Green Industrial Policy: Trade and Theory*

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Abstract

This paper studies the reality and the potential for green industrial policy. We provide a summary of the green industrial policies, broadly understood, for five countries. We then consider the relation between green industrial policies and trade disputes, emphasizing the Brazil-US dispute involving ethanol and the broader US-China dispute. The theory of public policy provides many lessons for green industrial policy. We select four of these lessons, involving the Green Paradox, the choice of quantities versus prices with endogenous investment, the coordination issues arising from emissions control, and the ability of green industrial policies to promote cooperation in reducing a global public bad like carbon emissions.

Keywords: green industrial policy, trade conflicts, green paradox, asymmetric information, coordination games, participation games
JEL classification numbers: F13, F18, H21, H23

An economist is someone who when asked "How is your wife/husband?" instinctively responds "Compared to what?"

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1 Introduction

Green industrial policy, as used in this paper, refers to government attempts to hasten the development of low-carbon alternatives to fossil fuels. There are similarities, but also important differences between the arguments concerning green industrial policy and those that apply to industrial policy in general. The same factors that complicate attempts to assess the record of general industrial policy also apply to green industrial policy. We review these arguments and describe some of the difficulties of evaluating actual policies. We then summarize the green industrial policies currently being used in a group of developed and developing countries. Disputes between the US and Brazil and the US and China illustrate the trade issues created by green industrial policy. We then provide several examples of the use of theory in illuminating aspects of green industrial policy.

Governments use industrial policy to promote the development of new industries and the creation and adoption of new technologies. Types of industrial policy include tax credits, input, output and R&D subsidies, minimum use requirements, standards, and trade restrictions. The usual rationale for industrial policy is that it corrects a market failure. There may be a coordination problem, where the development of an industry requires several components, each of which is profitable to develop only if the others are also developed. By directing the development of a key component, the government may give the private sector the incentives to develop the ancillary components. There may be learning by doing that is external to firms, or network effects, or economies of scale that cannot be captured by a single firm. These situations involve market failures that in principle can be remedied by government intervention. Persistent unemployment, the desire to diversify an economy that is heavily dependent on volatile primary commodity prices, or the attempt to capture a first mover advantage are other rationalizations for industrial policies. These policies may also be motivated by the desire to support allies in crony capitalism.

Many people are skeptical of the wisdom of industrial policy, because they doubt the ability of governments to correctly identify and then to correct market failures. In a 2010 Economist's online debate[1] Dani Rodrik and Josh Lerner summarize the positions for and against industrial policy. They both recognize the abstract argument, based on market failures, in favor of

[1] See *http://www.economist.com/debate/days/view/541*

government policy, and both recognize the practical difficulties of successfully implementing industrial policy, particularly the difficulty of identifying winners, and preventing regulatory capture. Both provide examples of industrial policy whose success or failure support their position. Harrison and Rodriguez-Clare (2010) review the developing country experience with industrial policy. Rodrik (2009) views the empirical evidence concerning industrial policies as "uninformative", but considers the informational and bureaucratic constraints on these policies to be mutable. Lin (2010) notes the prevalence of industrial policies across both developed and developing countries, and suggest some tools based on statistical analysis that might help to identify good candidates for future industrial policy. Chang (2006) evaluates the role of industrial policy in East Asia, and concludes that there is scope for industrial policy even in countries at the technological frontier.

Green industrial policy is motivated by many of the same considerations that apply to general industrial policy. There are also two important reasons for using green industrial policies that are either absent or at least less compelling in the case of general industrial policy: a commitment problem and the endogeneity of future policy. The rewards of general industrial policy depend on the targeted industries' eventual success in the market. A government might be able to influence the development of its domestic industry, but still have limited ability to influence the market in which that industry operates. In contrast, *future* government policy largely determines the size of the market facing green industries, and therefore determines the profitability of green investments. Industries may be reluctant to undertake green R&D or to adopt green technologies because they are uncertain whether future policy will render these kinds of investments profitable. Current governments are not able to make credible commitments about the types of policies that will be in effect during the lifetime of these investments. Lacking the ability to ensure firms that current green investments will be profitable, governments may use green industrial policy to promote those investments. The second difference between the motivations for green and general industrial policy rests on the endogeneity of future environmental policy. The practicality of future carbon taxes, for example, depends on the future availability of alternative fuels, which depends on current investment. Green industrial policy provides current governments a means of influencing future environmental policy.

The belief that society will move or should move toward low-carbon energy sources may be based on the decline in low-cost fossil fuel stocks, the desire to diversify energy portfolios and reduce dependence on foreign suppliers, and concern about climate change caused by the build-up of atmospheric stocks of greenhouse gasses. Even politicians who view the movement toward low carbon alternatives as exogenous may support green industrial policies as a means of ensuring that domestic industries will be positioned to take advantage of future opportunities. Politicians may also see green industrial policy as offering an opportunity to increase domestic employment. These types of considerations are common to industrial policy in general.

While countries with a *dirigiste* tradition consider industrial policy to be a natural activity for governments, it tends to be viewed with considerable skepticism in the US. Even there, however, it enjoyed a kind of vogue during the 1980s and 1990s. Proponents of industrial policy sometimes agree that although governments are not well placed to pick winners, they can nevertheless intervene to promote well functioning markets. However, green industrial policy – like industrial policy of any hue – often does involve picking winners. This choice occurs at a micro and a macro level. As an example of the former, when a government decides to offer a particular company a loan guarantee, it makes a bet that this company will be a winner. The macro choices are more important. Brazil promotes sugar-based ethanol, and the US supports corn-based ethanol; Germany emphasizes solar power and China emphasizes wind power.

A broad based policy, such as a carbon tax or technology-neutral performance standards allows the market to identify winners. Most economists prefer those types of policies, but political realities limit their applicability. Both taxes and increased regulation are currently in bad odor. They might also be ineffective because of the commitment problem described above. Unless mandated or subsidized, current investment and adoption decisions depend on the anticipation of future policies, over which current governments have limited control.

It would be helpful to have retrospective studies that determine whether past green policies have been successes or failures, but any such study would be quite subjective. Brazil's ethanol policy illustrates the difficulties. This policy has been in effect for decades, and has resulted in a strong ethanol producing industry. On that ground it appears to be a success. However, we do not know what the counterfactual is; we do not know the opportunity cost of the resources devoted to Brazil's ethanol policy. Brazilian ethanol currently has low production costs because of previous investments in production capacity and infrastructure. If it had to start from scratch in building its ethanol industry today, even given the improved technology relative to the 1970s, would it be a good investment? How would the answer depend on future oil prices? We also lack reliable measures of the extent to which Brazil's ethanol policy has contributed to environmental problems, in particular deforestation; and there is no consensus about how to price those environmental consequences.

Brazil's ethanol policy also illustrates the policy risk that investors face. Brazil backed away from its ethanol polices when oil prices fell in the 1980s. As situations change, so does policy, exposing investors to policy risk. Investment subsidies shift some of that risk from private investors to taxpayers. This kind of risk-sharing is efficient in circumstances where the profitability of an investment depends on future government policy. Other examples of the potential responsiveness of policy to current circumstances include the oscillations in US subsidies for wind and solar over the past 25 years, and the recent attempt in California to overturn AB32, the green legislation passed several years ago.

Some green industrial policies seem less promising. For example, Germany, with approximately 60 days of sunlight a year, has invested heavily in solar power. However, the German policy has been in effect only a few years, the time during which investment costs tend to be highest. If Germany eliminates nuclear power more quickly than planned, or if its carbon fuel prices spike (e.g. if Russia decides to curtail deliveries of natural gas), the German investment might in the future be viewed as a success.

Green industrial policies are seldom the cheapest of way of achieving goals such as the reduction of gasoline consumption or reduction of carbon emissions. However, the environmental purpose of green industrial policy is to create a basis for future benefits, not (primarily at least) to achieve short run goals, except possibly as a metric of progress. Thus, the cost of achieving short run goals is not an adequate basis for judging the policies. Under plausible scenarios, the future benefits may be large, but those scenarios are speculative. For example, current investments in non-carbon fuel may delay the need to build some high carbon power plants, while also reducing future low carbon fuel costs via learning by doing or by the presence of economies of scale. In this case, the green policies lower future climate related damages directly, and make it easier to implement future green policies.

Our paper consists of three parts, a summary of current green industrial policy, a consideration of trade issues that arise from those policies, and a more general discussion applying lessons from the theory of public policy to green industrial policy.

First, we review green industrial policy used in five countries, Brazil, China, the US, India, and Germany. These countries have a wide variety of policies that promote the development of green energy, and thus qualify as components of industrial policy. There has been a rapid growth in green energy capacity in these countries and more generally across the world, together with significant decreases in the cost of this energy. Nevertheless, solar and wind power, two of the fastest growing sources of green energy, still make up less than 1% of energy supply in four of the five countries, and less than 2% in the fifth, Germany.

The current green industrial policies have been associated with trade disputes between Brazil and the US involving ethanol, and a broader dispute between the US and China. The Brazil-US ethanol dispute is a fairly typical type of trade disagreement, comparable to the Brazil-US cotton dispute. WTO law entitles signatories to receive the same treatment for their exports as "like" national products. This requirement of national treatment of like products means that Brazil's ethanol exports to the US would receive the subsidy (indirectly) given to US producers. To prevent Brazilian exporters from undercutting US producers, and sending US tax dollars to Brazil, the US imposed a near-prohibitive tariff on ethanol imports until the end of 2011, when the subsidy lapsed. An agreement to accord green products a favorable status with low tariffs would help to eliminate this kind of trade friction. Given the lack of progress in the Doha Round of WTO negotiations, the prospect of that change is slight.

