5. The Use of Quantitative Models to Assess the Impacts of Carbon Market Integration

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INTRODUCTION

FOLLOWING THE PARIS CLIMATE AGREEMENT, many nations are formulating policies to meet the emissions targets for 2030 pledged in their nationally determined contributions (NDCs), on top of existing measures to curb greenhouse gases (GHGs) in some regions. Cooperation among carbon markets through international trading of emissions rights provides scope for lowering the costs of reducing emissions. The linking of carbon markets allows emissions abatement to occur where their costs are lowest, and regions taking on additional reductions are compensated by financial transfers from high-cost regions. Mechanisms to allow international trading of emissions rights are included in several existing policies, and there is interest in including such measures in future policies.

Estimating the impacts of carbon market integration requires the application of quantitative models. Applied general equilibrium (AGE) models—also known as computable general equilibrium (CGE) models—are commonly used to provide numerical estimates of the economic and emissions outcomes of climate policies. AGE models can also estimate the impact of international trading of emissions rights between two or more nations by leveraging the (implicit) marginal abatement cost (MAC) curves embedded in these models. As AGE models have an economy-wide perspective, they are also able to evaluate the broader economic impacts of international trading of emissions permits.

China, Japan, and Korea face both a high level of complexity in evaluating the costs, benefits, and trade-offs of potential linkage and the potential for symbiotic relationships.

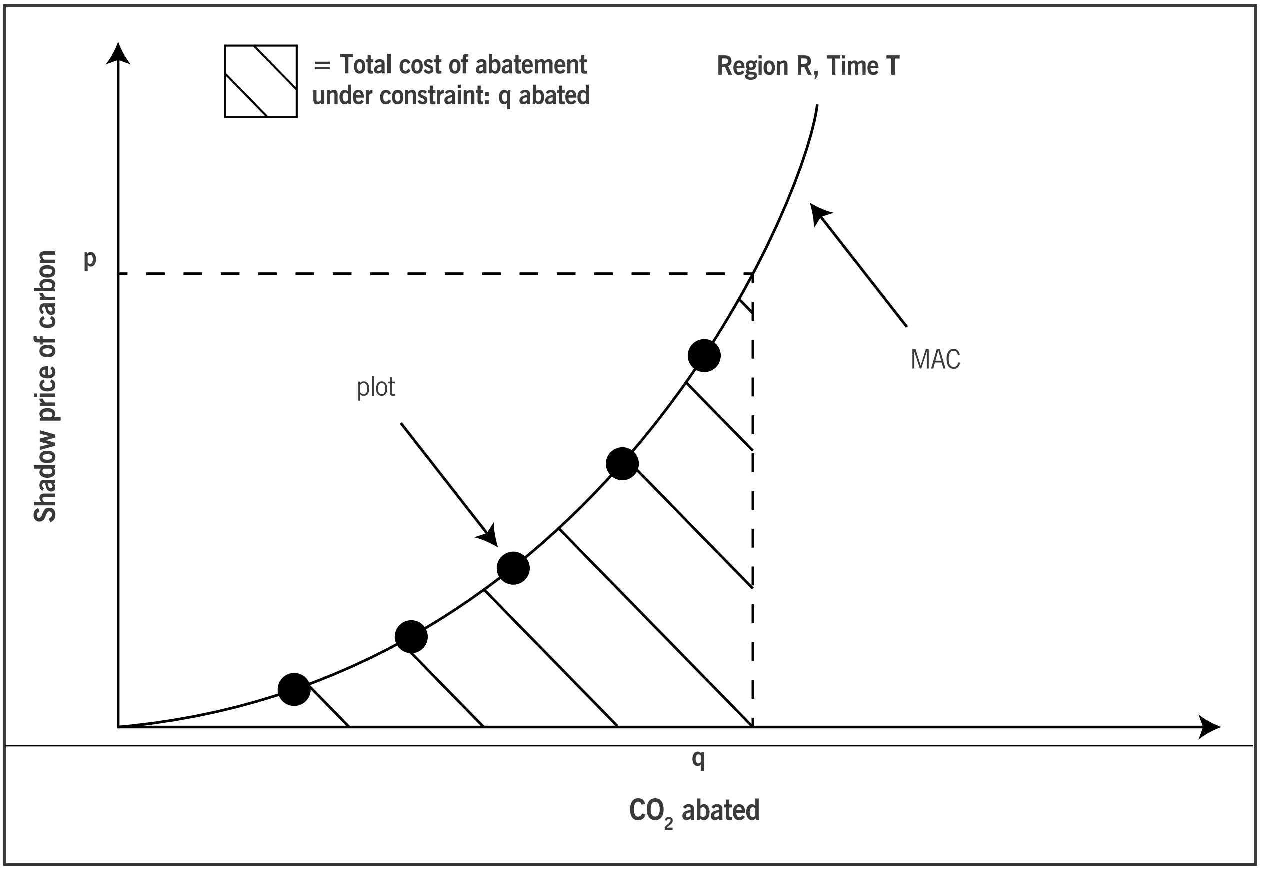
This chapter has four further sections. Section two provides an overview of MAC curves and illustrates how international trading of emissions permits can lower abatement costs. Section three provides an overview of AGE models used for climate policy analysis, outlines how marginal abatement cost curves can be derived from these models, and discusses the broader economic impacts of international permit trading that are captured by AGE models. Section four reviews selected AGE studies that estimate the impacts of international trading of emissions permits. The final section concludes.

