

A balance of bottom-up and top-down in linking climate policies

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Top-down climate negotiations embodied by the Kyoto Protocol have all but stalled, chiefly because of disagreements over targets and objections to financial transfers. To avoid those problems, many have shifted their focus to linkage of bottom-up climate policies such as regional carbon markets. This approach is appealing, but we identify four obstacles to successful linkage: different levels of ambition; competing domestic policy objectives; objections to financial transfers; and the difficulty of close regulatory coordination. Even with a more decentralized approach, overcoming the 'global warming gridlock' of the intergovernmental negotiations will require close international coordination. We demonstrate how a balance of bottom-up and top-down elements can create a path toward an effective global climate architecture.

The top-down approach to mitigating climate change as exemplified by the UNFCCC negotiations and the Kyoto Protocol has all but stalled, due to a panoply of political objections. To craft a more workable policy, states and non-state actors alike have shifted their focus to bottom-up 'linkage' of multinational, national, and subnational cap-and-trade systems^{1–8}. Although linkages between markets could provide a framework for international cooperation on climate policy, they cannot guarantee the seamless development of a decentralized and self-enforcing governance mechanism. We identify four obstacles to successful linkage, which turn out to be similar to those that have plagued the global climate negotiations. Domestically, they include the challenge of agreeing on and evaluating different levels of ambition as well as the potential incompatibility with other domestic policy objectives. Across jurisdictions, obstacles may arise from political objections to financial transfers, and the difficulty of close regulatory coordination.

Given the importance of finding a path toward an effective architecture for global climate policy, we suggest an incremental approach that combines elements of decentralized experimentation with strategic negotiations, which could help to manage and overcome these obstacles. Careful, gradual linkage could serve as an important political instrument and learning process, but it will not provide a way around 'global warming gridlock'³. An effective global policy architecture will still require close international coordination with a balance of bottom-up and top-down elements.

The rise of unilateral climate action

One of the main purposes of an international agreement is to provide incentives for coordinated action by curbing free-riding^{9–11}. It may therefore seem paradoxical that some nations averse to an international climate treaty have begun to adopt policies to address climate change unilaterally. These include cap-and-trade systems, carbon taxes, commitments to reducing energy intensity, forest codes to combat deforestation, and a host of sectoral and regulatory policies aimed at improving energy efficiency, and developing and deploying renewable energy sources. We focus on cap-and-trade systems, which are becoming increasingly prevalent^{12–15}. The European Union has a regional cap-and-trade system, New Zealand has a national system,

and several jurisdictions in the United States and Canada participate in subnational systems. Cap-and-trade systems are also becoming popular in the developing world. Seven Chinese cities and provinces are piloting various models of cap and trade. All told, the World Bank estimates that around 7% of global emissions are under some form of carbon cap¹⁶.

This emergence of a patchwork of national and subnational carbon markets has prompted calls for a bottom-up climate architecture: let countries or subnational governments set the pace through unilateral policies — and then link them. This has also been the recent *de facto* negotiating position of the US delegation to UN climate talks. Many academic observers have begun to consider the mechanics of implementing linkages^{2,4–8,17}.

Linkage plays a prominent role in such a bottom-up architecture. It can potentially produce economic benefits — more reductions at a cheaper cost — as well as political ones, by providing an alternative to global negotiations and a testing ground for bottom-up innovation. Indeed, some linkage arrangements are beginning to emerge or are already in place, such as between California and Quebec. There are also links between carbon markets and jurisdictions without a cap on emissions. These are often created by 'flexibility mechanisms' — so named, because they allow capped sources to procure low-cost emissions reductions from sources in uncapped jurisdictions. The Clean Development Mechanism is perhaps the most prominent example.

The mechanics of linkage

Linkage can take many forms, and can be applied to tax systems, renewable portfolio standards or other regulatory approaches⁶. The simplest version of linking cap-and-trade systems is a two-way direct linkage: Jurisdiction A agrees to accept Jurisdiction B's allowances and vice versa. (As cap-and-trade systems are implemented at multiple levels of governance, we use 'jurisdiction' as a general term to refer to any political entity with a trading system.) The linkage between California and Quebec is an example of a two-way direct linkage. However, if B chooses not to accept A's allowances, then the linkage is one-way. Moreover, if A is linked to B and B is linked to C, then jurisdictions A and C are indirectly linked. Systems may also become indirectly linked if two of them have one-way links to a third.