The US-China dispute is more fundamental. For over a decade China has run a balance of trade surplus, and a particularly large surplus with the US. At the same time China has financed US consumption, in the form of purchases of US Treasury notes. These two phenomena are two sides of the same coin. China finances its purchase of US debt by running the balance of trade surplus; it maintains that surplus by means of an undervalued exchange rate and by the simultaneous suppression of domestic consumption. US policymakers would like China to reduce its trade surplus, to increase the demand for US exports and to reduce competition facing US import-competing sectors, thereby increasing US employment. However, the sudden cessation of China's purchases of US paper would make it harder for the US to maintain its fiscal deficit. There is little likelihood of reducing this fiscal deficit in the short run, and given the state of the economy perhaps it would be counterproductive to do so.

This conflict between the US and China is not the result primarily of sectoral conflicts, unlike the situation with Brazil and the US. However, there is the potential that the conflict will manifest at sectoral levels. For example, the US green stimulus generated increased demand for wind and solar components. The environmental benefit of wind and solar installation does not depend on the source of the components, but the stimulus effect does. As increased demand is met by imports from China, there are calls to restrict Chinese imports of these products. Again, a WTO-sanctioned agreement to exempt green products from trade restrictions would help remove this kind of pressure.

It will probably take years for the US-China trade conflict to unwind. A resolution will require increased consumption (and higher wages) in China and responsible fiscal policies in the US. These changes will be associated with an appreciation of China's currency against the dollar and a reduction in its trade surplus. Academic economists should discourage trade measures, and especially those that contravene WTO law. We should also discourage arguments that trade restrictions are justified by our partners' *past* green industrial policies, an argument sometimes made in the context of the US-Brazil dispute.

The theory of public policy provides a number of insights about the application of green industrial policy. It is widely thought that green industrial policy, by making future abatement cheaper, is a substitute for current reductions in pollution. In some circumstances that hypothesis makes sense, but the "Green Paradox" explains why it may be false in the case of fossil-based fuels such as oil. The price of these fuels includes scarcity rent, attributable to the finite supply of currently known low cost sources of the fuel. That scarcity rent, and thus the equilibrium price of oil, falls if resource owners expect future competition from alternative energy sources to reduce future oil prices. In addition, the marginal damages associated with carbon stocks are likely to increase with the level of those stocks (i.e. damages are convex in the stock). Under these circumstances, the adoption of green industrial policies, (possibly) creating future low cost alternatives to fossil fuels, increases rather than decreases the importance of current regulation of emissions. We also discuss a limitation of the Green Paradox as a basis for policy advice.

As noted above, the cost of reducing emissions at a point in time depends on previous investments. A large literature in environmental economics compares the choice of taxes and quantity restrictions when regulators and firms have asymmetric information about abatement costs shocks. When abatement costs depend on previous investment, the asymmetry of information about current costs means that the role of industrial policy is sensitive to the choice of instruments. If the regulator uses an emissions quota (cap and trade), then firms' optimal investment decisions lead to the information-constrained first best level of investment. In that case (barring other considerations) there is no role for industrial policy, e.g. investment subsidies. If, however, the regulator uses an emissions tax, the tax creates an investment distortion. That distortion could be offset by means of an industrial policy. Thus, the importance of industrial policy in this setting depends on the type of regulation that is used to control pollution.

The manner in which pollution is regulated can *create* coordination problems at the industry level; those coordination problems can create a role for government intervention in investment decisions – a type of green industrial policy. Consider the case where non-strategic firms make lumpy investment decisions that influence future abatement costs. For example, power suppliers' choices are lumpy: they must choose among a small number of types of power plants, and cannot build a plant that is two thirds of the way between two alternatives. Investment in low carbon power plants lowers the future cost of maintaining emissions below a given ceiling. Optimal policy depends on both the benefit of emissions reduction and the cost of achieving that reduction. Because green investments affect future abatement costs, those investments also affect future optimal policy, e.g. the stringency of the future emissions ceiling. Rational firms understand this relation. If individual firms are small relative to the aggregate, their individual investment decisions have negligible effect on the future social cost of abatement. Their individual investment decisions therefore have negligible effect on the future emissions ceiling, so it is rational for firms to behave nonstrategically with respect to policymakers. However, the *aggregate* investment decisions do affect the future abatement costs, and therefore affect the future environmental policy. That future environmental policy affects the benefit, to an individual firm, of the investment: the more stringent is the future policy, the more profitable is the investment. Through this mechanism, the aggregate investment decisions affect the profitability of investment. In this setting, if regulators use a cap and trade policy, the level of investment is first best, and there is no need for industrial policy. However, if the regulator uses a pollution cap and forbids trade in permits, firms play a coordination game at the investment stage. There are multiple equilibria to this game, creating a role for industrial policy that influences the level of investment.

Finally, we consider the ability of industrial policy to promote cooperation in solving global externalities. The reduction in abatement cost achieved by the application of green industrial policy might increase with the number of other countries that adopt this policy. For example, there may be increasing returns to scale, or network effects arising from this policy. In this setting, even if green industrial policy does promote cooperation, it is likely to do so to a limited extent.

2 Current green industrial policies

There has been a surge in renewable energy investment over the last several years, spurred by more active renewables policy across the globe.[2] Currently at least 119 countries have some sort of renewable energy policy in place at the national level, more than double the number of countries with such policies in 2005. Solar photovoltaics (PV), wind, solar water heating systems and biofuels have been growing at average rates ranging from 15% to nearly 50% annually. Approximately half of the new electric capacity added in 2010 came from renewable sources. Total investment in renewable energy reached $211 billion in 2010, a 32% increase from the previous year. Renewable energy, including hydropower, geothermal and biomass, provided approximately 16% of global energy use in 2009.

Developing countries have recently overtaken developed countries in renewable energy investment. For the second year in a row, China was the global leader in new investment in renewables, attracting $49 billion in 2010, more than two thirds of investment for developing countries. The United States ranked second in investment in the renewables sector, followed by Germany.

Appendix A discusses current green industrial policies in Brazil, the US, China, India and Germany for wind, solar and biofuels. Here we provide a broad overview of these policies in transportation, and in large and in small scale electricity generation.

Mandatory blending requirements are probably the most influential policy support for biofuels. Other important policy tools include direct subsidies, tax incentives, infrastructure development, low-cost financing, and R&D support. Mandatory blending laws exist in 31 countries at the national level and

[2] Much of the data from this section is taken from the Renewable Energy Policy Network for the 21st Century, REN21 (2009, 2011).

29 states and/or provinces. They take the form of either nationwide usage targets, blending standards on all fuels, or simply a required option at the gas station. Biofuel mandates work by ensuring producers that there will be a minimal level of demand for their products. In the absence of subsidies, consumers bear some of the extra costs of this fuel. Unless demand is completely inelastic, producers also bear some of the incidence, in the form of reduced rents.

In 2010 the US was the world's largest producer of biofuels, followed by Brazil; the two together accounted for 88% of the world's total ethanol production. Sugar-based ethanol provided 41.5% of Brazil's light duty transport fuel, and corn-based ethanol provided 4% of the US fuel consumption. Globally, liquid biofuels provide about 2.7% of road transport fuels. The last few years have seen an increasing consolidation of the biofuel industry. Traditional energy companies have been moving into this field and supply chains have become increasingly vertically integrated.

The most common policy tool in promoting renewable electricity is the feed-in tariff, which is in place in 61 countries and 26 states/provinces. Although details differ among countries, this mechanism involves a guaranteed premium rate at which electricity is purchased from the generating source, as well as long-term supply contracts. The rate is usually specific to the energy source and depends on the type of renewable power that the government is trying to promote. The feed-in tariff is often combined with renewable portfolio standards (RPS) enacted on a state or national level; these require that a certain percentage of the electricity sold comes from renewable sources. Long term targets for renewable energy – most oriented towards electricity generation – now exist in 98 countries and typically have targets of 10-30% within the next one to two decades.

Amongst the renewables, PV has seen the fastest growth over the last few years. There were more than 5000 utility scale PV plants in 2010, up from 3200 in 2009. Both strong policy support and falling costs have contributed to this rapid growth. Between 2008 and 2010 the average cost of PV has fallen from approximately 4 to 1.4 dollars per watt of capacity, a 65% drop (IPCC 2011). However wind is still the dominant source of non-hydro renewable energy, with a global capacity of 198 gigawatts compared to 40 for solar PV. Wind has been growing by a fairly steady 25% per year average over the last five years. There has been a trend towards increased size of individual wind projects, driven by cost considerations such as grid infrastructure and licensing costs. China leads the world in wind capacity; Germany leads in solar PV.

The production cost for wind-generated electricity is 5-9 cents/KwH and for solar-generated electricity 15-30 cents/KwH. However, the cost of a *usable* kilowatt hour is higher for both. In many places wind is weakest during the hours of peak energy demand, and because electricity storage is expensive there is overproduction of electricity when it is least needed. Solar has the advantage of being produced during peak hours, but production varies significantly as clouds move across the sun. To compensate for this variation, extra energy must be kept in reserve, raising costs. Developing better electricity storage technologies would significantly lower the cost of using renewable electricity.