These modeling approaches have import for any jurisdictions considering carbon market linkage, including Northeast Asia. As a region with disparate economic and political systems, climate change goals, and emissions trading system (ETS) designs (see chapters one and seven of this volume), China, Japan, and the Republic of Korea (hereafter Korea) face both a high level of complexity in evaluating the costs, benefits, and trade-offs of potential linkage and the potential for symbiotic relationships. As will be demonstrated in this chapter, AGE models oriented toward MAC curves can shed light on these cross-border considerations, including how the emission reduction policies pursued will impact wider economic and social welfare dynamics.

MARGINAL ABATEMENT COST CURVES AND INTERNATIONAL TRADING OF EMISSIONS PERMITS

Mac curves describe the potential cost of emissions reduction policies, such as a cap on carbon dioxide (CO_2) emissions. Specifically, MAC curves relate the marginal cost of abatement to the total quantity of emissions abated. Because the market first adopts lower-cost options, the total cost of abatement is the area under the MAC curve, that is, the sum of the marginal costs of each ton abated, as illustrated in Figure 5.1.

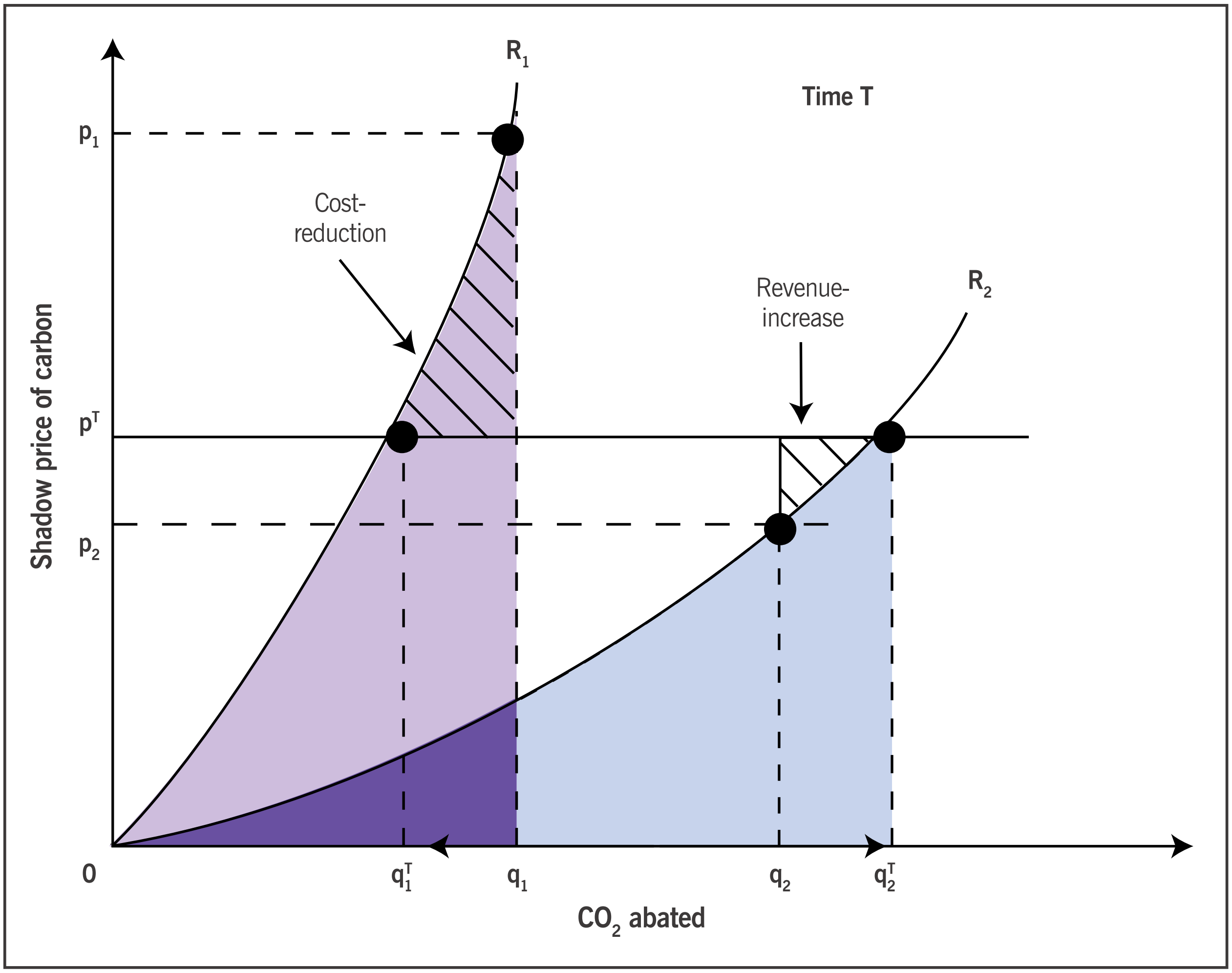
FIGURE 5.1. MARGINAL ABATEMENT COST (MAC) CURVE AND TOTAL COST OF ABATEMENT



Source: Modified from Denny Ellerman and Annelène Decaux, "Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves," *Joint Program Report Series Report 40*, 24 pp., 1998, https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Rpt40.pdf

MAC curves can also convey the potential gains from emissions permit trading among regions with different abatement costs. As an example, imagine a two-region world in which one region (Region 1) needs to reduce emissions by quantity *q1*, and the other region (Region 2) needs to reduce emissions by quantity *q2*. In addition, assume that Region 1 faces a higher cost