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Robust incentives and the design of a climate change governance regime

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Robust incentives and the design of a climate change governance regime

Gregory F. Nemet[1]

Abstract

In building a governance regime to address climate change, should we prioritize the development of global institutions or national ones? This paper adds insight to the issue of how much international coordination on climate governance is optimal by focusing on two neglected characteristics of the problem: first, the crucial role of incentives for private sector investors in low-carbon energy technology and second, that investors typically risk-adjust expectations of policy-induced payoffs because of historical policy volatility. Examining a case study of an important low-carbon energy technology, wind power, this study finds: (1) policy volatility has been substantial, (2) policy changes were uncorrelated across jurisdictions, suggesting that (3) investors could have substantially reduced their exposure to the risk of policy volatility by operating globally. While it also has downsides, a poorly coordinated international policy regime has the advantage of reducing the risk associated with a global policy failure. Beyond this case study, the importance of this positive effect depends on: the probability of policy failures in each country, the correlations among them and the probability of a global policy failure.

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1 Introduction

The design of an effective international climate governance regime requires consideration of many issues: the stringency and timing of emissions reductions; allocation of reduction responsibilities; commitments for mitigation versus adaptation; level of aid to developing countries, as well as implementation issues, such as reporting, verification, and the relative global warming potentials for greenhouse gases. Choices must address the concerns of a large number of stakeholders with heterogeneous preferences—in particular their time preferences and tolerance for risk.

A more fundamental issue is the gathering debate about whether it would be best to approach this problem by developing a set of international institutions or by leaving the bulk of important decisions to national governments. The case for a global approach relates to the inherently global physical characteristics of the climate system, the urgency of implementing a response, and the need to resolve economic competitiveness concerns. The case for a nation-led approach rests on the poor effectiveness to date of the globally-oriented approach, the tendency to for international action to be limited to stringency defined by the least common denominator problem, and the formidable difficulty of satisfying radically varied preferences. The divergence in views has become more apparent with lack of progress in both domains; key national governments have been reluctant to adopt their own targets while international agreements have not achieved resolution on any binding commitments since 2005. Meanwhile the physical aspect of the problem appears to have deteriorated substantially as global emissions have accelerated, worst case scenarios of climate damages have worsened, and best case scenarios of damages have remained stable.

1.1 Policy volatility and investment incentives

This paper seeks to add insight on the global vs. national debate by focusing on two considerations, which are typically not well characterized in policy analysis and government debates. First, the success of any agreement is inherently tied to the incentives that governments create for investors in low-carbon technologies. The long term effectiveness of climate agreements will be measured by the avoidance of climate damages, which depends centrally on the development and deployment of low-carbon energy technologies. Addressing the climate problem is not possible without profound changes to the technology we use to produce and consume energy (Pielke et al., 2008). The investments required to accomplish this transformation of the energy system are large; the International Energy Agency estimates that the investment required to address climate change will be $11 trillion between 2010 and 2030; this amount is in addition to the $26 trillion that will be needed to meet energy demand in the absence of concern about climate change (IEA, 2009). For the climate problem, appropriate pricing of the externality is necessary to induce investments in these technologies (Nordhaus, 2008). These investments thus depend on investors' expectations of future payoffs, which depend on their expectations of governments' actions to price externalities (Nemet, 2009a). If policies change, payoffs for the $11 trillion investment also change. Expected payoffs are vulnerable to changes in policy.

Second, consideration of the history of government actions in this area suggests that the design of a climate regime needs to be robust to failure of the regime itself. There is evidence that government actions in the energy sector are time inconsistent—priorities change, budgets change, taxes and subsidies change; programs are cancelled, in many cases with very little warning. Governments are unpredictable and policies are volatile. Because the payoffs to their investments depend on the details of public policy several years in the future, private-sector actors developing low-carbon energy technologies face substantial policy risk. This policy risk is pernicious because it reduces their incentives to invest in technology development and deployment. An important characteristic of policy volatility however, is that there is wide variation in public policy across countries and even within countries. While there is substantial sentiment in favor of policy harmonization, this paper examines the rival hypothesis that variation may actually be helpful for investment.

1.2 Governance with robust incentives

The approach of this paper is that fuller consideration of (1) the need for strong incentives for investment in technological change and (2) the tendency for private sector investors to include policy risk in their investment decisions is important; it may shift the case for a global vs. national approach to building an effective international regime that efficiently avoids climatic damages. The central issues about whether an alternative approach might be needed revolve around expectations of policy failure, and the extent to which failures are correlated across countries and time. This work is aimed at adding insight to two specific questions. First, does the globalization of the low-carbon energy industry mean that private actors can take advantage of the heterogeneity in policy regimes? Can they, in effect, hedge their policy risk by operating in several markets simultaneously? And second, would a 'bottom up' climate policy regime, based on national policies, provide more robust incentives for innovation than a single globally negotiated agreement, such as the Kyoto Protocol?

1.3 Study overview

This paper examines hypotheses related to these questions using the case of policy instruments implemented for wind power production over the past three decades. This paper proceeds by briefly reviewing the central issues at the intersection of financing for technology development and governance of climate change. Following that, section 3 lays out research questions as well as the approach to data collection and analysis. Section 4 describes the results of these analyses. Finally, section 5 discusses the implications of these results on design of an international climate policy regime.

2 International governance and investment incentives

Among many other considerations, the international response to the climate problem must accommodate three characteristics of the problem: multiple market failures, a need for massive technological change, and the longevity of requisite investments, the profitability of which depends on expectations of policy decisions several years in the future.

2.1 Needed technological change depends on government

Limiting greenhouse gas (GhG) concentrations to double pre-industrial levels would require cutting global emissions by 25–70% business-as-usual levels by mid-century (IPCC, 2007; O'Neill et al., 2010). Offsetting greenhouse gas emissions equivalent to hundreds of gigatons of CO_2, while affordably meeting the world's growing demand for energy, will require the deployment of tens of terawatts of low-carbon energy production and end-use technologies over that period (Hoffert et al., 2002; Edmonds and Smith, 2006). Cost-reducing and performance-enhancing improvements in carbon-free energy technologies are essential for reductions of this scale (Richels and Blanford, 2008).