Renewable energy policy is linked to development policy through incentives to provide electricity, hot water and cooking fuel to rural and poor communities. The challenges that rural communities face in connecting to grid infrastructure often make renewable energy sources the cheapest and most practical solution. Rural electrification is generally heavily subsidized. Financing is rarely given directly to individual households; investment funds are typically allocated through private companies, community groups, NGOs and microfinance organizations.

There have been many campaigns in the last ten years to bring solar, small-scale hydro and wind electricity to rural communities and to promote the use of solar water heaters, biogas plants and other projects. Solar water heaters operate through the absorption of the sun's heat through black pipes and tanks. Biogas plants (used often for cooking fuels) consist of an underground digester tank in which bacteria converts organic waste into methane, and a storage tank. Both systems are low-tech and easily implemented.

3 Trade issues

Large-scale industrial policy usually has trade ramifications, and green industrial policy is no exception. Frictions between the US and Brazil and the US and China illustrate the kinds of trade issues that are likely to become more frequent, as countries adopt low carbon energy policies.

China's green industrial policy has underwritten the fixed costs of developing an industry that produces components for solar and wind powered energy. The US and other of China's trading partners have embarked on more modest green industrial policies. In the US in particular, these policies have been presented as a means of achieving three goals: increasing aggregate demand in order to increase employment, nurturing an infant industry that one day will provide economic benefits, and reducing dependency on energy imports, chiefly in order to advance geopolitical goals. The environmental benefit of reducing US dependence on fossil fuels is usually given less weight in arguing for these policies. The import of cheap components from China undermines the first two goals, but reduces the short run cost of lowering dependence on fossil fuels, and thereby benefits the environment at least in the short run.

There are at least three reasons why, by harming US and European green industries, low cost green imports from China might be inimical to long run environmental goals. These kinds of arguments cannot be dismissed out of hand, but they are not compelling.

First, it may be important to develop green industries in several countries in order to maintain future competition. China's cheap exports of green products might be construed as dumping, a kind of predatory pricing intended to diminish future competition. The charge of predatory pricing is often made, but difficult to prove. This difficulty is especially great in new technology areas, where the price of a product is likely to be lower than average production costs because large sunk costs have not been amortized. Antidumping cases are brought in order to shield domestic firms from foreign competition. Even if there were a sound economic reason for bringing an antidumping case, it will become harder to do so when China gains the WTO status of a market economy in a few years.

The second environmental rationale for opposing low cost green imports is that policy is endogenous. The existence of an efficient green sector in the west will probably make it politically easier, in the US in particular, to adopt low carbon policies in the future. These policies create a market for green technology. Politicians may find manufacturers who want to ensure a market for their green products more persuasive than they find environmentalists. This argument cuts both ways. An efficient green sector in China also makes it politically easier for China to agree to future limits on carbon emissions. China has been an obstacle to achieving a climate agreement. Low carbon policies will have more support the cheaper these policies are to adopt.

The third type of rationale is even more speculative. The economies of scale within a single country are probably limited. Aggregate costs of producing green components might be lower if several countries rather than only one or two have large green sectors. To the extent that this claim is true, it probably has more to do with the increased competition that arises when production is geographically dispersed than from (obscure) technical mechanisms. Trade restrictions are the wrong way to go about promoting this competition.

Just as environmental objectives were not the primary rationale for US green industrial policy, they also are not the basis for objecting to low cost green imports from China. Industrial policy can promote a trade surplus in the targeted sectors but would be unlikely to matter much to the overall trade balance. China's green-sector trade surplus is part of a large aggregate balance of trade surplus, attributed to an undervalued exchange rate maintained by China's suppression of domestic consumption. This aggregate trade imbalance, rather than sectoral imbalances, is the source of US-China conflict. Unilateral action at the sectoral level, such as imposing tariffs against China's green exports, is not likely to contribute to the resolution of the tension between China and its trading partners.

The dispute between the US and Brazil regarding ethanol is another example of a green trade conflict. The GATT, Article III, enshrines the principle that "like" products produced at home and abroad receive the same treatment. In order to comply with this principle, the US ethanol tax credit (VEETC), which was eliminated at the end of 2011, was payable to both domestic and foreign ethanol suppliers. However, the US also imposed a tariff consisting of a 2.5% sales tax and $0.54 per gallon unit tax. Defenders of this tariff claim that it counteracted generous Brazilian subsidies and prevented Brazilian producers from taking advantage of domestic US subsidies – a right conferred by WTO membership. The idea that a tariff can be justified on the basis that it eliminates the fiscal cost of ensuring that domestic subsidies are WTO-compliant, has an Alice in Wonderland quality. Moreover, the tariff was approximately 33% higher than the tax credit, and Brazil had already eliminated direct subsidies. The claim that trading partners' past policies justify current trade restrictions seems unlikely to have a legal foundation; that kind of appeal to history would open the floodgates to protectionism.

It would be a considerable achievement to accord green products, including biofuels, special status that exempts them from tariffs, or at least limits the tariffs that they face. China has (at least on paper) adopted such a policy unilaterally. The prospects for such an agreement under the aegis of WTO seem no better than the prospects for the Doha Round in general. If such an agreement were reached, there would still be the option (under Article XX of WTO) of restricting trade for environmental reasons, as was established by the WTO Appellate Body in the dispute involving shrimp and turtles in the late 1990s. That flexibility would be important to prevent, for example, deforestation in developing countries for the creation of biofuel plantations.

Largely in response to concern about the US fiscal deficit, Congress allowed the ethanol tax credit to expire at the end of 2011, and with it the tariff (New York Times, January 1 2012). The US requirement to blend increasing amounts of ethanol in gasoline remains. The loss of the tax credit will therefore not reduce US demand for ethanol, but will reduce blenders' profits and possibly increase the price to consumers. In recent years, Brazil imported small quantities of ethanol from the US, as a result of high world food demand for sugar and for competing crops. If these conditions continue, US corn producers will not face increased competition from Brazil, and US corn prices will not fall. In that situation, US farmers will not be harmed by the elimination of the subsidy and the tariff. However, if conditions change (e.g. world demand for sugar falls or Brazil's sugar harvests increase), US corn farmers may face competition from Brazilian ethanol exports. In that situation, corn producers' demand for support, and concomitant trade frictions, might reappear.[3]

4 Lessons from the theory of public policy

This section provides four examples of the lessons that the theory of public policy has for green industrial policy. First, there are circumstance under which green industrial policy and current environmental regulation are complements, rather than substitutes as is often thought. Second, when there is asymmetric information about abatement costs, and moreover those costs

[3]The tax credit VEETC transferred nearly $6 billion from the US treasury to the US blending industry in 2011 (New York Times), and over $30 billion since 2004 (Taxpayers for Common Sense). The industry group, the Renewable Fuels Association, stated "We are not seeking an extension of the ethanol blenders tax incentive. The industry is moving on. VEETC did what subsidies are supposed to do: help build an industry, ensure that it is stable and successful, and then fade away." The Taxpayers for Common Sense states that companies and groups affiliated with the biofuels industry spent $31 million in lobbying in 2011 and are currently seeking federal funding for ethanol infrastructure and an expansion of the Alternative Fuels Tax Credit to subsidize E85. The Renewable Fuels Association appears to be "moving on" by seeking a different form of subsidy, not eschewing the public trough.

depend on previous investment decisions, the benefit of green industrial policy depends on whether the regulator uses an emissions tax or cap-and-trade to control emissions. Third, when firms have lumpy investment opportunities that affect abatement costs, the type of policy used to control emissions can alter the nature of firms' interactions and thereby alter the role of green industrial policy. Fourth, positive externalities might cause industrial policies in other countries to increase the benefit to a single country of using industrial policy; in this circumstance, industrial policies might alter the equilibrium amount of cooperation amongst nations.

4.1 The Green Paradox and industrial policy

The price at which an owner of a nonrenewable resource is willing to sell the resource in the current period depends on the price that they believe the resource will command in the future. The difference between equilibrium price and the extraction costs (absent oligopoly power) is the scarcity rent. A higher expected future price increases the scarcity rent,making it more attractive to store the resource rather than sell (and consume) it today. Thus, higher expected future prices reduce the availability of supply in the current period, increasing the current equilibrium price and reducing current consumption. Conversely, lower expected future prices increase the availability of supply in the current period, decreasing the current equilibrium price and increasing the current equilibrium level of consumption.

The Green Paradox suggest that this relation between future prices and current equilibrium consumption might cause green policies to backfire, actually worsening an environmental problem. Here we discuss the Green Paradox, emphasizing its relation to green industrial (as distinct from emissions) policies. We close the section by pointing out a complication that may limit the policy relevance of the Green Paradox.

The chain of causation underlying the Green Paradox is that future policies, e.g. carbon taxes that begin or increase in the future, lower the future producer price of oil, thereby lowering the scarcity rent and the equilibrium current price (Sinn 2008). Hoel (2008) and Winter (2011) note that green industrial policies have the same effect. Green industrial policies decrease the anticipated future cost of fossil fuel substitutes, decreasing anticipated future demand for fossil fuels and lowering the future fossil fuel price. These changes lower the scarcity rent and shift out the current supply function, increasing current equilibrium supply. To the extent that environmental damages are greater if a given amount of fossil fuels is consumed over a shorter rather than a longer period of time, green industrial policies can be counterproductive. In addition, the green industrial policies make current restrictions on carbon emissions more rather than less important. In this sense, emissions policies and green industrial policies are likely to be complements rather than substitutes.