of abatement than does Region 2, as illustrated by the two MAC curves in Figure 5.2. Without trading, Region 1 and Region 2 face marginal abatement costs of p1 and p2, respectively, with the resulting total costs shaded in blue for Region 1 and red for Region 2. However, with trading, both regions face a common trade price p^T such that $p2 < p^T < p^1$. Per the equimarginal principle, both regions will reduce their emissions until the marginal cost of reduction equals p^T, the marginal revenue of emissions permit sales. Thus, Region 2 will increase its total abated emissions to $q2^T > q2$ and will sell emissions permits at this higher trade price to Region 1. Conversely, Region 1 has

FIGURE 5.2. MARGINAL ABATEMENT COST (MAC) CURVE AND GAINS FROM TRADE



Source: Modified from Denny Ellerman and Annelène Decaux, "Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves," *Joint Program Report Series Report 40*, 24 pp., 1998, https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Rpt40.pdf an incentive to decrease its total emissions abatement to $q1^T < q1$ and shift its remaining reduction burden to Region 2 at the trade price. Consequently, compared to a world without trade, a trade price pT yielding the same aggregate emissions reduction ($q1 + q2 = q1^T + q2^T$) could create gains from trade in both regions. In this two-region example, trade gains are a cost-reduction for Region 1 and a revenue-increase for Region 2, as indicated by the striped regions in Figure 5.2.

The relationship portrayed in this hypothetical scenario is particularly relevant for Northeast Asia, where Japan, Korea, and China face different domestic abatement costs that could yield symbiotic economic efficiency gains if markets were to link (Ewing, 2016; Ewing and Shin, 2017). Japan and Korea have a relative paucity of low-cost emissions options domestically compared to China, which in turn could benefit from the revenue generation opportunities of selling permits abroad.