While the private sector is likely to continue to account for a dominant share of investments in innovation and deployment of new technologies, government decisions are crucial to the incentives that firms in the private sector face. Governments play a central role because market failures are prominent in this area; GhG emissions are an unpriced negative externality (Dales, 1968), new technical knowledge spills over from one firm to another (Nelson, 1959), and technology adopters have poor information relative to technology developers (Zhu and Weyant, 2003). The payoffs of firm investments in this area thus depend on the actions that governments take to remedy these public goods problems. However, since equipment in the energy sector typically lasts for decades and investments are large (Knapp, 1999), the payoffs for these investments take many years to accrue. In the intervening years, governments can change–and the policies they implement can change.[2] In part because of their large size and long lifetimes, investments in the energy sector are particularly vulnerable to policy volatility (Meijer et al., 2007a,b). Expectations of time inconsistency in energy policy lead to lower investment. Weakened investment incentives due to policy volatility are especially a concern in the area of climate change (Yang et al., 2008), where uncertainty in carbon prices interacts with uncertainty in fuel prices (Blyth et al., 2009).

As a result, investors in clean energy technologies seek not only strong signals, but stable ones—those with a reasonable amount of predictability over a multi-year time scale. For example, among venture capital and private equity investors, one can observe a strong preference for long term government commitments; feed-in-tariffs, in which subsidized prices are guaranteed for 10 or more years were found to be the government program most likely to stimulate investment (Borer and Wustenhagen, 2009). This preference for stability was also the case in the 1980s when an array of investment subsidies failed to produce large investment in wind and concentrating solar technology until ten-year procurement contracts were offered (Nemet, 2009a). The payoffs to investors in externality-improving energy technologies both rely on, and are vulnerable to, government actions.

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[2] Similar policy volatility in the macro-economy has pernicious effects (Fatas and Mihov, 2003).

2.2 Climate governance: organizing the response to a global problem

If government actions are needed to address public goods problems and the climate problem is a global one, how best to organize the policy response? The difficulty of forming a response is evidenced by the persistent collective action failures that have failed to produce an agreement leading to actual reductions in global emissions over the course of two decades of meetings, most prominently in Toronto (1988), Rio de Janiero (1992), Berlin (1995), Kyoto (1997), Montreal (2005), and Copenhagen (2009). Not only must public goods problems be addressed, but, due to the physical scales of both the climate system and the global energy system, they occur in an international context. In summary, the challenge is to design a response to a truly global public goods problem, under deep uncertainty about future impacts—and about costs to address those impacts—with heterogeneous risk tolerance and time preferences, all over the course of several decades. It is an unprecedented challenge for global environmental governance.

One important divergence in normative approach is whether this problem is best dealt with at a global level or at a more disaggregated level; this distinction is sometimes referred to as top-down and bottom-up. The global (top-down) approach is best characterized by the United Nations Framework Convention of Climate Change, which involves the meetings described above beginning formally in 1992. The objective is to use the forum of the United Nations to secure a global agreement on targets for emissions reductions, forest protection, and aid to developing countries, among other items. Once signed, each member country ratifies the agreement on its own and adopts it as binding domestic legislation. A key distinguishing feature is that negotiation of targets occurs at a global level, and the agreement is administered by the United Nations. An alternative (bottom-up) is to devolve much of the decision-making, in particular selection of targets and administration, to national governments. Where there is cooperation among countries it occurs on a bilateral basis, and presumably a limited set of coordination functions, such as information collection and dissemination, would remain at a global level.

The globalist approach has been criticized for several deficiencies: the large number of players make negotiations slow and the need for consensus leads to a lowest-common-denominator problem; international organizations are too weak to enforce an agreement so closely tied to industrial competitiveness; a single agreement cannot adequately resolve heterogeneity in national preferences; past success in globally addressing other international environmental problems, such as ozone depletion, are poor analogies to climate change (Victor et al., 2005; Prins and Rayner, 2007). On the other hand, the disaggregated approach is criticized for being too slow; unlikely to overcome the appeal of free-riding; less likely to represent the concerns of the most vulnerable; lacking essential coordination mechanisms; and not making use of the institutional capacity, developed over two decades, for supporting, monitoring and enforcing an agreement (Schellnhuber, 2007; Flachsland et al., 2009; Webster et al., 2010). This paper seeks to inform this debate by adopting the perspective of an investor seeking to manage policy risk under time-inconsistency as well as large and long-lived investments.

3 Approach

This study seeks to add insight on the design of a international climate policy regime by assessing the links between policy volatility and investment incentives. This section describes an approach to providing quantitative insight on the following questions:

1. Were markets for clean energy technologies volatile?

2. To what extent does policy affect market size and volatility?

3. What is the resulting effect of policy on investment risk?

4. Is there an opportunity to hedge this risk?

The core of the approach to addressing these questions is to identify the role of policy in affecting market size over time and across geographies. Measures of volatility and industry concentration are then used. To perform these analyses, a panel data set is constructed for the 12 distinct wind power markets, as well as two aggregate markets, the U.S. and the world. The panel includes these 14 geographies over 28 years.

3.1 Scope

The study examines these questions for the case of a single clean energy technology, wind power. The wind power industry was selected for several reasons. First, that the technology consumes no fuel and emits no pollutants gives it public goods attributes that governments must somehow account for. Second, the industry is sufficiently well-established to provide an adequate historical record for analysis; wind turbines for electrical generation have been commercially available for three decades. Third, the technology is still dynamic so that incentives for technology development, as well as deployment, are policy relevant on their own. Fourth, while it is close to being cost competitive without government intervention, wind power still depends on government actions for widespread use. Fifth, governments have implemented a diverse set of policy instruments affecting incentives for the deployment of wind power across many jurisdictions for the life of the commercial industry. Finally, the industry is global.

The time period analyzed is the beginning of 1981 until the end of 2008 a period that spans the emergence of a commercial market for wind power to the most recent data available. The geographic extent of the project was selected as the six countries with the highest installed wind power capacity as of the end of 2007: Germany, the U.S., Spain, India, China, and Denmark (Wiser and Bolinger, 2008). These six markets account for

Table 1: Description of variables.