To simplify the discussion, we ignore here the oligopoly rent. The usual static supply and demand model provides a useful way of thinking about the spot market equilibrium, except that in this model the supply function consists of both the marginal production costs and the scarcity rent. We can view this static model as representing supply and demand for the near future, e.g. the next 25 years. The relevance of the Green Paradox, in the current context, depends on the assumption that damages are convex in the amount of emissions that occur during a relatively short period, such as a quarter century. We explain the result taking that assumption as given, and then discuss its plausibility.

A linear example helps to make the relation between green industrial policy and current emissions policy concrete. In this example, Q is the amount of the fuel brought to market during the 25 year period. The inverse demand is $P = A - BQ$ and marginal cost (inclusive of scarcity rent) is cQ. With a linear relation between Q and GHG emissions and a linear marginal damage function, the marginal externality cost is also linear, DQ. The optimal *ad valorem* tax in this static setting is $\tau = \frac{D}{c+D}$, the tax that causes the private tax-inclusive cost of bringing the commodity to market to equal the social cost. A green industrial policy lowers the scarcity rent and therefore lowers c, increasing the optimal tax. Figure 1 illustrates this model.[4] As the slope of the private marginal cost decreases from c to $c' < c$, the optimal *unit* tax decreases from the height of the line segment labelled t to the height of the line segment labelled t'. This comparative statics experiment illustrates the complementarity of the industrial policy and the policy that limits current emissions.

The example also shows that the complementarity of the two types of policies depends on the assumed convexity of damages. If marginal damages were constant, the optimal tax is also constant, and independent of c. If damages are concave in the stock of greenhouse gas (e.g., beyond a certain

[4]The parameter values used to construct this figure are $A = 10, B = 1, c = 2, c' = 0.8$ and $D = 0.5$.

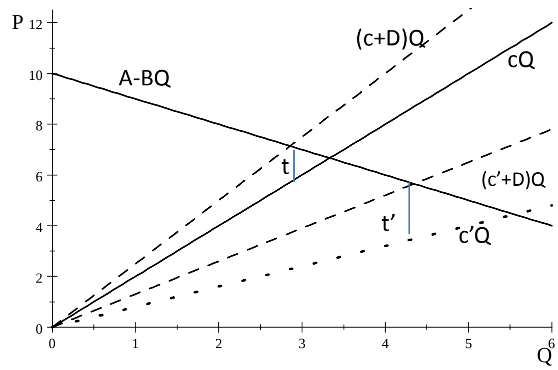

Figure 1: A downward rotation of the supply curve increases the optimal tax

level, additional stocks cause little additional damage) current regulation and green industrial policies are substitutes.

Most environmental economists think that damages are likely to be convex in *stocks*. We now turn to the plausibility of the assumption that damages are convex in Q, which represent emissions, a flow. The usual challenge to that assumption is based on the fact that GHGs are a stock rather than a flow pollutant, and that emissions during a short period (relative to the half life of the stocks) are small relative to the stock size. This observation means that the change in damages arising from a change in emissions can be adequately approximated using a first order Taylor approximation to the damage function. If that claim is correct, then as noted above, green policies that lower future prices and thus lower the current rent have no effect on the current optimal emissions tax. There are, however, reasons to doubt that a constant marginal damage provides a good approximation to the true damage function.

First, there is considerable inertia in the climate system, which is associated with the potential for abrupt changes that are not reversible on a policy-relevant time scale. Consider two scenarios; in one, there is an additional $2x$ units of emissions over the next 25 years, and in the second there is an additional x units of emissions in both of the next two 25 year periods. In the absence of inertia or the potential for abrupt changes, the world 100 years from now is better off in the first scenario. Moving the x units of emissions from the second to the first quarter century gives it longer to decay, so the stock (and thus damages) 100 years from now is lower in the second scenario than in the first. The possibility of abrupt changes favors the second scenario, because there the stock of GHGs is (slightly) less likely to cross a threshold that triggers an abrupt change. If the second scenario is worse for the future than the first, then there is a plausible case that (the present discounted value of) marginal damages are increasing in emissions.[5]

There is also a more subtle issue, that arises because here we use a static model to represent a situation that is actually dynamic. The optimal emissions tax ($\frac{D}{c+D}$ in the linear example above) depends on the relative slopes of marginal costs inclusive of scarcity rent, c, and marginal environmental damage, D. In a static model, these slopes have the same units, so their comparison is sensible. The two slopes do not have the same units in a dynamic setting, where one involves the slope of costs with respect to the flow of emissions, and the other involves the slope of costs with respect to the stock of GHGs.[6] The intuition underlying the belief that marginal damages are nearly constant and that therefore the green industrial policy is unrelated to the optimal level of the current emissions policy, is misleading. In a dynamic setting, other considerations, including the decay rate of the stock and the discount rate used to evaluate future costs and benefits, also play an important role.

The model underlying the Green Paradox, like all models, is built on a number of simplifying assumptions. One of these is almost certainly not correct, and it limits the policy-relevance of the Green Paradox. The Green Paradox, at least in its standard form, takes potential future supply as exogenous, so the only effect of policy is to change the timing of emissions. Of course, potential future supply depends on investments in the exploration and development of oil fields and the transportation infrastructure (pipelines) needed to bring the product to market. These investments sometimes involve enormous sunk costs: consider Canada's tar sands and Brazil's offshore oil deposits. The optimality of making these initial investments depends on expectations of future prices. Once the investments are made, marginal

[5] Another way to think about this is that we are at a point where expected damages are extremely convex in the stock, so that a first order Taylor approximation to damages is not adequate for the purpose of formulating policy.

[6] The same problem arises if we attempt to use intuition from the static model used to compare taxes and quotas under asymmetric information. In the static model, comparison of taxes and quanties depends on the relative magitude of the slope of marginal abatement cost and marginal damages. These slopes have different units in a dynamic setting, so comparison of policies is necessarily more complicated (Hoel and Karp 2002).

extraction costs are moderate and it is optimal to exploit the fields even if the return does not cover the sunk cost. Green industrial policy or credible future emissions taxes both lower future oil prices, lowering the profitability of investing in these fields, overturning or at least weakening the Green Paradox.

4.2 Instrument selection with information asymmetries

The cost to firms, and thus the cost to society, of reducing pollution at a point in time depends on firms' stock of "green capital" at that time. Because of the expense of rapidly changing the stock of this capital (i.e. convex adjustment costs), the cost of reducing pollution at a point in time depends on previous investment decisions. In world where the unpriced pollution externality is the sole distortion, a pollution tax or a cap and trade scheme that achieves the optimal level of pollution conditional on firms' level of green capital, also achieves the optimal level of investment in green capital. In this setting, with the optimal emissions tax or quota, there is no need for green industrial policies to encourage firms to invest in green capital. This result arises because the tax or quota cause firms to internalize the cost of emissions, and their cost-minimizing behavior then leads to socially optimal investment.

Here we consider a situation where both taxes and cap and trade are politically feasible, and there are none of the investment-related market failures often used to motivate industrial policy. However, there is asymmetric information: firms receive a shock that effects their marginal abatement costs, and this shock is private information to the firms. The regulator knows only the distribution of these shocks.

If the regulator uses a cap-and-trade policy, there is no additional benefit of also having a green industrial policy that enables the regulator to influence investment. With a cap-and-trade policy the regulator has a single instrument (the cap) and only one target (one "bird"), the level of emissions. However, the regulator who uses a pollution tax has two targets (two "birds"), the level of emissions and the level of investment, but still only one instrument (here, the tax). When the regulator uses an emissions tax, the availability of a second policy, such as green industrial policy that enables the regulator to directly influence the firms' investment decision, improves welfare. The only exception to this claim occurs under quite special circumstances: when the "two birds" under the tax are exactly lined up, so that it is as if they were a single bird (Karp and Zhang 2012). This claim is not obvious, and it does not (apparently) have a simple explanation. Section 4.2.1 provides a formal model that confirms the claim. Readers willing to accept the claim on faith can skip that section without loss of continuity.

Thus, with asymmetric information about abatement costs and the possibility of investments that lower abatement costs, the value of green industrial policy depends on the form of policy used to control pollution. With asymmetric information regarding abatement cost shocks, the use of a pollution tax creates a role for green industrial policy to target investment. In contrast, when the regulator uses an emissions cap, the private investment decision is information-constrained optimal, and there is no role for green industrial policy.

4.2.1 Model details

A one period, multistage model, helps to explain why the tax and the cap and trade have different implications for green industrial policy. In the first stage, the regulator chooses either a tax or an emissions ceiling. Taking the current policy level – the tax or the quota – as given, firms then make their investment decision, which affects their next-stage abatements costs. Nature then reveals a current cost shock (e.g. the price of labor or materials needed to abate) and firms then make their production and emissions decisions conditional on this information.[7]

Denote x as emissions, k as the level of green capital, and θ as the random variable that affects abatement costs. Denote $C(x, k, \theta)$ as the sum of abatement costs plus environmental costs, and denote $I(k)$ as the (convex) investment costs. The regulator's objective is to minimize the expectation over θ of the sum of these costs, $E_\theta [C(x, k, \theta) + I(k)]$.