THE IMPACT OF EMISSIONS TRADING IN ECONOMY-WIDE MODEL

Applied General Equilibrium Models for Climate Policy Analysis

AGE models used for climate policy analysis represent economies as a series of interconnected sectors, include a detailed representation of energy production, and link production to GHG emissions. AGE models are simulation tools that combine general equilibrium theory with realistic economic data to solve numerically for the levels of supply, demand, and price that support equilibrium across all markets (Sue Wing, 2004). These models also capture interactions among regions through imports and exports. AGE models are particularly useful for evaluating how policies targeting a small number of sectors will be transmitted to other sectors and have economy-wide impacts. These models have become increasingly popular for quantitative policy analysis and are widely used to analyze climate policies—see, for example, Caron et al. (2015) and Winchester et al. (2010).

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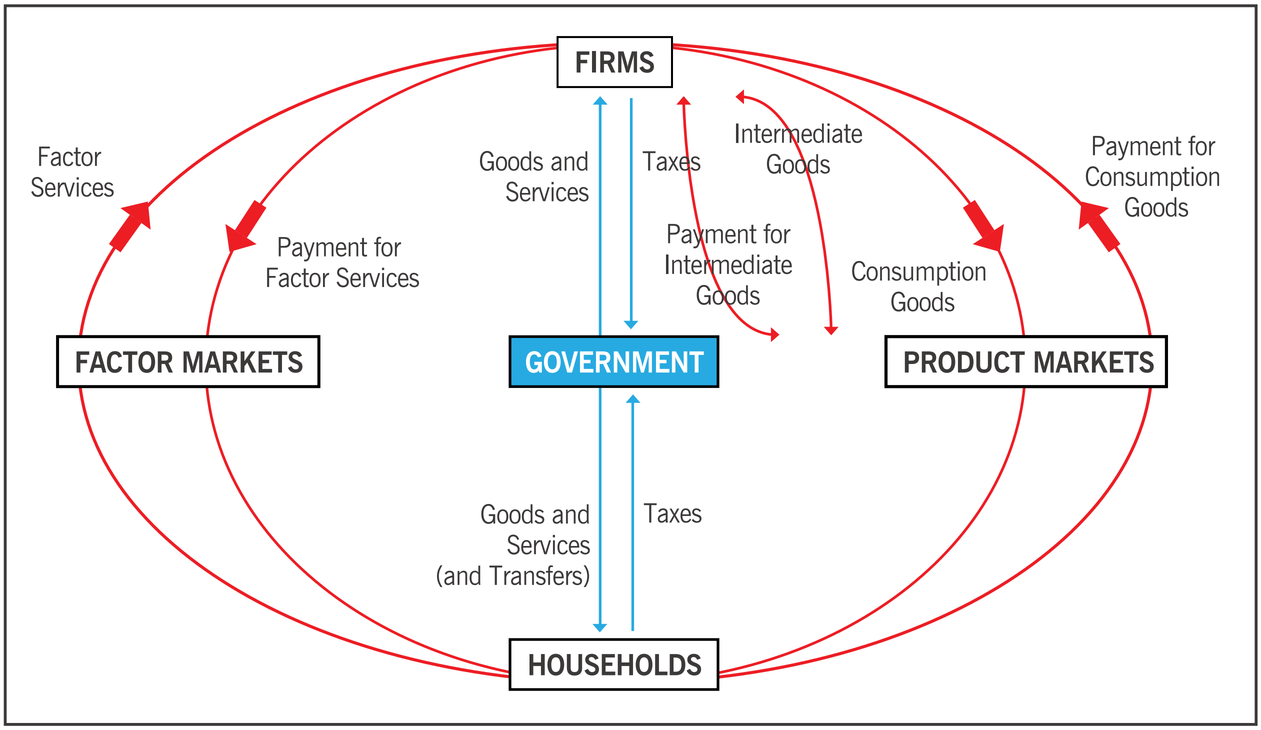
AGE models represent interactions among three types of agents: households, firms, and the government, as illustrated in Figure 5.3. Households own the factors of production (e.g., labor, capital, and natural resources) that they rent to firms and use this income to purchase goods and services. In each sector, firms produce commodities by combining factors of production and intermediate inputs (i.e., goods produced by other sectors). The government sets policies and collects tax revenue, which it spends on providing goods and services for households and on transfer payments to households. Equilibrium is obtained through a series of markets (for both factor of production and goods and services) that determine prices so that supply equals demand.