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For example, if A and C both accept B's allowances, they will both compete for them in times of shortage⁵. Similarly, when allowances and offsets are mutually interchangeable (fully fungible) within one jurisdiction, linking jurisdictions, *de facto*, must accept allowances and offsets from that jurisdiction. In this sense, the New Zealand and European Union systems, for example, are indirectly linked via the mutual acceptance of Certified Emission Reductions of the Clean Development Mechanism.

The complex effects of economic incentives

Bigger markets are better: that is the economic logic for linking carbon markets. Global trade in goods and services maximizes the benefits from comparative advantage and increases output. Global trade in emissions allowances would fulfil a similar promise. Open and linked markets are more liquid and more efficient, allowing money to flow where the marginal cost of abatement is lowest. Firms that can produce reductions more cheaply will do so and sell allowances and offsets to firms for which emissions reductions are more expensive to generate. These transactions can occur both within jurisdictions and across linked ones.

In theory then, linking carbon markets should advance efforts to mitigate climate change. Such an approach would increase the total amount of reductions and lower total costs. It would also increase financial flows from developed to developing countries, as marginal costs of abatement are often thought to be lower in the developing world¹⁸.

Yet the economic effects of linkage are not one-dimensional. In addition to potentially catalysing reductions, they also create incentives for weaker emissions targets that need to be anticipated and managed. 'Abatement' is unlike many other goods. The supply of emissions allowances depends on government policy to create and enforce property rights and willingness to commit to an emissions cap.

Economic incentives work in two directions. On the one hand, access to cheaper allowances and offsets should facilitate more ambitious targets. On the other, the potential revenue from exporting excess allowances may prompt a government to choose a less ambitious emissions cap to generate more of these allowances. Generally, as the difference in permit prices across jurisdictions increases, so do the potential gains from linkage, and the incentive to loosen the cap. The crucial question is which force dominates: the positive incentives that make it more difficult for linked jurisdictions to manipulate their own markets to their domestic advantage, or the economic forces that motivate jurisdictions to do exactly that.

Ultimately, choosing a multi-jurisdictional emissions cap is a problem of joint action. When jurisdictions wishing to link set caps simultaneously, ambitious targets make more sense than when one jurisdiction is unilaterally setting a cap in response to the previously established caps or commitments of other linking jurisdictions. The same is true within each jurisdiction. Individual governments may have incentives to lower standards, allow lax enforcement, and generally devalue allowances and credits to minimize economic costs at the expense of environmental integrity.

The environmental effectiveness, which we define as reducing net long-term greenhouse gas emissions, and economic efficiency of cap-and-trade systems are based on two conditions. First, there is no variation in quality of allowances or offsets across jurisdictions. Thus, all allowances must be of equal value, and all offsets must represent real and additional emissions reductions. Second, all jurisdictions are capable of creating and enforcing durable property rights. When governments are lax in emissions monitoring, admit questionable offsets or are unable to enforce property rights, the economic value and environmental effectiveness of the trading system is eroded. In the extreme, trading systems would be little more than 'Potemkin markets': the mere appearance of an emissions-reducing market³.

Clearly these two conditions will not always be met. Many jurisdictions suffer from lack of political will and capacity to implement

their own carbon markets. The prospect of gains from linkage then may act as a catalyst in some jurisdictions. It is also clear, however, that prematurely linking with a jurisdiction that fails to meet these basic criteria threatens the integrity of the entire linked market.

The politics of linkage

Differential costs of abatement are also often central to political concerns. Although linkage might be expected to increase the willingness of a government to accept stringent targets because of access to cheaper abatement options, the politics of linking are likely to depend on a host of factors, in particular on whether a jurisdiction's most influential political industries or sectors are net sellers or buyers of allowances. That, in turn, depends on factors such as the availability of domestic low-cost emissions reductions, how baselines are set, how concentrated the benefits and costs are, and how quickly economies and economic sectors grow.