The regulator who uses a tax, τ, understands the the firm's optimal investment level depends on the tax, $k = k^*(\tau)$, but not on θ, because the firm

[7]It may appear that the results of the model are sensitive to the timing of actions, in particular the assumption the regulator chooses the level of the policy before firms make their investment decisions. However, this one period model is merely a device for thinking about a genuinely dynamic model. In that model, the stock of GHGs and of green capital at the beginning of a period depend on previous stocks and previous emissions and investment decisions. Even if, as in the one period example, the regulator moves before firms within a period, firms in the current period move before regulators in future periods. Thus, the game is really one of alternating rather than sequential moves. Changing the timing within a period does not qualitatively affect the model.

chooses investment before observing θ. In addition, the firm's emissions level depends on the tax, the level of green capital, and the realization of the random variable, $x = x^* (\tau, k, \theta)$. The regulator's first order condition is

$$\begin{array}{c} E_\theta \left[C_x (x^*, k^*, \theta) \frac{\partial x^*(\tau, k^*, \theta)}{\partial \tau} \right] + \\ E_\theta \left[(C_x (x^*, k^*, \theta) + I'(k)) \frac{\partial x^*(\tau, k^*, \theta)}{\partial k} \frac{dk^*}{d\tau} \right] = 0. \end{array} \tag{1}$$

The two terms on the left side of this equation are the two margins that the regulator would like control, i.e. the two "targets" that she would like to hit. The first term is the marginal (abatement plus environmental) costs resulting from a marginal increase in emissions due to a change in the tax, holding the level of investment constant. The second term is the change in marginal cost resulting from a change in investment, due to a change in the tax. A regulator who has two policies, an emissions tax and an investment tax/subsidy can set each of these margins equal to zero. In contrast, a regulator with a single policy, here the emissions tax, can only set the sum of the two margins equal to 0. Except in very special circumstances, when the two targets are perfectly lined up, having a second policy instrument increases the regulator's expected payoff.

Now consider the situation of a regulator who uses an emissions cap, X. We assume that the environmental problem is great enough that the cap is binding for all realizations of θ. In this case, the regulator controls emissions directly, rather than merely influencing emissions (as under the tax). The first order condition for the regulator's problem is now

$$E_\theta [C_x (X, k^*, \theta)] + E_\theta \left[(C_k (X, k^*, \theta) + I'(k)) \frac{dk^*}{dX} \right] = 0. \tag{2}$$

The important difference between the two first order conditions is that the emissions decision depends on the realization of θ under the tax, in equation (1); under a cap, the regulator chooses emissions, so $x = X$, which is independent of θ, in equation (2).

We now decompose the total cost associated with emissions:

$$C (x, k, \theta) = A(x, k, \theta) + D(x).$$

where A is the firm's abatement cost (which depends on the allowable level of emissions, the stock of green capital, and the cost shock) and D is the social damage of emissions, which depends only on the level of emissions. Using this definition, we rewrite the first order condition (2) as

$$E_\theta \left[A_x(X, k^*, \theta) + D_x(X)\right] + \frac{dk^*}{dX} E_\theta \left(A_k(X, k^*, \theta) + I'(k)\right) = 0. \qquad (3)$$

The firm's optimal investment decision, under the quota, requires

$$E_\theta \left[A_k(x, k, \theta) + I'(k)\right] = 0,$$

so the second term in equation (3) is zero. Consequently, under the cap and trade, the regulator has a single margin, the first term in equation (3), together with a single instrument.

4.3 Coordination issues

The design of environmental policy in general, and green industrial policy in particular, is rife with coordination issues. The private and social returns to one type of investment depend on the level of investment of a different type. China's investment in wind farms without simultaneously creating a means of transporting the power to high demand areas illustrates a particular kind of coordination failure. India's lack of policy coordination across states, resulting in the failure to take advantage of arbitrage opportunities that would have reduced the overall cost of achieving a renewable resource target, illustrates a different kind of coordination failure. These kinds of coordination failure are easy to spot, at least *ex post,* which of course does not make them easy to solve.

Because coordination failures come in so many forms, it is hard to imagine a general theory on the subject, or even a set of general guidelines that we can present to policymakers to deal with these issues. Probably the most help that theory can give is to develop simple models that illuminate generic policy issues. The purpose of this section is to illustrate the possibility that a second best policy can *create* coordination failures. Without theory, it might be difficult to detect the coordination failure, because we only observe the outcome that emerges, not other potential outcomes. However, once we are alert to the possibility of coordination failure, the policy remedy quickly becomes apparent. In the setting here, that remedy is likely to involve industrial policy that nudges an industry to adopt one type of investment strategy rather than another.

The coordination problem discussed here arises when firms have lumpy investment opportunities, and a regulator uses a second best policy to control pollution (Karp 2008). A two-stage model suffices to explain the issue. In the first stage, non-strategic firms decide whether to make a lumpy investment that reduces their future average and marginal abatement costs. For simplicity, assume that firms are ex ante identical. In the second stage, the regulator observes the fraction of firms that have made the investment, and is able to calculate the industry marginal abatement cost. Based on that calculation, the regulator chooses the optimal allowable level of per firm emissions.

The important assumptions are that the regulator conditions the emissions level on aggregate investment, and that all firms receive the same emissions allowance. The time consistency problem associated with unconditional policies motivates the first assumption; the examples of Brazil's changing ethanol policy during the 1980s, the US changing subsidies to wind and solar power during the last quarter century, and recent attempts to overturn putatively binding green legislation in California illustrate the responsiveness of policy to current circumstances. Informational and incentive problems motivate the second assumption. The informational problem is that the regulator may not be able to identify the abatement costs of individual firms. The incentive problem is that firms that chose not to invest will subsequently have higher abatement costs than firms that did invest. In the absence of trade, it is ex post optimal to give the high cost firms a higher allowance of permits; the anticipation that the regular would behave in that way undermines firms' incentives to make the investment.

For the purpose of comparing the effect of policy, consider the following two scenarios. In the first, the regulator chooses a market based policy, cap and trade. In the second, the regulator chooses a command and control policy: firms are all restricted to the same level of emissions, despite the fact that the firms that invested have lower marginal abatement costs. The optimal level of aggregate emissions permits differs in the two scenarios, but not in an obvious way.[8]

When firms have binary choices, the aggregate level of investment is proportional to the fraction of firms that invest. Because the policy scenario

[8]Even though the opportunity to trade reduces the total cost of achieving any level of abatement (compared to the no trade scenario), the marginal social cost of abatement might be higher or lower under trade. Thus, the optimal level of emissions can be higher or lower under the trade scenario *even for the same level of industry investment.*

(market-based versus non-market-based) affects the equilibrium level of permits conditional on (most) levels of investment, the policy scenario also affects the equilibrium level of investment; that relation is our concern here. An individual firm's incentive to invest equals the profits net of investment costs that the firm expects to receive if it invests, minus the profits that it expects to receive if it does not invest. The equilibrium price of permits is a decreasing function of aggregate investment. Therefore, when firms anticipate that the regulator will allow trade, the decisions to invest are strategic substitutes: any firm's incentive to invest is a *decreasing* function of the fraction of other firms that invest. In this setting, there is a unique equilibrium level of aggregate investment, which equals the socially optimal level. Here, the cap and trade policy achieves both the socially optimal level of investment and the optimal level of emissions. The emissions policy is first best, and there is no need for an industrial policy to control investment.

In contrast, when firms anticipate that the regulator will choose a per-firm emissions cap with no ability to trade, the investment decisions are strategic complements: a firm's incentive to invest is an *increasing* function of the fraction of other firms that invest. The explanation is that an increase in aggregate investment lowers the industry marginal abatement cost and makes the optimal emissions policy more stringent (lowers the per firm quota). As the allowable level of emissions fall, the advantage to a firm of investing in the new technology increases. The no-trade emissions policy transforms the equilibrium problem into a coordination game. There are in general two equilibria, in which neither or all of the firms invest.

In both of these equilibria, firms all make the same decisions, so they are all identical; there is no apparent cost of forbidding trade in emissions, because there are no opportunities for arbitrage. This absence of arbitrage opportunities is an endogenous outcome, however. Taking into account the endogeneity of investment, the prohibition against trade results in potentially large losses in welfare. In this scenario, a green industrial policy might involve either an investment tax or a subsidy. The constraint against trade causes the social planner's problem to be convex in the fraction of firms that invest, so having either all firms or no firms invest is constrained socially optimal. Both of these outcomes are equilibria in the absence of an investment policy; an investment (or an alternative) policy is needed to induce firms to coordinate on the constrained socially optimal equilibrium.

This example, like the one in Section 4.2, shows that the role of green industrial policy depends on the other policies that are used to control emissions. With market based policies (here, cap and trade), green industrial policies have no role; with command and control policies (here, cap without trade) they are potentially important.

4.4 Incentives to cooperate

There may be increasing returns to scale in green policies. The benefit to any country of adopting such policies may increase with the number of other countries that adopt them, due to traditional economies of scale, larger markets for their green products, the increased ability to take advantage of returns to specialization, or positive spillovers from network effects. Countries are (plausibly) more likely to adopt green policies if they join an international environmental agreement (IEA) that promotes or mandates emissions reduction. To the extent that the kinds of international positive spillovers from green industrial policies mentioned above exist, it might seem that they would increase the incentive to cooperate in an IEA. A model that has been widely used to study the formation of IEAs helps to understand why that conjecture might be wrong.

