polluting industry with N firms producing a single homogeneous product, q_i, and generating CO_2 emissions in proportion to their output levels. CO_2 emissions are primarily due to burning fossil fuels to produce energy that is required for

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