Variable		Description	Units
Installations	I_{it}	Capacity of new turbines	MW
Capital investment	K_{it}	$I_{it}W_t$	\$m
Elec. consumption	C_{it}	Size of electricity market	TWh
Energy prices (1)	E_{it}	Regional gas prices	\$/tcf
Energy prices (2)	N_{it}	Regional gas/coal prices	\$/tcf
Wind cap. cost	W_t	Cost of installed equipment	\$/kW
Policy: exists	$P1_{it}$	Dummy for wind policy	binary
Policy: stringent	$P2_{it}$	Dummy for stringent wind policy	binary

75% of cumulative world installed capacity and, with the exception of the past few years, have accounted for close to 90% of the world market for new wind power turbines. Because of the size of the market and the importance of sub-national policies, the U.S. was further separated into the five states comprising the largest installed capacities in the U.S.: Texas, California, Minnesota, Oklahoma, and Iowa. As a result, this study includes analysis of 12 distinct markets for wind power: the five U.S. states, the rest of the U.S., Germany, Spain, India, China, and Denmark, and the rest of the world.

3.2 Data

To address the research questions, a panel data set of 14 geographies over 28 years is assembled for variables related to: (1) investment in new wind power capacity, (2) prices for the competing technologies, (3) energy consumption, and (4) public policy. Table 1 provides a summary of the variables used, which are described in this section.

3.2.1 Investment in new capacity

Data were assembled on the megawatts (MW) of new wind turbine capacity installed in each market, i in each year, t. We denote installations using I_{it}. The annual share of

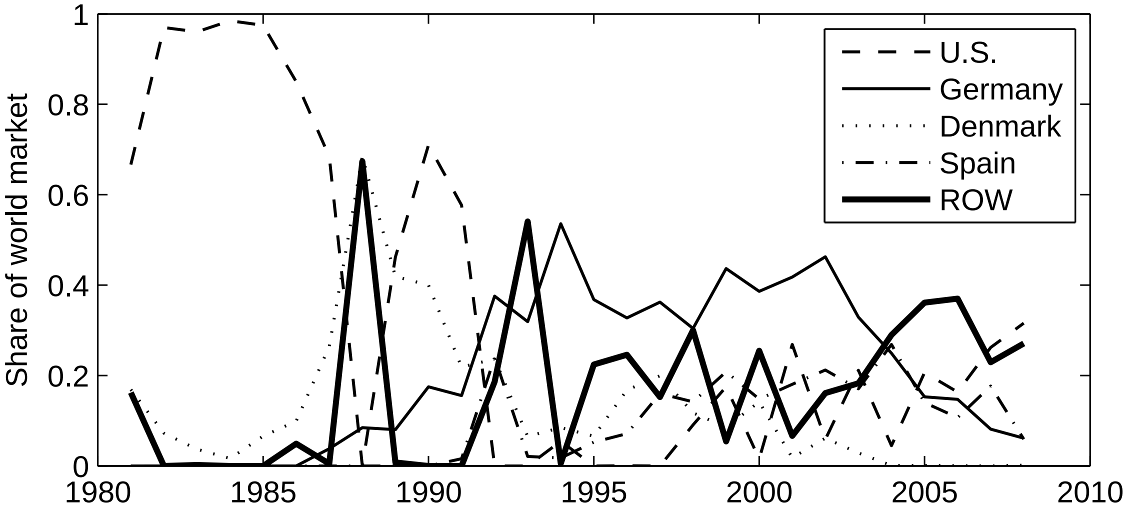

Figure 1: Share of worldwide wind power installations by country.

installations in each country as a share of the worldwide total is shown Fig. 1; ones sees an initial indication of the presence of market volatility.

We also assemble a time series of the prices (\$/kW of generation capacity) for installed wind turbines, W_t (Nemet, 2009b; Wiser et al., 2009). We make the simplifying assumption of a single worldwide price for wind turbine equipment. The global nature of the wind power industry supports this assumption, although unaccounted for local market dynamics, exchange rate fluctuations, and some locally produced equipment produce price differences across markets. In this study, the changes in annual installations dominate the changes in market size, such that the results are be robust to price differences across countries. The prices for wind turbines have declined considerably over time—by more than a factor of five in this time period.

Market size is defined by capital investment in wind turbines in each country in each year, K_{it}. Capital investment is the product of the capacity of turbines installed and the capital cost of turbines, $K_{it} = I_{it}W_t$. We treat market size as a proxy for the profitability of each market, i.e. we assume constant returns across markets. Enhanced by a factor of 4 decline in the prices of turbines, the annual world market for wind turbines has increased to tens of billions of dollars. The global wind market in 2008 was ten times larger than the market during the peak of the California wind boom of the mid-1980s. Note however that the value of turbines installed in California in 1984 remained the largest annual market in the U.S. until Texas in 2007.

3.2.2 Energy prices

Since nascent energy technologies, like wind, compete with established ones, the prices of the latter have important effects on incentives for investment in the former (Popp, 2002). Energy prices are notoriously variable over time and are thus important to control for. We construct a panel of energy prices representing a competitive price for each location over the study period.

In most cases, wind power competes with the highest marginal cost energy source, which is typically electricity from the combustion of natural gas. Pricing of natural gas varies over space, as well as over time, because transportation is expensive. We use average annual prices of natural gas for three regions (North America, Europe, and Asia) and convert prices into 2008 dollars per thousand cubic feet (tcf) (BP, 2009). In Asia, coal use for electricity is so dominant that it may represent the appropriate competing technology, rather than natural gas. We thus include an estimate for coal prices in Asia. We convert the coal price into equivalent physical units (tcf of natural gas) and further adjust for the fact that coal plants are typically less efficient at producing electricity than natural gas plants (Maruyama and Eckelman, 2009; Graus and Worrell, 2009); this factor inflates the gas equivalent price of coal by a factor of 1.25. Fig. 2 shows energy prices for natural gas for three geographies. Asian coal prices are also included to represent the competing technology in Asia. We thus