Barrett (2006) Barrett (2003)shows that lower abatement costs can decrease the equilibrium number of countries that decide to join an IEA. This conclusion arises in a two stage model where pollution is a public bad, so abatement is a public good. In the first stage, identical countries simultaneously decide whether to join the IEA or to remain as a non-member. The outcome of this participation game is a noncooperative Nash equilibrium. In the second stage, non-members choose their level of abatement to maximize their individual welfare, and the IEA chooses its level of abatement to maximize the joint welfare of members. Because members' abatement levels take into account the positive benefits on other members, members (typically) abate more than non-members. All countries enjoy the same benefit from aggregate abatement, but members incur larger abatement costs and therefore have lower payoffs, compared to non-members.

In deciding whether to join the IEA, in the first stage, countries understand the effect of their membership on the equilibrium abatement decisions of other members (and possibly also of non-members). It is individually rational for a country to join the IEA if and only if, by joining, it increases the aggregate level of abatement by enough to compensate it for the additional cost that it incurs, as a member, of having to increase its own abatement.

Trade in emissions permits, like green industrial policies, lowers expected abatement cost. A brief detour to consider the role of emissions trade may be instructive in thinking about the likely role of green industrial policies in promoting cooperation. The more countries that join the IEA, the greater is the probability that members will have different marginal abatement costs, and that there will be opportunities to trade. The expected value of allowing international trade in permits increases with the number of countries in the agreement. Consequently, conditional on trade being allowed, an additional member creates two kinds of benefits. First, the additional member increases the equilibrium amount of abatement, creating a direct benefit to all other countries. Second, the additional member increases the expected value of the option to trade, benefiting other members of the IEA.

Karp (2009) shows that allowing trade reduces equilibrium participation, and is likely to reduce equilibrium global welfare. Membership by an additional country weakly increases equilibrium abatement by more when trade is allowed, compared to the scenario without trade. However, one country leaving an IEA decreases equilibrium abatement by less when trade is allowed, compared to the scenario without trade. Therefore, trade has ambiguous incentives on the incentive to participate in the IEA, but in this model the effect opposing membership is larger.

A less extreme parametric example (available on request) shows that the type of positive externality that is plausibly associated with green industrial policies, leads to a small net increase in the incentive to participate in an IEA. However, the magnitude of the effect is not likely to result in substantial additional membership.

All of the models described above rely on specific functional forms. In contrast, Karp and Simon (2011) provide a non-parametric analysis of this type of participation game. Depending on the manner in which green industrial policy alters marginal abatement costs, the policy change might lead to large (or small) increases or decreases in equilibrium participation. Making *marginal* abatement cost more convex weakly reduces the equilibrium membership size, and making marginal abatement costs more concave weakly increases membership size. The policy implication of this conclusion is largely negative, because we are unlikely to be able to determine, with any confidence, the effect of a policy change on the curvature of marginal abatement. The analysis is still useful, as a remedy against drawing strong (and unwarranted) policy conclusions based on parametric models.

5 Conclusion

The debate concerning green industrial policy shares many of the features of the debate about industrial policy in general. Neither debate is likely to be resolved either by theoretical or empirical work, but research is nevertheless valuable in helping us to think more clearly about these questions.

Despite the considerable overlap, the debate about green industrial policy has some elements that are either absent or less important in the more general debate. The success of a general industrial policy depends on the ability of the targeted industry to meet market challenges that are largely exogenous to the policy. In contrast, the profitability of an industry targeted by green industrial policy depends to a great extent on the type and magnitude of environmental policy that will be used in the future, e.g. the size of the carbon tax or the stringency of the emissions ceiling. Current policymakers cannot commit to future policy; all agents understand that future policy is likely to be conditioned on circumstances that prevail in the future. Current investments are important determinants of future abatement costs, and those future abatement costs are important determinants of future policy. The future policy affects the profitability of current investments. The endogeneity of future policy and the inability of current policymakers to make binding commitments regarding future policy, create a rationale for green investment policy. Green industrial policy provides a means of sharing the policy-induced risk, and also of influencing future policy.

Proponents of industrial policy often agree that governments should avoid trying to pick winners; but it is hard to envision an industrial policy that does not do exactly that. However useful it would be to have studies that categorize as successes or failures previous attempts at green industrial policy, there are conceptual and measurement problems that would make such studies quite subjective.

Green industrial policy, broadly understood, is prevalent in both developing and developed countries. There have been rapid increases in the capacity of green energy sources, and corresponding reductions in costs, but these energy sources are still only a small component of total energy supplies.

Green industrial policies are associated with, but may not be the cause of trade disputes. The Brazil-US ethanol dispute is a "typical" trade disputes and can be dealt with (however imperfectly) using the WTO dispute settlement mechanism. The US-China trade dispute is "fundamental", rather than caused by sectoral policies. However, the underlying friction sometimes manifests as sectoral disputes. These should be dealt with using WTO mechanism, recognizing that the fundamental causes of the friction will take years to resolve. Exempting green products from tariffs, or at least the recognizing that biofuels are industrial rather than agricultural products is desirable but unlikely to happen.

The breadth of issues arising from green industrial policy makes it unlikely that anything resembling a general theory for that policy can be constructed. Nevertheless, the theory of public policy provides many lessons for green industrial policy. Four examples illustrate the kinds of lessons that we might expect.

If the potential stock of fossil fuels were exogenous, then green industrial policies might be a complement to, not a substitute for current environmental regulation. This policy conclusion is weakened or even overturned to the extent that green industrial policy affects exploration and development decisions, and thereby affects the stock of fossil fuels. With asymmetric information about firms' abatement costs, in a setting where the investment in green capital affects abatement costs, the use of emissions taxes creates a rationale for investment policies, whereas the use of a ceiling on emissions does not. When firms make lumpy investment decisions that affect their abatement costs, the form of future emissions policy (cap-and-trade or cap-without-trade) determines whether their investment decisions are strategic substitutes or complements. In the latter case there are multiple investment equilibria, creating a role for industrial policy that selects the equilibrium level of investment. If economies of scale or network affects cause the average benefit of green industrial policy to rise with the number of countries that employ the policy, then the green industrial policy might promote international cooperation in reducing a global bad. Example cast doubt on this theoretical possibility, but a more general analysis shows why we should be cautious about deriving general conclusions from parametric examples.

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A A summary of current policies

This section summarizes renewable energy policies in Brazil, US, China, India and Germany. It provides an overview of each country's renewable energy policies related to the topics discussed above, and a more detailed analysis of several areas of particular interest.

country Mtoe energy use	coal	oil	gas	nuclear	hydro	renew. & waste	geoth. solar, wind
Brazil 249	5.6	39	7.7	1.5	13	32	0.1
US 2,284	24	37	24	10	1	3.7	0.7
China 2,116	66.5	17	3.2	0.8	2.4	9.7	0.3
India 621	42	23	5.7	0.6	1.6	26.4	0.2
Germany 335	24	33	23	11	0.5	7	1.3

Table 1: 2008 Energy use (Mtoe = Million Tonnes of oil equivalent) and percent of energy use from different sources. (OECD/IEA 2010)

Table 1 shows the 2008 energy use of these five countries (the first column) and the approximate percentage of their energy coming from different sources. All five countries rely on coal, oil and gas for more than 50% of their energy needs – about 85% for the US and China. The US and China consume seven to eight times the energy of Brazil and Germany. Despite high recent growth rates, geothermal, solar and wind comprise only a fraction of one percent of energy use for all the countries except Germany, where it is slightly over 1%.

A.1 Brazil

Brazil began a concentrated campaign to support ethanol in the wake of the oil crises of the 1970's. At the time, about 90% of its fuel consumption depended on foreign oil. High oil prices and the doctrine of industrialization via import substitution motivated the adoption of an industrial policy to create a domestic source of fuel. The government subsidized sugar cane growers and required service stations to install ethanol pumps. In less than a decade, almost all new cars sold in Brazil ran on 100% ethanol. However as oil prices fell, subsidies to sugar growers were eliminated, and the auto industry reduced production of ethanol-only cars, although service stations continued to provide ethanol for those cars. Advances in research lowered the price of producing ethanol by more than 50% between 1975 and 2004 (IPCC, 2011), and as oil prices began to rise in the early 2000's ethanol again became economical.

Although Brazil eliminated direct subsidies, its ethanol sector receives continued support from the legacy of previous policies (e.g. infrastructure and previous investment in ethanol-fueled cars) and also by current blending requirements, tax incentives, and financing through the Brazilian National Development Bank (BNDES). Ethanol ad valorem taxes are significantly lower than gasoline taxes, although the difference varies over states. The mandatory blend of ethanol in gasoline ranges from 18-25% in recent years, and is currently at the low end of that range. The reduced blending requirement may be a response to increased global biofuel demand.

