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GREEN INDUSTRIAL POLICY

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I. Introduction

Green growth can be defined as a trajectory of economic development that fully internalizes environmental costs, including most critically those related to climate change, and that is based on sustainable use of non-renewable resources. Green growth requires green technologies: production techniques that economize on exhaustible resources and emit fewer greenhouse gases. The availability of green technologies both lowers social costs in the transition to a green growth path and helps achieve a satisfactory rate of material progress under that path. A critical task facing policy makers is ensuring investments in green technologies take place on an appropriate scale.[2]

If markets worked well, natural and environmental resources were priced appropriately at full social marginal costs, and technological benefits were fully internalized by those who undertook R&D, we could in principle leave such investment decisions in the hands of entrepreneurs, corporations, and financial markets. But there are three sets of considerations that drive a wedge between private and social returns to investment in green technologies.

First, the development of new technologies generates positive spillovers that are not fully captured by the original investors. These may take the form of cross-firm externalities, industry-wide

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[2] For various analytical perspectives on green growth, see Jaffe et al. (2004), Acemoglu et al. (2012), Bowen and Fankhauser (2011), Schmitz et al. (2013), Karp and Stevenson (2012), Hallegatte et al. (2011), and de Serres et al. (2010) for conceptual analyses of policies that promote green growth. On industrial policy, see Rodrik (2007, chap. 4) and Rodrik (2008), on which this paper draws.

learning, skill development, or agglomeration effects. Such "market failures" exist in general for all kinds of new technologies, whether they are of the green or dirty kind. However, their novelty, their highly experimental nature, and the substantial risks involved for pioneer entrepreneurs suggest green technologies may be particularly prone to these failures.

An additional reason why green technologies may need to be publicly subsidized is that carbon (which I use as shorthand for greenhouse gases [GHGs] generally) is greatly mispriced. This is a second-best reason for government intervention in support of green technologies. The presence of subsidies on fossil fuels and the failure to implement taxes or controls that would internalize the risks of climate change result in the user cost of carbon falling substantially below the level that is appropriate from a long-term societal perspective.[3] This means that the private return to green technologies lies significantly below the social return, even when we ignore the traditional R&D spillovers.[4]

These two considerations provide mutually reinforcing reasons for why the world would be collectively better off if governments nurtured and supported green technologies. However, what is true for the world as a whole need not be true for national governments interested in maximizing domestic welfare. The benefits of carbon abatement represent the archetypal global public good, generating strong incentives for individual countries to free ride on others' efforts. In a world where governments do not internalize the global benefits of carbon taxes/controls in the first place, it is unlikely that they will place much value on green technologies on account of these technologies' impact on the global stock of GHGs. Similarly, R&D externalities from the development of new green technologies are in many instances global rather than national. Learning sometimes spills over

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[3] The IMF (2013, pp. 13-14) estimates that effective subsidies on energy amount to $1.9 trillion (or 2.5% of world GDP). The bulk of this subsidy arises from the absence of taxes needed to internalize the negative climate and health externalities generated by burning fossil fuels.

[4] On the empirical relation between fuel prices and carbon-saving innovation in the auto industry, see Aghion et al. (2012). This second-best role for policies supporting green technologies is also emphasized by Jaffe et al. (2004). Bosetti et al. (2010) consider quantitatively the role of innovation policies to substitute for explicit carbon control policies and conclude that they are not sufficient, even under optimistic assumptions, to stabilize GHG concentrations and temperatures.

quickly across national borders to firms located in other countries. To the extent that governments anticipate (or fear) such spillovers, their incentive to invest in green technologies is further diluted.

Yet as I document in the next section, government support for green industries is rampant, both in advanced and emerging economies. Often, the motive seems to be to give the domestic industry a leg up in global competition. Under certain conditions, this may be a sensible strategy from a national standpoint – although the global implications (absent the two considerations above) are often ambiguous or negative. For example, a first-mover advantage in certain technologies can tilt the future path of technological development in a direction that is closer to a country's initial comparative advantage, providing long-term terms-of-trade benefits to the home economy. Or, subsidizing investment in home technologies can shift rents from foreign producers in imperfectly competitive industries. Such competitive motives are the third set of considerations that drive a wedge between private and social optimality in markets for green technologies.

Normally, we consider these competitive motives to be of the beggar-thy-neighbor type. Terms-of-trade or rent-shifting effects are zero-sum from a global standpoint, and any resources invested in generating those national gains come at the cost of global losses. However, in the highly second-best context of green growth, national efforts to boost domestic green industries can serve to offset the two sets of market failures discussed above, even if the motives are narrowly national and carry beggar-thy-neighbor connotations. When cross-border spillovers militate against taxing carbon and subsidizing technological development in clean industries, boosting green industries for competitive reasons is largely a good thing, not a bad thing. However, by the same token, when these national strategies take the form not of subsidizing domestic industries but of taxing or restricting market access to foreign green industries, they have to be considered triply damaging. Luckily, as the overview in the next section shows, trade restrictions have so far played a small role relative to subsidies to domestic industry.[5]

[5] An important exception that does not take away the main point is the raising of tariffs on imports of Chinese solar panels in the U.S. and Europe (Deutch and Steinfeld 2013, Freund 2013). On the potential conflict between green industrial policy and trade laws see Wu and Salzman (2013).

Economists traditionally exhibit scepticism – if not outright hostility – toward industrial policies. But these considerations suggest that they should look kindly at industrial policies geared towards green technologies. Industrial policies have an indispensable role in putting the global economy on a green growth path. The imperative of addressing climate change places industrial policy squarely on the policy agenda of governments.