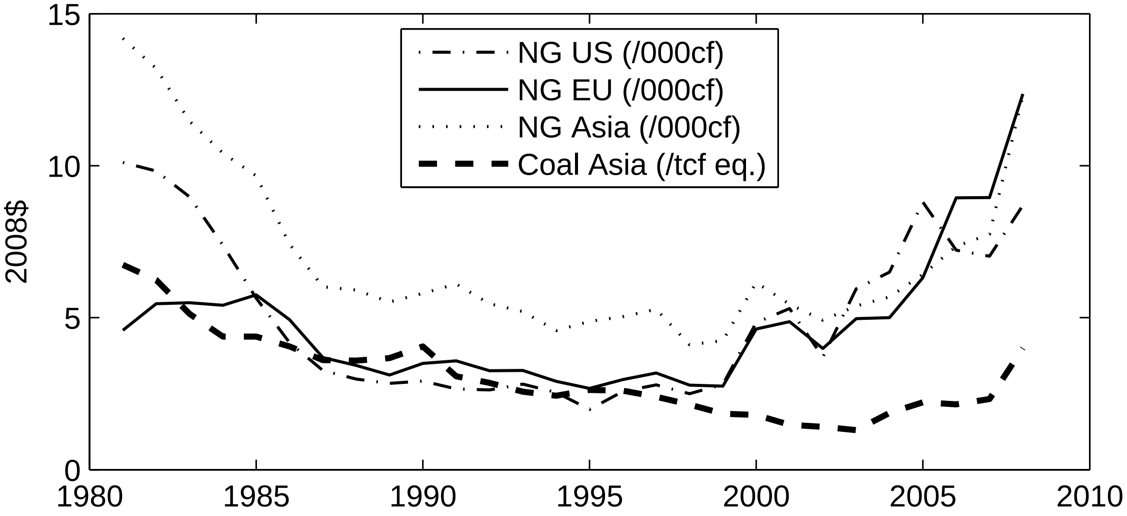

Figure 2: Energy prices in 2008$/000 cubic feet. Coal converted into tcf and adjusted for coal plants being 25% less efficient than natural gas plants.

construct two panels for energy prices—one which incorporates coal prices in Asia and one which uses natural gas prices in Asia. The first (E_{it}) assigns the regional price of natural gas to locations in North America and Europe, and assigns the regional price of coal (in natural gas equivalents) to China and India. The second (N_{it}) assigns the regional price of natural gas to all locations.

3.2.3 Electricity consumption

The market opportunity for new energy technologies also depends on the size of the total potential market for energy. We proxy for this market opportunity using estimates of electricity consumption, C_{it} over time for each location in units of terawatt hours (EIA, 2009a,b).

3.3 Policy variables

To identify the effect of policy on the incentives for investment in wind power, we surveyed the history of government actions related to wind power for each location from 1981–2008. We then coded each location according to whether a policy related to wind power was in place and, if so, whether any of those policies were stringent.

3.3.1 Policy history

A history of policies affecting demand for wind power was assembled for each of the six countries and 5 states for each year, 1980–2008. We identified the full set of policies related to wind power and documented the relevant characteristics of each including: the date the policy was signed into law; the date the policy went into force; the date the policy expired; the type of instrument, e.g. capital cost subsidy, feed in tariff, or renewable portfolio standard; the level of any financial incentives, e.g. % tax credit, $/kWh credit, $/kwh tariff, % renewables required; and additional descriptive information. A detailed compilation of these policies, including the references cited, is available as supplementary on-line information.

3.3.2 Coding the policy history

The policy environment for wind power for each country and each year was coded for whether a policy existed and whether any existing policy was stringent. Coding for whether a policy existed was straightforward. A policy was considered to "exist" if in location i at year t, a policy was in place that would have increased the market for wind power, regardless of how big an effect it was expected to have. Policy instruments that qualified included: financial incentives for producing power or installing equipment, technology mandates (such as renewables obligations), rules that enabled installation (such as interconnection agreements), and the imposition of costs on substitutes (such as eco taxes or carbon prices). We coded the variable $P1_{it} = 0$ in the absence of such a policy and 1 if any such policy was in place.

A second variable was used to code each location and year for *stringency.* Policy stringency $P2_{it} = 0$ if no stringent policies were in place, and 1 if there was at least 1 stringent policy in place. A two stage process was used to identify stringent policies. First, based on interviews with industry participants in earlier work on wind power policies (Taylor et al., 2006), we use the *type* of policy instrument described in our policy history to distinguish between policies that have the potential to be stringent and those which do not. For example, renewables purchase obligations, guaranteed purchase prices, and capital cost discounts have the potential to be stringent while loan guarantees, information programs, and interconnection agreements do not. The rationale for assigning policy instruments to the latter category is that while they may be helpful, and even necessary, they are not sufficient on their own to create an incentive for wind power development. Second, for those policies with the potential to be stringent, we compared the *level* of each policy instrument to threshold levels, which varied over time with the cost of wind power. For example, a tax credit of 1.5c/kWh would have been considered stringent in the 2000s but would not have been considered stringent in the 1980s when wind power was much higher than the cost of the competing technology.

Finally, two analysts independently coded the policy histories according to this protocol, each producing one matrix of dummy values for existence and one for stringency. The Appendix provides a more detailed explanation of the policy coding process including the selection of threshold levels, as well as the values themselves.

4 Results

This section uses the data described above to address the questions posed at the beginning of section 3. The first part of this section describes the finding that the influence of policy volatility on investment incentives is large, negative, and significant. In the second part, the data are used to asses the extent to which policy volatility can be hedged; it can be, but it relies on non-harmonized national policies.

4.1 Policy volatility has a large negative effect on investment

The first claim that emerges from these results is that policy volatility has a significant effect on the incentives for investment in clean energy technologies. This claim is based on observations that: (1) policy has been volatile, (2) that policy significantly affects the market opportunity, and (3) that volatile markets raise the risk of investment.

4.1.1 Volatile markets and volatile policies

The data support a fundamental premise of this research—both markets and policies have been volatile. Descriptively, one can see the effects of market volatility in Fig. 1. Market share for each location, measured as the share of the global market, has changed dramatically over time. Four different countries, the U.S., Germany, Denmark, and Spain, have at times been the largest wind power market in the world. In addition, in four years, the rest of the world, which is the sum of the markets outside the six analyzed in this study, has been larger than all of the individual large markets. The frequent changes in market share suggest that there is risk in concentrating investment in a single country.