An important characteristic of AGE models is the representation of inter-sectoral linkages through each firm's use of intermediate inputs. Purchases of intermediate inputs are captured in input-output tables used to calibrate AGE models. For each sector, these tables list the value of output produced and the value of each input used, which can be linked to physical quantities (e.g., tons of coal). For example, the coal power sector will use inputs of capital and labor and output from the coal-mining sector along with other intermediate inputs to produce electricity. These inter-sectoral linkages allow AGE models to evaluate how policy changes will propagate throughout an economy.

FIGURE 5.3. THE STRUCTURE OF AN AGE MODEL



Source: Arun Singh, "Clean Development Pathways for India: Evaluating Feasibility and Modeling Impact of Policy Options" (Master of Science thesis, Technology and Policy Program, Massachusetts Institute of Technology (MIT), June 2017) https://globalchange.mit.edu/sites/default/files/Singh_MS_2017.pdf.

Other key features of AGE models include the representation of competition from competing technologies/sectors and substitution possibilities among inputs. For instance, an increase in the price of coal-based electricity will provide scope for the expansion of electricity generation from other sources, such as wind and solar. At the same time, an increase in electricity prices will incentivize firms to use electricity more efficiently by investing in more efficient plants, at an additional cost, than they would have in the absence of the price increase.

Marginal Abatement Cost Curves in Applied General Equilibrium Models

MAC curves can be constructed using an AGE model to calculate the shadow price of a particular emissions constraint. For carbon reduction policies, the shadow price of the constraint is equivalent to the cost of abating an additional unit of CO_2 emissions. Thus, for a given region and time, the marginal costs for different levels of abatement are determined, and MAC curves are assembled as increasing functions of the total reduction in emissions.

Drivers of abatement costs in AGE models include (1) the existing energy mix, (2) the scope to substitute among fuels, (3) the responsiveness of efficiency improvements to rising (gross of carbon charges) energy costs, (4) the availability and cost of low-carbon energy sources, and (5) consumers' willingness to substitute among goods with different CO_2 intensities. Thus, MAC curves are not directly specified in AGE models but depend on the calibration and interactions among the drivers of abatements costs. However, a MAC curve can be derived as a response surface from an AGE model and is thus implicitly embedded in these models.

As explained by Morris et al. (2012), MAC curves vary by region, time period, and greenhouse gas and thus are sensitive to key modeling decisions. For example, cost estimates within a region are affected by the region's historical policies as well as the policies of the region's trading partners. Furthermore, in light of these sensitivities, the CO_2 permit price should not be interpreted as a welfare cost, with welfare defined as the change in a nation's aggregate consumption. In neoclassical economics, the optimal, welfare-maximizing production and consumption levels are at the point where the marginal welfare of consumption equals the marginal cost of production, which is the carbon price in the context of a permit-trading system. However, as demonstrated by Goulder (1995), a CO_2 price may not be a reliable indicator of welfare costs amid preexisting energy policies and taxes. Nevertheless, a MAC analysis can provide valuable insights into the potential costs of permit trading and other emissions reduction policies, provided that precautions are taken in the MAC curve development and interpretation.

The Broader Economic Impacts of International Trading of Emissions Permits

Analyses of international permit trading using AGE models also evaluate broader economic impacts, such as interaction with preexisting economic distortions (e.g., taxes and subsidies) and terms of trade effects. Interactions between international permit trading and preexisting distortions may have a negative impact on welfare if international trading causes an economy to increase production from sectors with relatively high taxes or subsidies. On the contrary, there will be additional welfare increases if international permit trading induces expansion of sectors with relatively low preexisting distortions. A nation that exports emissions permits may face a negative terms-of-trade effect if the increase in the permit price decreases the competitiveness of that nation's exports of goods and services. If the terms-of-trade effect is large enough, a permit exporter may experience a decline in welfare due to international permit trading. On the other hand, an importer of emissions rights may experience an increase in the competitiveness of its exports due to a decrease in the domestic permit prices. As terms-of-trade effects sum to zero, they do not affect the global welfare impacts of international permit trading, but their distributional impacts across countries can be significant.