Setting baselines and determining levels of ambition are huge challenges in global climate negotiations. Linkage of domestic cap-and-trade systems may appear to skirt these issues: individual jurisdictions first choose their targets and then pursue linkage. But these two steps are not independent from each other. At least four political obstacles may impede successful linkage. The first two — different levels of ambition and competing domestic policy objectives — describe different ways in which domestic politics may affect regulatory design and function at home. The third and fourth obstacles — the need to support financial flows and the loss of regulatory autonomy — describe the challenges likely to arise once linked systems are up and running. Simply creating linkages may not generate sufficient political support to sustain the effort.

Different levels of ambition. The political appeal of a bottom-up linkage approach is its flexibility. Each trading jurisdiction can choose its level of ambition, according to the political constraints, growth projections, and emissions reduction opportunities both domestically and in linked jurisdictions. Too much flexibility, however, may also prompt governments to choose an unambitious cap. Setting a high cap may be perceived as a sensible hedging strategy to ensure that compliance costs are not too onerous, if economic growth exceeds expectations or abatement is more expensive than anticipated.

The trial phase of the EU emissions trading system provides a useful illustration. From 2005 to 2007, individual member states had considerable autonomy in setting their own emissions reduction targets¹⁹. These were then summed to set the EU-level cap. As a result of concerns about costs as well as a lack of historical emissions data, there was a large over-allocation of allowances in the trial phase. This contributed to a significant drop in prices in April 2006, once over-allocation became evident to market participants. The problem of over-allocation improved only when the European Commission was granted greater authority to adjust the caps to manage supply, although this authority alone has not yet solved the problem of over-supply. Moreover, while the Commission has this authority for the EU emissions trading system, no equivalent institution currently exists on the global level.

If compliance becomes too costly, a linked jurisdiction could attempt to lower its level of ambition by raising its cap or increasing the availability of credits from other third-party sources. But such a policy would deflate the economic value of permits and erode the environmental effectiveness of the cap. Thus in the extreme, linking without an agreement on targets would be like a monetary union between countries where each had the right to print money²⁰.

Moreover, any linkage agreement should cover both the overall level of ambition — the cap — and the quantity and quality of offsets. Otherwise, jurisdictions may simply plan to fill shortcomings through purchases from 'looser' (that is, cheaper) linked markets, in which allowances may be over-supplied or offsets may not represent real reductions.

Preventing oversupply requires binding enforcement mechanisms such as strong bilateral or multilateral agreement among 'climate' or 'linkage club' members⁸. For a small number of linked jurisdictions, such an institution may be feasible. For more, it quickly approaches the complexity and political difficulty associated with a global agreement.

Competing domestic objectives. The economic logic for linkage assumes the desire to reduce costs of compliance, holding levels of ambition constant. Yet like trade liberalization more broadly, linkage will produce winners and losers within a given jurisdiction. Those with high marginal costs of abatement will benefit from lower compliance costs. Potential permit sellers with low costs of abatement will lose out, since demand for their permits will decline.

Similarly, there will be winners and losers across jurisdictions. Consider a jurisdiction that faces a higher carbon price after linkage. The jurisdiction as a whole benefits from exporting permits, as will individual permit sellers. Buyers in that country, however, will face higher prices. Whether this tips the scales in support of or in opposition to linkage will depend on the relative power of various affected groups. Much like with trade liberalization, the fundamental economic logic is often at odds with specific effects on powerful industries and other competing domestic policy objectives²¹.

Early movers like the European Union have implemented a comprehensive climate policy unilaterally. Cheaper allowance prices then are not the sole or even the primary policy goal. Rather, EU climate policy is often seen as a way to create the preconditions for a long-term transformation to an economy free of fossil fuels. The carbon market serves as one tool for this purpose, but it is only one of many. Others include direct support for renewable energy and energy efficiency that comes at higher costs per tonne of carbon dioxide abated in the short run but fulfils other long-run goals.