In 2009 and 2010 Brazil imported small amounts of ethanol from the United States in order to meet its mandate. The imports followed two years of poor cane harvests in Brazil and higher prices of sweeteners, diverting cane production from ethanol to food uses. These imports, although anomalous, are still noteworthy in view of Brazil's historic reasons for promoting ethanol and the fact that its sugar-based ethanol is significantly more efficient than the corn-based ethanol produced in the US. The typical cost of producing a gasoline-equivalent liter of sugar ethanol ranges from 30-50 cents, whereas corn ethanol costs range from 60-80 cents (REN21_GSR, 2011). It is also striking that recent imports occur in the context of trade frictions. Brazil has threatened to bring a WTO complaint against the US ethanol subsidies and import tariffs. To the extent that Brazil imports ethanol, it benefits from those US policies.

For the purpose of evaluating current industrial policy proposals, it would be useful to have a measure of whether past industrial policy was successful. In the case of Brazil's ethanol policy, such a calculation requires estimates of the past opportunity costs of investments and current and future benefits. Estimates of these benefits requires a counterfactual: what would Brazil's energy sector have looked like had the industrial policies not been adopted? We have not seen such estimates There are examples of unsuccessful industrial policies, cases where significant resources were spent with little apparent benefit. There are other examples where a relatively modest expenditure created enormous benefits, as with transcontinental railroads in the US. Most industrial policies are neither spectacular failures nor successes – or at least measurement problems make to hard to conclude that they were. It is noncontroversial that Brazil's policy led to the creation of a biofuel sector that would in the absence of that policy probably not exist, or at least be much smaller. Whether this policy would pass a cost benefit analysis is unclear.

Brazil generates a large share of its electricity through hydroelectric power, but its Program of Incentives for Alternative Energy Sources (PROINFA) promotes other forms of renewable electricity generation. Founded in 2002, this program aims to increase the percentage of electricity generated by wind, biomass and small hydroelectric sources through pre-set preferential prices and 20 year contracts. These costs are passed on to end users, with an exception for low-income people. Low cost financing is available through Brazil's development bank, BNDES (IEA, 2011). Brazil's electricity sector is now fully deregulated, with generators selling their electricity to distributors via auctions. However most of the generators are government-controlled companies, with federally owned Electrobras dominating in generation and transmission.

There have also been several programs for rural electrification, most recently "Luz Para Todos", established in 2003. Access to electricity is a right guaranteed by Brazil's constitution, and by 2009 there was a national electrification rate of 97.8%, with 88% coverage in rural areas. Despite the high costs and losses of long distance transmission lines, rural electrification has largely been achieved through grid extension. This option is increasingly difficult for the communities that have not yet been reached. The policy preference for grid expansion rather than stand-alone systems is partly due to the delegation of electrification responsibility to regional concessionaires, companies whose know-how and business practices are centered on traditional energy distribution. Remote regions of the Amazon, relying on private contractors working under the concessionaires, make greater use of decentralized renewable energy.

The collection of bills is a major challenge to the electrification of remote areas. The Brazilian government encourages projects that cover most of the costs up front, but the capital constraints facing the rural poor make it hard to achieve this objective. These problems, as well as the expense of operation and maintenance, have led to significant under-capacity in regions that are considered electrified, aggravating the development challenges of remote regions.

A.2 The United States

As in Brazil, subsidization of ethanol in the United States began as a response to the oil shocks of the 1970s. Between 1978 and the late 2000's the ethanol subsidy ranged between $0.40 and $0.60 per gallon (Taheripour, 2007). Currently this subsidy of $0.45 per gallon is a tax credit distributed to gasoline blenders. The tax credit works in conjunction with federally mandated blending minimums that ensure a domestic market for ethanol. Due to these blending requirements, the blenders' demand for ethanol is likely quite inelastic, which implies that ethanol producers and their suppliers, corn farmers, receive most of the subsidy.

A Congressional Budget Office study (CBO, 2010) finds that the actual cost to taxpayers, which includes the interacting effects of different policies, is higher than the $0.45 tax credit. Once adjustments are made for the different energy content of ethanol and the loss in revenues based on the lower excise tax for ethanol, the cost to taxpayers of reducing gasoline consumption by one gallon (using the ethanol policy) is $1.78. Similarly, the cost to taxpayers of reducing greenhouse gas emissions through corn-based ethanol is approximately $750 per metric ton of carbon dioxide, compared to the roughly $20 carbon price established in Europe's cap and trade system. CBO estimates that ethanol subsidies cost taxpayers $6 billion in 2009. An Environmental Working Group (2010) study states that the reduction in fossil fuel use achieved by ethanol substitution could have been achieved by a less than a half-of-a-mile-per-gallon increase in fleet-wide fuel economy in 2009. Maintaining tires properly inflated yields a half-of-a-mile-per-gallon increase in fuel economy.

Ethanol policy has achieved unimpressive gains in energy security and GHG reduction, and has come with a high price tag. A possible defense of the policy is that the infant has not yet reached maturity, and that the benefits will arrive later. This defense cannot be ruled out entirely, but it seems implausible. The current technology does not provide a basis for a mature US ethanol industry, and there is little evidence of learning-by-doing that will be transferable to a technology that will support such an industry. The science for that technology is not yet at a stage needed for industrial scale use.

As noted above, Brazil has a lower cost of producing ethanol than the US, largely due to the advantage conferred by Brazil's climate and the fact that sugar is a better feedstock than corn. We do not have estimates of the costs of Brazil's policy that are comparable to the US estimates above. Absent these, it is not self-evident that the Brazilian policy has been more successful than the US policy. However, Brazilian policy appears to dovetail with Brazil's comparative advantage; it is difficult to argue this for the US.

In both countries, creation of the ethanol industry had unintended negative consequences. Brazil's ethanol industry has come at the expense of the rainforest. The expansion of US corn production has used marginal land and increased fertilizer runoff into waterways. Both policies probably contributed to food shortages and the 2008 run-up of global food prices (Bobenrieth, 2009), although the causal relation is likely much more direct in the case of the US. Corn is a more important food commodity than sugar, and the rapid expansion in the US ethanol industry occurred just before and during the food price increase, not years before as was the case with the Brazilian industry. The US also uses ethanol import tariffs, discussed in Section 3.

Demand for a commodity depends both on its price and the price substitutes. Because ethanol is a gasoline substitute, it is useful to compare ethanol subsidies with the implicit and explicit subsidies to the oil industry. Direct tax breaks for the oil industry amount to $4 billion a year, not including the taxes avoided by oil service providers based, at least on paper, in tax shelters like the Cayman Islands (NYT Kocieniewski, 2010). Improperly managed royalty collection for oil extracted from public land increases taxpayer losses. One study, which includes tax breaks, lost revenues and direct spending, estimates subsidies for fossil fuels at $10 billion a year (ELI, 2009). These subsidies are the result of both intentional policies and mismanagement. The Interior Department's management of federal oil and gas resources is on the GAO's high-risk list for fraud, waste and abuse. For example, poorly designed royalty exemptions put in place during periods when oil prices were low could cost the government between $21 billion and $53 billion over the life of the leases, depending on oil costs and production levels (GAO, 2008). To put the revenue issue into global perspective, the same GAO report notes that the tax and royalty revenues received by the U.S. government in the Gulf of Mexico, as a percent of produced value was the 93rd lowest out of 104 regions evaluated. The (often implicit) subsidies granted to the fossil fuel sector do not include the defense costs needed to protect foreign sources of US and developed world fossil fuel supply.

Although economists may disagree on optimal levels of taxes and subsidies, basic principles establish that a commodity that creates a negative externality should be taxed, not subsidized. Fossil fuels create a negative externality. The energy mix that a market economy adopts depends on relative prices. For political reasons, it might be convenient to shift relative prices using subsidies rather than taxes. However, the fact that current policy subsidizes fossil fuels increases the level of the subsidy that would have to be applied to green energy, in order to move toward optimality. Furthermore, the difficulty in raising public revenue needed to finance subsidies means that the fossil fuel subsidies have an opportunity cost that exceeds their nominal cost.

Support in the US for electricity produced using renewable energy occurs mostly on the state level; there are currently 33 states that have renewable portfolio standards (RPS) in place. These standards require that electricity providers obtain a minimum percentage of their power from renewable sources by a given date. A system of renewable energy credits (RECs) allows providers who otherwise fail to meet the standard to be in compliance by purchasing credits from providers who exceed the standard. This system is a form of cap and trade, but here the cap is an intensity target rather than an absolute target (one based on a ratio rather than an absolute level). The American Recovery and Reinvestments Act, which allocates $80 billion to clean energy initiatives in the form of direct appropriations and tax breaks, also subsidizes renewable energy. This program includes research funding, infrastructure development, loan guarantees, weatherization of low-income homes, clean-energy workforce training, and tax incentives for investment in and production of clean technologies.

A.3 China

In 2001 China began the Township Electrification Program to bring electricity to rural communities using solar PV, small hydro, and wind. A competitive bidding process at the provincial level, involving government-affiliated institutions and semi-private parties, dispersed program funds (IEA Rural Elect, 2010). Within 20 months, power had been brought to over one million people, with a program cost of $310 million (NREL, 2004). Through multiple programs, China has achieved an electrification rate of 99.4%, with 99% rural electrification by 2009. Despite its impressive surge of investment in renewables, most rural electrification was achieved through grid extension. Remaining regions that lack electricity are largely located in the sparsely populated north-western region and eastern coastal islands. These areas are rich in renewable energy sources and are better suited for decentralized systems.