For Northeast Asian stakeholders, from firms to governments to citizens, these final points are particularly salient. As with other commodities, the terms of trade for carbon permits in a potential linked system would be intrinsically competitive and likely rivalrous (Marcu, 2018). Policy makers in each country will weigh any prospective linkage from such a cost-benefit analysis, which includes all of the relational information captured by an AGE model as well as more qualitative concerns (political considerations, historical relationships, geopolitical contexts, etc.) that are not specifically targeted.

THE IMPACT OF INTERNATIONAL TRADING OF EMISSIONS PERMITS

Many studies have compared the costs of meeting emissions targets with and without trading, often showing that permit trading results in significant cost reductions. Ellerman and Decaux (1998) evaluate the regional costs of meeting Kyoto Protocol commitments under both permit trading and non-trading scenarios. They assess abatement costs using MAC curves derived from Version 2.6 of the MIT Emissions Prediction and Policy Analysis (EPPA) model for six Annex B regions—defined as the United States, Japan, European

Union, Other OECD Countries, Eastern Europe, and former Soviet Union—in the year 2010. Compared to the non-trading case, permit trading among Annex B countries results in a trade price of USD 127 per ton and a reduction in total abatement cost of USD 66 billion. Japan and the European Union (EU) accrue USD 26 billion of these gains because of their high marginal abatement costs in a no-trade world (USD 584 per ton in Japan and USD 273 per ton in the EU). Moreover, the inclusion of non–Annex B regions in a trading scenario results in a trading price of USD 24 per ton and reduces global abatement cost to USD 11 billion from USD 120 billion without trade.

Similarly, Babiker et al. (2000) use Version 3 of the EPPA model to compare the trading and non-trading abatement costs associated with Kyoto commitments and also find that permit trade among Annex B countries results in substantial welfare gains. For example, in the United States, the marginal abatement cost decreases by 55 percent from USD 205 per ton without trade to USD 92 per ton with Annex B trading. Additionally, Babiker et al. (2000) observe that Annex B trading lessens the drop in energy prices resulting from the CO_2 cap, which in turn moderates the welfare losses faced by oil exporting nations.

Extending beyond the early focus on MAC curves and trade gains, more recent work demonstrates the ability of AGE models to capture the nuances of international emissions trading. Qi et al. (2013) evaluate various combinations of existing or proposed national carbon markets in the EU, the United States, Australia–New Zealand (ANZ), and China. They find that each region's permit trade position depends on the system's coverage. For example, an EU-ANZ-China linked market results in a permit price of USD 11.2 per ton and makes the EU a permit importer. However, the addition of the US makes the EU a permit exporter at a trade price of USD 17.5 per ton. This work demonstrates that the use of an AGE model to represent various market structures can produce valuable insights into countries' potential permit-trading positions.

Other studies focus on the welfare implications of international permit trading while accounting for broader economic impacts, challenging the assumption that welfare improves for all trade parties. Babiker et al. (2004) use an AGE framework to explore the distortionary impacts of preexisting energy taxes and the terms of trade effect. They consider Annex B countries within the EU under scenarios without trading, with trading, and with trading under fewer distortions. They determine that implementation of a trading system can exacerbate the welfare losses from an emissions cap in permit-exporting countries because the negative terms-of-trade effect of exporting outweighs the income gains. For example, relative to a non-trading scenario, permit trading results in a 0.0026 percent increase in welfare in Great Britain when there are 50 percent fewer distortions but causes a 0.51 percent decrease in welfare with full preexisting distortions.

Gavard et al. (2011) also explore the welfare impacts of trading, focusing on sectoral trading between developed and developing countries. They use an AGE model to accommodate a US-China carbon market with an economy-wide cap in the United States and a sectoral cap on emissions from electricity generation in China, a feature that allows the model to capture emissions leakage from capped to uncapped sectors. They observe that under unlimited sectoral trading in China and the United States, a cap on emissions in China's electricity sector causes a 15 percent decrease in the price of coal. However, other sectors in China substitute toward the cheaper coal and negate 19 percent of the electricity sector's emissions reductions. Additionally, while US welfare increases by USD 88 billion in 2030 relative to a no-trade scenario, Chinese welfare decreases by USD 6 billion due to negative terms of trade effects. Expanding on this work, Gavard et al. (2016) consider international emissions trading with an upper limit on the quantity of permits that are traded and compare the effects of limited and unlimited permit trading. If the upper limit is binding, carbon prices will not be equalized across linked carbon markets. They use a certificate system to limit the trade of permits. Under this structure, each CO_2 permit traded requires a trade certificate, but certificates are limited in supply and can be allocated to either the United States or China. Gavard et al. (2016) conclude that if revenue from a trade certificate system (which represents rent from purchasing emissions rights at a lower cost than the selling price) is allocated to the developing country, it is possible for both trade parties to benefit relative to a no-trade case.