One can also see volatility in the annual variation in market size. While Fig. 1 shows the volatility in the relative importance of each market, here we look at the absolute growth of each market. Using the 6 countries examined here, there were 130 annual growth rates

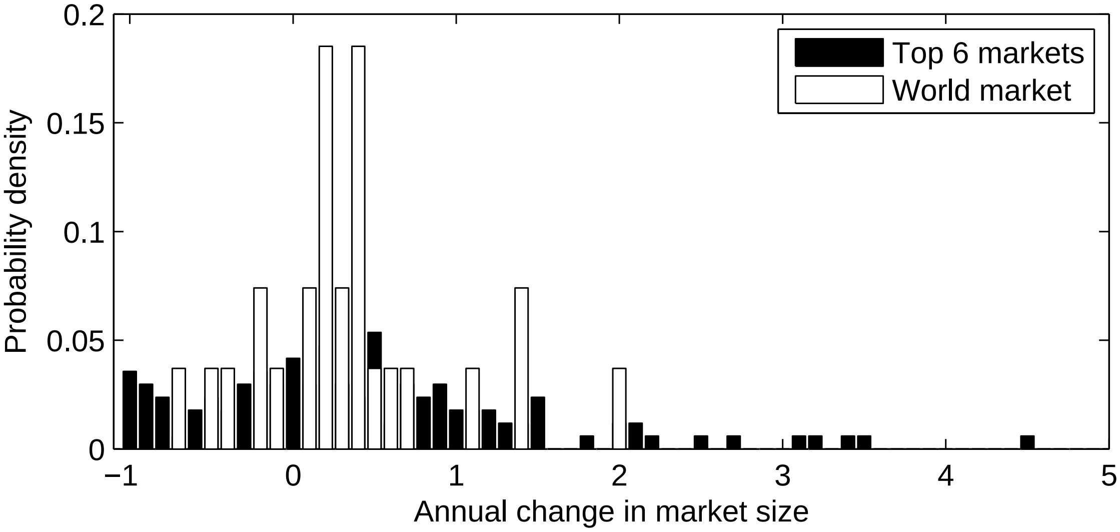

Figure 3: Probability density for annual change in market size. Black indicates six largest markets. White includes the entire world as one market.

between 1981 and 2008. Fig. 3 shows the distribution of those rates of change. One can see many examples of growth rates above 1 (100%), where markets more than doubled from on year to the next. Conversely, one also sees many instances of growth rates of -1, that is, where a market ceases to exist in a given year. Table 2 provides descriptive statistics about these annual changes. An important characteristic of these data, which is central to this paper, is that the standard deviation across the individual markets is substantially larger than that of the world taken as a single market. Volatility—calculated as standard deviation divided by the mean—is substantially larger for the individual markets. One can see this graphically in the flatter distribution of the individual markets (in black) compared to the world market (in white).

Policies in the large wind power markets have also been volatile. One can see this directly in the policy coding shown in the electronic Supplementary Material. Implementation of wind power policies emerged in different times—as early as 1981 in 3 countries

Table 2: Annual change in market size.

	World aggregated	6 countries	6 states, 5 countries
mean	0.40	0.76	0.90
median	0.32	0.35	0.34
std. dev.	0.60	1.74	2.31
volatility	1.51	2.29	2.56
n	27	130	174

and 3 U.S. states and as late as the mid-1990s in others. The implementation of stringent policies occurs later. Of central interest for this study, there were several instances in which a government implemented stringent polices and then eliminated them. For example, two years after introducing them, California cancelled its generous contracts for guaranteed purchase prices with little warning in the fall of 1985. The federal U.S. production tax credit has been allowed to expire three separate times in the 2000s. Note that collapsing a rich set of policies into a binary variable makes this measure a lower bound on policy volatility. It masks variation in the intensity of polices coded as stringent and does not count as a policy change cases in which one stringent policy was replaced with another.

4.1.2 Policy affects market size

Not only are both markets and policies volatile, but they are also linked. This section finds that policies have a significant effect on market size. The panel data described above are used to test the significance of variables for policy existence and policy stringency as determinants of the size of wind power markets. The estimation approach is as follows. We regress policy and control variables on two indicators of investment in wind power technology. The first dependent variable we use is megawatts of new wind power capacity, I_{it}. This measures actual deployment of the technology, not accounting for changes in prices, but primarily focused on the social goal, which is deployment of wind power technology.

Table 3: Descriptive statistics for dependent and independent variables.

Variable		n	Mean	Std.dev.	Min.	Max.	Units
Installations	I_{it}	308	297	718	0	6,160	MW
Cap. investment	K_{it}	308	492	1,230	0	11,796	08\$m
Elec. consump.	C_{it}	308	467	749	22	3,166	TWh
Energy prices 1	E_{it}	308	4.57	2.39	1.30	12.36	\$08/tcf
Energy prices 2	N_{it}	308	5.28	2.64	1.98	14.19	\$08/tcf
Wind cap. cost	W_t	308	2,213	1,021	1,340	5,652	08\$/kW
Policy: exists	$P1_{it}$	308	0.85	0.35	0.00	1.00	binary
Policy: stringent	$P2_{it}$	308	0.43	0.50	0.00	1.00	binary

The second dependent variable is annual investment in wind power in each location, K_{it}. This variable represents a direct measure of investment and as such an indicator of the effect on incentives, rather than on deployment of the technology itself. We identify the effect of policy using two binary variables: one for the existence of any wind power policy $P1_{it}$ and another for the existence of stringent wind power policy, $P2_{it}$. The two are additive so both dummies are included simultaneously. The three possible combinations for (P1, P2) are: (1,0), (1,1), and (0,0).

We add controls for energy prices, electricity consumption, and the cost of wind power. The strategy employed here is to control for two non-policy influences on investment incentives: (1) the size of the market potential, and (2) the relative cost of wind power and the competing technology—gas or coal. We proxy for the potential size of the market using a measure of electricity consumption, C_{it}. We account for the cost differential between wind and its competing technology using the cost of wind power capacity, W_t and region-specific indicators of energy prices, E_{it} and N_{it}. The hypothesis is that the cost of wind power should have a negative effect on investment and that energy prices should have a positive effect. Table 3 shows descriptive statistics for the dependent and independent variables used in the regression. For estimation, all ratio variables are logged.