Conversely, linkage may be a policy goal in itself, regardless of the economic benefits (or costs). The European Union has long been a global leader on climate change, and is using multiple tools to reduce its emissions and encourage other regions to do the same. Linkage is part of this overall plan. The European Union plainly says that an international carbon market will develop "through 'bottom-up' linking of compatible emissions trading systems"²². It further states that "linking the EU ETS with other cap-and-trade systems offers several potential benefits, including... supporting global cooperation on climate change." Importantly, this is a different motivation for linkage than a purely economic short-run logic.

Need for supporting financial flows. Buying permits is tantamount to a financial transfer between trading entities. The overall flow of funds depends on whether a jurisdiction is a net seller or buyer of permits. As long as differential costs of abatement across linked markets are small, the value of transfers will be correspondingly small — as will the efficiency gains. As economic differences grow and climate goals become more ambitious, however, financial flows will also increase. Once these transfers reach billions of dollars annually, competing policy objectives and possible political objections will come to the fore.

The Clean Development Mechanism exemplifies the complex politics of financial transfers. At its height in 2006 and 2007, annual transfers approached \$10 billion. Most of the money came from the European Union and was invested in China¹⁶. Many of these credits were generated by industrial gas projects. Little investment was funnelled to other developing countries, which raised concerns about the distribution of wealth transfers. As a result, the European Union has since restricted certain types of offsets, both by sector and region.

Linked cap-and-trade systems have one crucial advantage over offset mechanisms and other types of transfers: money flows between covered entities rather than from covered entities to governments or uncapped sources. Economically, this is more cost-effective than funding investments in specific emissions reductions from those

sources. Politically, it will generally be more acceptable to have financial flows across linked markets than from one capped jurisdiction to an uncapped one, especially if the transaction crosses national borders. Yet that does not imply that states can implement trading without fear of political backlash.

Loss of regulatory autonomy. Linking markets entails coordination on important design elements, since design choices in one jurisdiction will affect policy in another. Consensus across linked systems may be easily achieved between two parties but quickly becomes more complex as the number of jurisdictions grows.

Much of the appeal of bottom-up markets is to provide a testing ground for different design options. Conversely, complex linked trading systems may propagate possible early mistakes in system design^{23,24}. Linkages could create a race to the bottom in regulatory standards. Moreover, as the terms of the linkages will be the product of political bargaining, 'winning' political groups will oppose reforms that threaten their interests. As such, design choices will be difficult to reverse.

In an entirely different realm, the recent financial crisis serves as a powerful example of the vulnerabilities of linked systems with decentralized regulatory oversight. At the extreme, the collapse of one system — either because of design flaws, regulatory uncertainties, or other economic or political circumstances — could result in serious impacts on linked carbon markets.

An incremental approach to linkage

The EU example shows that many regions view linking markets as an important political incentive and interim step toward stronger global climate commitments. Linkage may serve domestic political objectives, even without the economic benefits of lower compliance costs. Once linked, the political consequences of changing the rules of the game will make it more difficult for jurisdictions to manipulate their emissions caps, even if doing so is in their short-term economic interest.

These political reasons alone may provide sufficient justification for linkage as a short-term strategy. But even politically motivated linkage will face the same issues of potentially different levels of ambition, competing domestic policy objectives, the need for supporting financial flows, and the potential loss of regulatory autonomy.

Successful linking requires navigating tradeoffs between efficiency and political feasibility. Confronting these tradeoffs necessitates an incremental approach. For example, informal linkages, such as through 'memoranda of understanding', can help jurisdictions to 'align' their practices before formal arrangements are codified²⁵. In the short term, the goal of bottom-up policy should be to focus on building operational best practices. As such, experimentation and learning are important²⁶. Those experiments require strong domestic institutions before moving toward an expansion of markets. Careful linkage — at first among developed-country markets, like in the case of California and Quebec — will serve as an important testing ground for further expansion of markets. Moreover, they may create incentives and supportive constituencies who in turn help states develop domestic carbon markets and catalyse more ambitious global action⁸.