Problems with rural renewable energy systems often begin after installation. Theft and vandalism have been issues, as have operation and maintenance. There is a lack of qualified electricians in rural regions; increasing training and pay for locals involved in protecting, operating and repairing the system will help to mitigate these problems. Private parties contracted to install the electrical systems should face incentives that promote long term operation, not the mere completion of a project.

The Chinese government also subsidizes 17% of the purchasing cost for rural adoption of solar water heaters, a technology that is already less expensive than electric heaters once lifetime energy costs are taken into account (REN21 China, 2009). China accounted for more than 50% of the world's total use of solar water heaters in 2008; these heaters accounted for more than a third of China's renewable energy consumption excluding hydropower and traditional biomass. China also leads the world with an estimated 50 million biogas plants, funded in part by low cost loans.

Support for utilities-scale renewables began in 2003 with a wind concession program in which different firms bid for the rights to build relatively large-scale wind farms with prices guaranteed for a period of time. Support for renewables was not fully established until the 2005 Renewable Energy Law which, along with its 2009 amendments, provides the framework that organizes the development of renewable energy in China. This law sets targets of 10% and 15% for renewable final energy for 2010 and 2020 respectively. Incentives rely largely on feed-in tariffs, determined either at the regional or national level, depending on the energy source. End-users pay the additional costs via a surcharge on their electricity bill. Grid companies are required to purchase all electricity generated by renewable energy. The 2010 target of 10% total renewable energy was nearly reached (Table 1).

Tax incentives exist but are limited in China. Policies include a tax reduction for wind power projects and lowered tariffs on renewable energy equipment not produced in China. State owned banks provide generous financing. A $30 billion green stimulus package was introduced in response to the 2008 financial crisis. Neither ethanol nor biodiesel is heavily supported because they would divert scarce food stocks.

China's domestic demand for electricity is rising by 15% per year. To meet demand in the coming decade, China will have to add nine times as much capacity as the United States will during the same period. Huge domestic demand, low interest loans, low-wage workers, and government support in workforce training, infrastructure development and R&D have enabled Chinese manufacturers to take advantage of economies of scale. China is now the world's largest manufacturer of wind turbines and solar panels, and the renewables industry employs well over a million workers (NYT Bradsher, 2010).

The opportunity cost of the resources devoted to these policies is difficult to quantify, making it difficult to determine whether they increased income growth. However, China has severe local pollution problems, the causes of which are positively correlated with greenhouse gas emissions. Even if China put zero value on future reductions in external climate damage, policies that reduce the pollution associated with fossil fuels would likely increase its welfare. The development of the renewable resource sector makes it cheaper for China to reduce its future use of fossil fuel; China's industrial policies are likely responsible in large part for the growth of this sector. By this measure at least, the policies have been successful.

The rapid creation of the renewable resource sector is testimony to Chinese leaders' ability to mobilize resources more quickly than their Western counterparts. However, both sets of leaders operate under political constraints. Although credible pollution taxes might have been a more efficient means of promoting renewable energy, such policies could probably not have been implemented even if they could have been legislated.

The rapid growth of China's renewable electricity sector was accompanied by uneven development of components of the system, as large wind and solar farms were built far from urban areas. The cost of building grid infrastructure to connect producer to user, and the electricity losses involved in transmitting over distance, led to large unused capacity. In an attempt to remedy this imbalance, the 2009 amendments to the Renewable Energy Law strengthened the penalties imposed on grid operators who did not buy the renewable energy in their district. Policymakers should take into account these kinds of coordination issues, but often appear not to.

There are various explanations for this failure. First, consequences that are evident ex post may not be obvious ex ante. Second, political capture may promote inefficiencies, when a particular group's gains are tied to achievement of specific targets rather than the overall goal. Third, political constraints may dictate apparently inefficient sequencing. For example, although it is socially rational to develop production and distribution of energy in tandem, insistence on this might have led to the development of neither. Once the production facilities, here the wind and solar farms, are developed, they are a fixed cost. At that stage, development of the transmission lines may represent a fairly modest additional cost. It might have been impractical to overcome resistance to the package of production and transmission, but feasible to push through just the production plans. Once those were achieved, perhaps it became easier to push through construction of distribution networks.

A.4 India

India suffers from serious electricity shortages. Irregularities in voltage and frequency disrupt equipment; chronic black-outs and other disruptions cause factories to suspend operation. The gap between electricity demand and supply in 2009-2010 was 10% of total requirement, and the demand deficit during peak hours was almost 13% (NREL India, 2010). These problems of electricity supply impede India's development.

Like China, India has a goal of achieving 15% renewable energy by 2020. However the responsibility for achieving these goals is less centralized than in China. Individual states have been given the mandate to create renewable portfolio standards and as of April 2010, 18 out of India's 28 states had such policies in place. State level incentives are so low that they have not led to much investment, although they can be supplemented with central level incentives such as accelerated depreciation and direct price subsidies. The low rates charged for electricity, a means of subsidizing the poor, make it difficult to finance renewable energy investment.

Inadequate coordination between states is another stumbling block. Before 2010, there was no inter-state trade in renewable energy certificates, increasing the cost of meeting standards. The Renewable Energy Certificate (REC) program now allows producers of renewable electricity to either sell to their local distributor at preferred rates, or receive the standard electricity rate and sell the REC separately to another state. However this market-based approach applies to only the 18% of electricity capacity controlled by the private sector. Approximately 50% of India's electricity generation capacity is owned by the states, down from 83% thirty years ago, and 32% is owned at the national level. The private sector dominates in renewable electricity, much of which is captive generation for industrial use. (Captive generation refers to plants built for the purpose of providing electricity to a particular factory, group of factories, or neighborhood.) In the wind market 70% of capacity is produced for direct consumption by large industrial facilities (NREL India).

The efficiency of India's wind farms is lower than in many other countries due to a misalignment of incentives. In the past, the main incentive for investment was accelerated depreciation, leading to shoddy construction of wind farms that sometimes sat unused. As the incentive structure has changed from tax write-offs to production-based incentive schemes, efficiency will likely improve.

Poverty is pervasive in India, with 42% of its population below the international poverty line (World Bank, 2005). Electrification rates are 93% and 52% in urban and rural areas respectively, with an overall rate of 64.5%. A large-scale electrification effort known as RGGVY was implemented in 2005. Grid extension was the primary mechanism, with renewable or non-renewable stand-alone systems considered for remote regions. The Remote Village Electrification (RVE) program is responsible for electrifying remote regions through the use of renewable energy sources. Both RVE and RGGVY are mandated to provide electricity for both household and production purposes. However 95% of communities serviced by RVE have received only solar PV for home lighting. Electricity for irrigation pumps provides large improvements in agriculture, and RVE recipients complain of discrimination. The list of villages to be served by RVE is being shortened each year (IEA Rural Elect., 2010).

Franchisees that are granted jurisdiction through a competitive bidding process manage local power distribution. They purchase bulk power and are responsible for maintenance of electrical infrastructure and bill collection. Delegation of these responsibilities to the local level increases efficiency in revenue collection and ensures stable electricity delivery (IEA Rural Elect., 2010). However, there are not enough workers trained in maintenance and operation of renewable energy systems, particularly as technology continues to change and develop. Because the electricity demand gap in urban areas remains quite high, rural regions are unlikely to see their electricity problems solved soon.

Both solar water heaters and biogas plants are supported in India through capital subsidies and low cost loans. India has a total of 4.3 million biogas plants and 3.5 million square meters of SWH collection area.

A.5 Germany

Germany began using feed-in tariffs to encourage renewable electricity as far back as 1991. Passage of the Renewable Energy Act in 2000 significantly expanded these policies; between 2000 and 2010 Germany has nearly tripled its share of renewables in final energy consumption. The share of renewables is currently 10% and Germany has set the ambitious target of 35% renewable energy by 2020. As renewables expand, nuclear energy is being phased out.

Germany offers preferential rates for different types of renewable electricity with 20 year contracts. Under the assumption that technological developments will continually lower the cost of producing renewable electricity, the rates offered new plants are ratcheted down annually, a process known as tariff digression. An already completed plant has a confirmed electricity price for the next 20 years, but a similar plant that is completed the following year receives a lower price. This mechanism is an attempt to balance commitment, needed to induce investment, and flexibility, needed to respond to changing costs.

Solar PV costs have fallen by 65% between 2008 and 2010 (IPCC, 2010), leading to a multi-year boom in solar investment. With low costs and a 20 year contract to sell at high prices, many solar generating firms have locked in a profitable investment. Much of these costs will be passed on to German consumers, with a 70% increase in the renewable energy charge added to their energy bill in 2011. The 2011 cost to the German government of their renewables program is 13.5 billion euros, compared to 8 billion in 2010 (GENI, 2010). The economic research institution RWI Essen claims that reducing greenhouse gas emissions in Germany through solar PV is 53 times more expensive than the ETS price, while wind is 4 times more expensive (Frondel et al, 2009). With approximately 60 sunny days per year, Germany has 40% of the worlds installed solar capacity. The report recommends capping investment levels and insuring that the tariff digression keeps pace with the cost of installation.

An EU mandate requires gas stations to sell E10 (a minimum 10% ethanol blend), but so far only France and Germany have complied. Adoption of this new blend has been low in Germany, where consumers worry that the new fuel will hurt their engines. Although E10 is safe for 93% of German vehicles, many consumers are either uninformed or wary of the new product, illustrating the importance of education campaigns to change consumer behavior.