Table 4 shows the results from regressing policy variables and controls on wind power investment. The table shows results for both random (1,2, and 3) and fixed effects (4,5, and 6) models. First, to account for both within and between location effects, three versions of a random effects model are estimated: (1) an initial version using investment as the dependent variable and an energy price variable that uses coal in Asia, (2) a similar version that uses the price of natural gas in Asia, and (3) a version of model 2 that uses installed capacity rather than dollars of investment as the dependent variable. The coefficients for the independent variables are all significant and with signs as expected. These results are robust to whether coal or gas prices are used and to whether dollars or megawatts of installations is used as a dependent variable. Both policy indicators are significant determinants of investment; but the effect of having stringent policy is a factor of 2–2.5 more influential than having any policy at all. Because the policy variables are additive, the total effect of having stringent policy is > 3 times the effect of having policy that is not stringent. The residuals are not correlated with any variables or with their lags. Second, to acknowledge that difficult to operationalize country-specific contexts may influence investment, three models that estimate geographic fixed effects are used as well. The variables used in models 4–6 correspond to the those used in models 1–3. The biggest change from the random effects model is that the coefficients on market size (electricity consumption) are now larger. Otherwise, the coefficient results are similar to what was found in the random effects model; policy is significant and stringent policy has a stronger effect. These results show that policy significantly affects investment. And since section 4.1.1 indicates that both policy and markets have been volatile, investors face a real concern that policy volatility makes investment risky.

Table 4: Coefficient estimates for 6 models. T ratios below coefficients.

		Random effects			Geog. fixed effects		
		(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable		$ln(I_{it})$	$ln(I_{it})$	$ln(K_{it})$	$ln(I_{it})$	$ln(I_{it})$	$ln(K_{it})$
Independent variables:							
Elec. consump.	C_{it}	0.57	0.43	0.48	2.30	2.01	2.19
		4.93	3.84	3.72	5.80	4.97	4.83
Energy prices (1)	E_{it}	1.68			1.84		
		6.52			7.20		
Energy prices (2)	N_{it}		1.83	1.86		1.79	1.82
			6.92	6.27		6.76	6.13
Wind cap. cost	W_t	-2.48	-2.67	-2.38	-1.83	-2.03	-1.70
		-5.90	-6.29	-4.99	-4.15	-4.40	-3.28
Policy: exists	$P1_{it}$	1.12	1.23	1.42	1.05	0.92	1.10
		3.60	3.96	4.06	3.11	2.73	2.92
Policy: stringent	$P2_{it}$	2.91	2.77	2.94	2.29	2.28	2.39
		12.28	11.48	10.85	8.90	8.72	8.13
Summary statistics:							
R^2		0.665	0.682	0.650	0.381	0.407	0.376
n		308	308	308	308	308	308
geographies		11	11	11	11	11	11

4.2 Operating globally reduces policy risk

If policy volatility makes investment risky, is it possible to hedge that risk? The second main claim that emerges from these data is that a hedge against policy risk is available because policies across locations are decided independently. Policies are not well correlated, in part because a diverse set of motivations exists for implementing policies that favor wind power. Investing globally reduces policy risk. However, an important caveat is that the value of globalization as a hedge against policy volatility depends on the independence of policies; policy harmonization would lessen the value of this hedge and may expose investments to greater risk.

4.2.1 Policies are uncorrelated across geography

Policy volatility is hedgeable because policies related to wind power are uncorrelated. One can observe this lack of correlation in Fig. 4, which shows annual growth rates for each location over time. Note that every single year from 1981–2008 includes locations in which the market was larger than the previous year and that every year also includes locations in which the market was smaller than the previous year. Growth rates for the two most important national wind power markets over this period, Germany and the U.S., have a correlation coefficient of -0.057. This paper does not seek to explain the reasons that countries and states decide to enact policies relevant to wind power, but is seems clear that the motivations for doing so are diverse.

4.2.2 Hedging policy risk

Because markets are not correlated, operating globally provides a hedge against volatility. This opportunity to hedge policy risk can be observed in two ways. First, as seen in Fig. 3 and Table 2, the volatility in the market growth is substantially smaller when considering

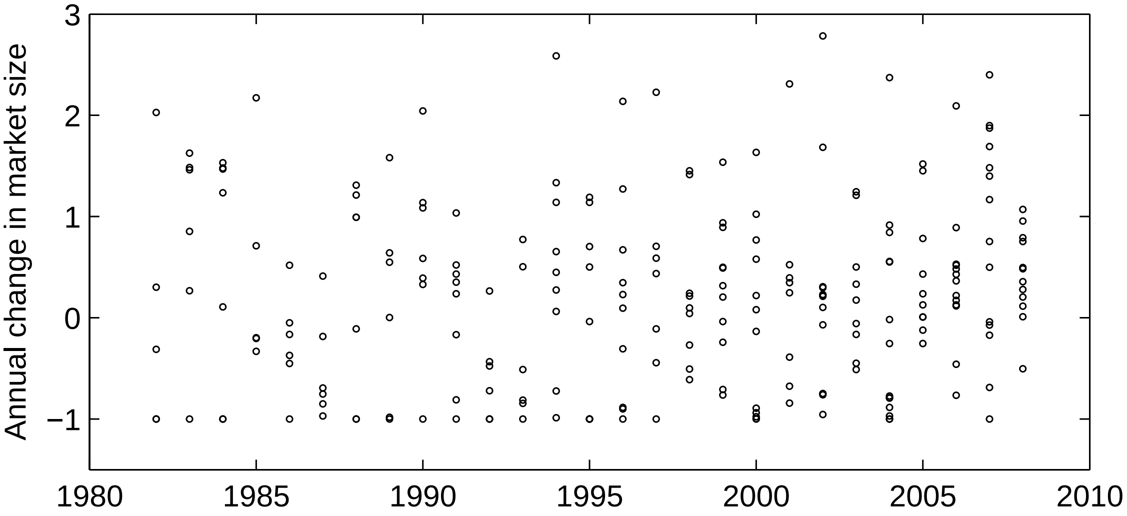

Figure 4: Annual growth rates for all markets.

the world as a single market (volatility=1.51) rather than viewing the 6 largest countries as individual markets (volatility=2.29). An investor operating globally would face a volatility of 1.51 while an investor operating in a single country would face a higher level of volatility, as characterized by the 2.29 value across all large markets. Including the individual states would raise volatility even higher to 2.56.

Second, one can compare two investment strategies. A wind power investor who maintained a market share of 10% of the world wind power market from 1981–2008 would generate revenues of just under $20b (converted to 2008 dollars but not discounted). An equivalent revenue could have been obtained with a 44% constant share of the U.S. market. Given equivalent mean annual revenues of $713m, standard deviation for the world market was $1189 while that for the U.S. was $1518. Put another way, concentration in the U.S. market would generate five years with zero revenues, while there were no years in which a 10% share of the world market produced no revenues.