Jurisdictions should consider several design strategies to manage the political impacts of linkage. First, because political obstacles rise with the economic benefits of linkage, cultivating linkages between developed country markets is likely to be a productive starting point. This is true for two reasons. Developed countries are more likely to have robust regulatory systems to support successful implementation, monitoring and compliance mechanisms required for a functional system. In addition, as the differences in marginal costs of abatement are likely to be relatively small, wealth transfers will be correspondingly low, relative to total allowance value.

Second, linking markets may also introduce political uncertainty associated with a loss of regulatory autonomy, heightening the need for coordination among jurisdictions. This uncertainty suggests

keeping indirect linkages to a minimum. Jurisdictions should only be linked if each one expressly agrees to do so, and the two negotiate directly on the terms, rather than through the shared third party. Thus, links may be initiated ‘indirectly’, but they must be agreed upon directly, among all parties involved.

Third, consistency among rules across jurisdictions is important for the proper functioning of linked markets. For example, differential time horizons among linked jurisdictions might increase opportunities for gaming. The EU emissions trading system’s linear decrease of 1.74% with respect to a 2008–12 baseline continues indefinitely. In the future, other linked jurisdictions with shorter time horizons may exploit the European Union’s commitment as an opportunity to set less ambitious caps themselves without the European Union being able to adjust its own cap. Coordination to ensure consistency will be crucial.

Fourth, allowing for intertemporal markets through banking and borrowing should — in principle — increase price stability, and would thus be desirable in mature carbon markets. But the combination of linking and banking may also accentuate the tradeoffs discussed above and expose fledgling systems to additional risks. These may include: propagating inadvertent design flaws, mistakes in allocation, gaming or manipulation of the system and lock-in that makes future adjustment difficult.

Fifth, these potential problems indicate a clear need for strong bilateral or multilateral coordination. A global treaty may be too politically difficult, but a wholly bottom-up solution is not a panacea. Instead, a ‘polycentric’ approach, which creates ‘linkage clubs’ that are able to coordinate multi-jurisdictional issues without the pitfalls of a treaty negotiation, can help build an effective climate architecture²⁷.

Finally, linking jurisdictions should also consider the implications of unsuccessful linkage. A marriage analogy serves parties well here. Linking may be thought to be forever, yet ‘prenuptial’ agreements may still be beneficial to all parties involved, not least because they create more certainty in case of an eventual ‘de-linking’²⁸.

Building a stable foundation for a global carbon market

A bottom-up approach to climate policy may solve some political problems that have plagued the intergovernmental process in the short term. Eventually, however, as different domestic systems try to link, they will confront issues related to the level of ambition, oversight and policy design that are similar to those faced by a negotiated, top-down solution. Linking jurisdictions should focus on incremental steps, cultivating small victories in service of a larger goal: a global carbon market, which, in turn, is ultimately in service of emissions reductions at least cost²⁹.

Given the complexity of creating a global market for carbon, it may be prudent to proceed with caution: simpler linkage arrangements are better. Early linkages, for example, may warrant quantitative limits on flows much like limits on offsets to provide some insurance against bad actors, while minimizing the risks of unanticipated adverse consequences. Meanwhile, global treaty negotiations should support these efforts and use global targets and timetables to evaluate and steer bottom-up policies. Global negotiations could similarly provide frameworks for best-practice linkage design and institutions. Experimenting with linkages can provide useful lessons and open new paths to international cooperation and negotiations on climate change.