Webster et al. (2010) assess the value of emissions trading as a hedge against uncertain economic growth, finding that emissions trading under uncertainty could often be welfare worsening in any region. Such uncertainty is significant because economic growth impacts future emissions levels and thus the optimal emission caps. Webster et al. (2010) analyze several policy variations with and without uncertainty, using both a partial equilibrium model and an AGE model, and find that only the AGE model captures fuel tax distortions and terms-of-trade effects in its estimates of regional welfare change.

Nevertheless, AGE models are based on several simplifying, albeit informed, assumptions and thus struggle to capture short-term market volatility. Reilly and Paltsev (2006) attempt to use an AGE model to identify the driving forces behind the unexpectedly high permit prices in the EU emissions trading system beginning in 2005. They develop scenarios to represent the leading theories (e.g., that drought and high temperatures constrained hydro generation) but could replicate the observed permit prices only with an extreme scenario surrounding expectations on the bankability of permits. Reilly and Paltsev (2006) conjecture that the early spike in the observed price trend would not be representative of future prices, and, indeed, prices fell from their peak of about EUR 30 per ton in April 2006 to around EUR 15 per ton in the summer of 2006 (Ellerman and Buchner, 2008). This work highlights the difficulty of using AGE models to capture short-term market volatility and suggests that AGE models are better suited to evaluate long-term trends and impacts.

Policy-making communities in Northeast Asia would do well to embrace these limitations early on. Running AGE model simulations on different forms of linkage can provide invaluable insights into broad cost-benefit calculations. These simulations are unlikely to provide accurate, granular information on near-term price discovery and the day-to-day machinations of such a linked market.

CONCLUSION

Quantitative models can estimate the economic and emissions impacts of climate policies and the trading of emissions rights among regions. AGE models represent economies as a series of interlinked markets, include a detailed representation of energy production, and link production to GHG emissions. Abatement costs in AGE models reflect assumptions concerning the responsiveness of efficiency improvements to changes in energy prices, the availability and cost of low-carbon energy sources, and other characteristics. These factors give rise to implicit MAC curves. International trade of emissions rights will result in deeper emissions cuts in regions with lower marginal abatement costs and smaller emissions reductions in regions with higher abatement costs, which also compensate regions for taking on additional emissions reductions.

Owing to their economy-wide nature, AGE models are also able to evaluate the broader economic impacts of international trading of emissions permits. For example, the increase in the emissions price in a nation that exports emissions permits will decrease the competitiveness of exports of goods and services from that nation. Previous numerical studies of the impacts of integrating carbon markets reveal that international permit trading can lower the costs of reducing emissions and that broader economic impacts can be substantial.

AGE models are therefore useful tools for exploring market linkage scenarios in Northeast Asia both for the maturation of domestic systems and for possible future linkage. They can help reveal relationships between different domestic policy instruments at the intersection of environmental and economic policy making. China is employing a mix of command and control measures alongside multiple market instruments (Ewing, 2017). Japan mixes international offsets, a national carbon tax, selective subsidies, and voluntary and subnational carbon markets (see chapter nine of this volume). Korea's ETS is enmeshed in a wider green growth policy space replete with market incentives and non-market regulations designed to drive energy efficiency and a transition toward cleaner energy sources (IEA, 2018).

For regional linkage scenarios, AGE models can provide policy makers with a clearer—if imperfect—sense of the benefits and trade-offs linkage will entail for their national position. Given the wealth of support on the mitigation and economic value of international carbon market integration (see chapter four of this volume), it is likely that such modeling will reveal net positive gains for China, Japan, and Korea. Most practically, modeling these relationships under different linkage scenarios can help policy makers reach decisions about the value and resulting prioritization of linking efforts, and the pathways that can be most palatable for their national interests.

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