4.2.3 Evidence of a global and less concentrated industry

Given the apparent opportunity to hedge policy risk, the data show that: (1) firms are taking advantage of this hedge and (2) the reduced concentration of the industry is making this hedge more viable. International trade in wind turbines has been large for three decades. In the 1980s, when California accounted for more than 90% of the world wind market, imported turbines accounted for 45% of new capacity in 1985, the peak year of the 1980s, and 75% in 1986 (WPRS, 1986). International trade continues to be important in more recent years. For the top-10 wind markets, 60% of the turbines installed in 2006 were imported from another country—an increase from 46% in 2005 (Lewis and Wiser, 2007; Lewis, 2007). Denmark, home to the world's largest turbine company (Vestas) has exported 91% of the 30 GW of turbines manufactured there between 1996 and 2006. China's domestic industry has grown rapidly, but still 42% of their new installations in 2007 were imported.

Reduced concentration and the emergence of multiple large markets have enabled this possibility to hedge policy risk. Wind power installations have been less geographically concentrated over time so that no single market dominates the industry. Calculating the Hirschman-Herfindahl index for these data shows that industry concentration has decreased over time (Fig. 5) (Hirschman, 1964). The trend in, and the level of, the index value is insensitive to the universe of markets used to define the index; whether using the top 6 countries, including the largest 5 states, or including all 76 countries in which some wind power installed, the industry has become less geographically concentrated. Consequently it has become less vulnerable to policy changes in any single location.

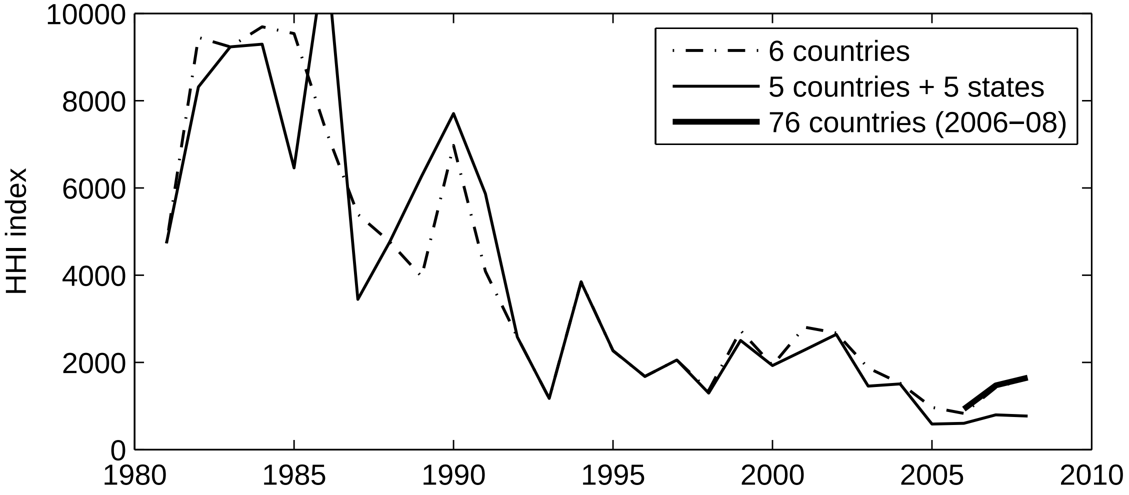

Figure 5: Concentration index (higher HHI score indicates higher concentration).

4.2.4 Implications of policy harmonization

An important limitation on this hedging possibility is that it hinges on policies being independent across locations. A mechanism that would tend to reduce independence would also reduce the value of the hedge. While there are certainly benefits to harmonization, as the following section discusses, it also introduces risk that is difficult to avoid.

5 Implications for climate governance

The magnitude of the changes required for the energy system to meaningfully address climate change make the incentives for technology development and deployment a central concern. The preferences of investors for stable and growing returns conflict with the history of energy policy, which is prone to rapid changes and even reversals. The data in this study show that this policy risk has been problematic. They also show that firms could have substantially reduced their risk by operating globally, so that they could take advantage of uncorrelated policy changes. Indeed, the high degree of globalization in the wind power industry, even from early on, is at least in part attributable to firms taking advantage of this opportunity to hedge policy risk. An important caveat is that the availability of this hedging opportunity in the future depends on policy decisions that are uncorrelated. Yet much of the effort on climate change governance has been oriented around implementing a more harmonized global approach to addressing the problem.

5.1 A simple model for future work

If the goal is to maintain incentives for technology development, would we be better off with a set of uncorrelated national and sub-national policies or with a harmonized global regime? As described above, strong claims have been made on both sides of the debate (Victor et al., 2005; Prins and Rayner, 2007; Schellnhuber, 2007). Since it looks at historical evidence of a single technology, this study does not clearly support either stance. But the evidence does imply a need to pay close attention to what we might lose with a harmonized global solution. More generally, this historical case suggests that design of a climate regime that optimizes incentives for technology investment depends primarily on three variables:

- the probability that any government, i will cancel its policy in period t (r_{it}).
- the correlation of policy changes with each other; in this case a covariance matrix for all governments i and j (c_{ij}).
- the probability that a harmonized global agreement will fail, in effect canceling policies globally (R_t).

The effects of a global collapse of a climate agreement occurring would be devastating to markets; essentially reducing incentives to zero. One could imagine technology developers populating a model that optimizes returns based on these three parameters. The higher the values for r_{it}, relative to R_t, the more likely the world would be better off with a global regime that limits the discretion of national governments to change their policies. However, the benefits of a global regime decrease with values for c_{ij}; the less correlated national policies are, the more viable it becomes to hedge national policy risk by investing simultaneously in multiple markets. Low values for c_{ij} can offset high values for r_{it}. Still, avoiding r_{it} completely is better than hedging some of it. The world would be better off with a harmonized global regime unless there is some possibility that that regime itself is vulnerable to policy volatility. The apparent failure, at the 15th Conference of the Parties to the UNFCCC in Copenhagen in late 2009, to extend and expand an existing global agreement supports the notion that $R_t > 0$. The possibility that a harmonized global regime may collapse, R_t, is what makes the model of disparate national policy mechanisms attractive. An important caveat with this strategy is that values for c_{ij} need to be much less than unity. A bottom-up approach to climate policy that is universally sensitive to the same roll-back mechanisms as a global agreement, is not superior to a global one.