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References

- Rayner, S. How to eat an elephant: A bottom-up approach to climate policy. *Clim. Policy* **10**, 615–621 (2010).
- Falkner, R., Stephan, H. & Vogler, J. International climate policy after Copenhagen: Towards a ‘building blocks’ approach. *Glob. Policy* **1**, 252–262 (2010).
- Victor, D. G. *Global Warming Gridlock: Creating More Effective Strategies for Protecting the Planet* (Cambridge Univ. Press, 2011).
- Jaffe, J., Ranson, M. & Stavins, R. N. Linking tradable permit systems: A key element of emerging international climate policy architecture. *Ecol. Law Quart.* **36**, 789–808 (2009).
- Jaffe, J. & Stavins, R. N. in *Post-Kyoto International Climate Policy: Implementing Architectures for Agreement* (eds Aldy, J. E. & Stavins, R. N.) Ch. 4, 119–150 (Cambridge Univ. Press, 2010).
- Metcalfe, G. & Weisbach, D. Linking policies when tastes differ: Global climate policy in a heterogeneous world. *Rev. Environ. Econ. Pol.* **6**, 110–129 (2012).
- Ranson, M. & Stavins, R. N. Post-Durban climate policy architecture based on linkage of cap-and-trade systems. *Chicago J. Int. Law* **13.2** (2012).
- Stewart, R., Oppenheimer, M. & Rudyk, B. A new strategy for global climate protection. *Clim. Change* **120**, 1–12 (2013).
- Olson, M. *The Logic of Collective Action: Public Goods and the Theory of Groups* (Harvard Univ. Press, 1965).
- Weitzman, M. L. Can negotiating a uniform carbon price help to internalize the global warming externality? *J. Assoc. Environ. Resour. Econ.* **1**, 29–49 (2014).
- Wagner, G. & Weitzman, M. L. *Climate Shock: the Economic Consequences of a Hotter Planet* (Princeton Univ. Press, in the press).
- IPCC Summary for Policymakers in *Climate Change 2014: Mitigation of Climate Change* (eds Edenhofer, O. et al.) (Cambridge Univ. Press, 2014).
- Nachmany, M. et al. *The GLOBE Climate Legislation Study: A Review of Climate Change Legislation in 66 Countries* 4th Edn (GLOBE International/Grantham Research Institute, London School of Economics, 2014).
- Mansell, A. (ed.) *Greenhouse Gas Market 2012: New Markets, New Mechanisms, New Opportunities* (International Emissions Trading Association, 2012).
- Grubb, M. Emissions trading: Cap and trade finds new energy. *Nature* **491**, 666–667 (2012).
- State and Trends of Carbon Pricing* (World Bank, 2014).
- Victor, D. G., House, J. C. & Joy, S. A Madisonian approach to climate policy. *Science* **309**, 1820–1821 (2005).
- Dellink, R., Jamet, S., Chateau, J. & Duval, R. Towards global carbon pricing: Direct and indirect linking of carbon markets. *OECD J. Econ. Studies* **2013** (2014).
- Ellerman, A. D., Convery, F. J. & De Perthuis, C. *Pricing Carbon: The European Union Emissions Trading Scheme* (Cambridge Univ. Press, 2010).
- Victor, D. & House, J. A new currency: Climate change and carbon credits. *Harv. Int. Rev.* **26**, 56–59 (2004).
- Milner, H. V. *Interests, Institutions, and Information* (Princeton Univ. Press, 1997).
- International Carbon Market* (European Commission, 2014); http://ec.europa.eu/clima/policies/ets/linking/index_en.htm
- Jervis, R. *System Effects* (Princeton Univ. Press, 1997).
- Raustiala, K. & Victor, D. G. The regime complex for plant genetic resources. *Int. Org.* **58**, 277–309 (2004).
- Burtraw, D., Palmer, K., Munnings, C., Weber, P. & Woerman, M. *Linking by Degrees: Incremental Alignment of Cap-And-Trade Markets* Discussion Paper 13–04 (Resources for the Future, 2013).
- Sabel, C. F. & Zeitlin, J. *Experimentalist Governance in the European Union: Towards a New Architecture* (Oxford Univ. Press, 2010).
- Ostrom, E. A polycentric approach for coping with climate change. *Ann. Econ. Finance* **15**, 71–108 (2014).
- Pizer, W. A. & Yates, A. J. *Terminating Links between Emission Trading Programs* Discussion Paper 14–28 (Resources for the Future, 2014).
- Urpelainen, J. A model of dynamic climate governance: dream big, win small. *Int. Environ. Agreements Polit. Law Econ.* **13**, 107–125 (2013).

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