Additional variables would enhance development of this type of model. For example, the benefits of reduced transactions costs from uniform policy would influence choice in the opposite direction of the hedging value. Also, one could argue that the levels of national policy stringency may be endogenous to the amount of correlation among them. For example, coordinated policies encourage willingness to pursue more ambitious targets by allaying competitiveness concerns. Conversely, they may lead to less ambitious targets due to lowest common denominator problems inherent in global negotiations. A more explicit discussion of these parameters would help inform debates about the optimal design of climate policy, from a technology development perspective. Work that estimates values would benefit debates as well. Finally, examination of incentives for the development of other low-carbon technologies would be helpful to address any concerns about generalizability of the case of wind power to low-carbon energy technologies in general.

5.2 Persistent drivers of policy volatility

A primary insight from this study is that climate policy design that assumes monotonically increasing stringency conflicts with historical experience of related policies over the past three decades. It would be socially risky to consider policy volatility a historical aberration from which we have learned. Volatility in energy policy is attributable to a diverse set of factors: rapid changes in energy prices due to supply shocks and demand shocks; emergent geo-political threats associated with access to energy; focusing events that raise the immediacy of perceived environmental problems; the electoral cycle, which both creates and limits opportunities for implementing policies; issue fatigue associated with portraying long term energy challenges as crises; the business cycle and associated concerns about employment and economic growth; and changes in the urgency of competing social priorities, such as wars, finance, health care, and education. It seems unlikely that any of these factors will become less important in the future. Meanwhile, the physical characteristics of both the climate and energy systems mean that problems will not be solved quickly, even if we make unprecedented and successful efforts to address them. As a result, there will always be competing social concerns at stake—and always an option of altering climate-related commitments. Given the inherently long time horizons required, policy needs to be robust to both the risk of a collapse of an international deal and the risk of correlated national policies in a bottom up framework. This situation implies that we should pursue national and international governance, independently—not because we want to see which is more effective, but rather because we need to protect those with large investments at stake from the inevitability of society's, and policy makers', competing social concerns. Another interpretation is that complementary policies may be needed to make up for incentives that are reduced due to policy risk (Galiana and Green, 2009).

5.3 Conclusion

The heterogeneity of public policies affecting wind power has provided an effective way for private sector innovators to reduce their exposure to the substantial policy risk resulting from chronic policy volatility. The development of a global regime for reducing emissions of greenhouse gases holds the promise of enlarging the market for new technologies and enhancing the incentives for deployment of needed low-carbon technologies. However, the consolidation of the bulk of important decisions in a single supra-national institution limits the ability of firms to hedge policy risk by entering multiple markets. Optimal policy design depends on valuations of policy volatility, correlation of policy changes, and the probability of a collapse of global regime. A harmonized global climate regime may be more efficient; but it could simultaneously be more risky.

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Appendix

This appendix describes the methodology used to code the existence and stringency of wind power policies in each year and geography. Details about the policies themselves are available as online Supplementary Material.

Policy existence

The main text describes the simple criteria used to identify whether a wind power policy was in place in each country and year. The value for $\mathrm{P1}_{it}$ was coded as 1 if a policy was in place that had the effect of increasing demand for wind power in that location and time. An observation was coded as 1 regardless of the strength of the effect.

Policy stringency

Each location's policy environment was coded for its stringency ($\mathrm{P2}_{it}$); 0 = not stringent, 1 = stringent. Coding for stringency involved the following: First, two categories of policies were defined based on their importance in affecting demand for wind power. The items within these categories were determined from interviews and analyses in Taylor et al. (2006) and Nemet (2009a), in which certain types of policies were found to be inherently more stringent than others. The following policy instruments have the potential to be coded as stringent:

- Purchase obligations: quantity based targets that require some entity—government agencies, electric utilities, companies—to buy a specified amount of wind or renewable power. A common example is state renewable portfolio standards (RPS).
- Guaranteed tariffs: agreements in which governments guarantee revenues to a wind power producer at a premium (e.g. \$/kWh) above the market electricity price for

a pre-specified period of time. Sometimes referred to as "feed-in tariffs", examples include programs in Spain and Germany in the 2000s and in California (SO#4) in the 1980s.

- Capital cost subsidies: governments offer to pay a specified portion of the capital cost of a wind power project. Payment is provided to the wind power producer as a tax credit or in the form of a direct payment as a rebate.
- Performance incentives: Government provides a subsidy to the power producer based on the amount of electricity they produce, either as a tax credit or as a direct payment.

In contrast, other policy instruments were considered inherently non-stringent because on their own they were insufficient to generate a substantial increase in demand for wind power. These include: loan discounts, loan guarantees, information programs, interconnection agreements, mandates that utilities buy from independent generators, renewable energy certificate programs, and policies that are limited to small wind power projects

Second, for those policy instruments categorized as having the potential to be stringent, threshold levels were calculated for each type of policy.

- Purchase obligations: any level of mandated purchases qualifies as stringent.
- Guaranteed tariffs: the threshold is calculated as the difference between the unsubsidized cost of wind power and the price of competing power generation technologies, assumed to be stable at 4c/kWh. These calculations imply approximate price thresholds of 10c/kWh in the 1980s, 3c/kWh in the 1990s and 1c/kWh in the 2000s.
- Capital cost subsidies: similarly, the threshold for stringency for capital cost discounts declined over time as the unsubsidized cost of wind power declined. Subsidies required to qualify as stringent are 1980s: >=50%, 1990s: >=30%, 2000s: >=25%.

- Performance incentives: we use the same threshold levels as described in capital cost subsidies.

Coding results

Using this protocol, two analysts independently coded the policy histories, each producing two 12×28 matrices of ones and zeroes. The two analysts agreed on 95.5% of the cells for policy existence (n=308) and 93.2% of the cells for policy stringency (n=308). The majority of conflict cases involved feed-in tariffs with rates that were close to the threshold level. Conflicting cells were then resolved by reading the policy history documentation and re-interpreting the stringency and existence of the policies with conflicting interpretations.