The trouble is that industrial policy has a very chequered history. While it has undoubtedly worked in many places in East Asia to foster structural change and new industries (Japan, South Korea, Taiwan, China), in advanced countries and many developing countries it remains synonymous with white elephants, rent-seeking, and good money spent after bad. In truth, such caricatures are wildly at variance with the actual contribution industrial policy has made to technological development in the United States and Europe (Block and Keller 2011; Mazzucato 2011). And infant-industry promotion in developing nations does not quite deserve its negative reputation in academic circles (Rodrik 1999). Nevertheless, making industrial policy work is a challenge, and one that needs to be confronted head on if green industries are to play their proper role in green growth.

The case against industrial policy comes in two forms. The first counter-argument is that governments do not have the information needed to make the right choices as to which firms or industries to support. Usually presented with the formulaic statement "government cannot pick winners," this suggests governments are likely to make lots of mistakes and hence waste considerable resources, even when they are well intentioned. The second counter-argument is that once governments are in the business of supporting this or that industry, they invite rent-seeking and political manipulation by well-connected firms and lobbyists. Industrial policy becomes driven by political rather than economic motives. In the United States, the case of Solyndra – a solar cell manufacturer that folded after having received more than half a billion in loan guarantees from the U.S. government – provides a recent illustration where both failures were apparently in play. I shall review and discuss the Solyndra case later in the paper.

I will argue in this paper that the first of these arguments – about lack of omniscience – is largely irrelevant, while the second – about political influence – can be overcome with appropriate institutional design. Good industrial policy does not rely on government's omniscience or ability to pick winners. Mistakes are an inevitable and necessary part of a well-designed industrial policy program; in fact, too few mistakes are a sign of underperformance. What is needed instead is a set of mechanisms that recognizes errors and revises policies accordingly. This is a much less demanding requirement than that of picking winners. The chief argument of this paper is that an explicit industrial policy that is carried out self-consciously and designed with pitfalls in mind is more likely to overcome the typical informational and political barriers than one that is implemented, as is so often the case, surreptitiously and under the radar screen.

The outline of the paper is as follows. In the next section, I provide a brief overview of the range of green industrial policies already in place in the United States, Germany, China, and Japan. I then discuss the case of Solyndra, where I argue the real lessons are quite different from those that are conventionally drawn. In section IV I provide some general guidelines about the design of industrial policy. In section V I offer some concluding remarks.

II. A snapshot of green industrial policies in selected countries

It is generally accepted that governments have been timid in reducing GHG emissions and instituting other steps that would avert catastrophic climate change. Yet there has been plenty of government activism in the area of "green growth." Look around most developed and emerging market economies and you will find a bewildering array of government initiatives designed to encourage renewable energy use and stimulate green technology investment. Even though full pricing of carbon would be a far better way to address climate change, it appears most governments would rather deal with the problem through subsidies and regulations that increase the profitability of investments in renewable energy sources.

As Steer (2013) points out, the concept of “green growth” has spawned the idea that policies that promote environmentally friendly technologies are actually advantageous from a national standpoint. Such policies are viewed as providing broad-based technological capabilities, a head-start and in new industries, competitive advantage in global markets, and well-paying jobs. In other words, green growth has become “sexy.” Steer (2013) notes that more than 50 developing countries have now instituted practices such as feed-in tariffs or renewable energy standards to foster green technologies – costly policies “that at first sight seem not to be in their country’s narrow interest” (2013, 18). Fankhauser et al. (2012) review what they call the “green race” and provide an empirical analysis of the determinants of relative success across countries.

It would take too much space to cover the full range of these policies. Here I provide a quick overview of existing programs in two advanced countries and two emerging-market economies: the United States, Germany, China, and India. The relevant information is summarized in Tables 1-4. The tables list for each of the countries the key pieces of legislation, policy tools used, and illustrative programs. The information has been compiled from national and international sources.

Among the countries shown, Germany and China have the most aggressive policies. But even the others make use of a wide range of policy instruments. While some of the instruments listed do not qualify as industrial policies (e.g., cap-and-trade policies, mandated energy efficiency standards), many others clearly are (R&D grants, government procurement, subsidized loans and loan guarantees, direct subsidies).

Important laws and policies
- Clean Air Act; National Energy Conservation Policy Act; Energy Policy Act of 2005
- Energy Independence and Security Act of 2007; Energy Improvement and Extension Act of 2008
- Food, Conservation, and Energy Act (2008 Farm Bill)
- Executive Orders 13423 and 13514
- American Recovery and Reinvestment Act of 2009: over $80 billion to support clean energy R&D and deployment
- EPA's Final Greenhouse Gas Tailoring Rule (2010) and *proposed* Carbon Pollution Standard for New Power Plants
Tools used
- Federal Production Tax Credit (about to expire) and Investment Tax Credit (or direct grants): the PTC reduces the federal income taxes of renewable energy facility owners per KWh produced, and ITC reduces federal income taxes for investments in renewable energy projects
- Tax credits for energy efficiency upgrades (both for commercial entities and individuals) and purchases of electric vehicles
- EPA standards for greenhouse gas emissions from mobile and stationary sources under the Clean Air Act (in process of being implemented but facing legal challenges)
- Loan guarantees and concessional lending for projects that reduce GHG emissions
- Grant funding for R&D in renewable energy, energy efficiency, CCS, electric vehicle, fuel cell technologies
- Grants to support training of "green-collar" workers
- Government procurement policies (e.g. purchasing energy-efficient vehicles)
- Renewable fuel standards, fuel efficiency standards (Corporate Average Fuel Economy, or "CAFE," standards), and a "gas guzzler tax" on new cars
- Accelerated deductions for renewable energy investments
- Energy efficient mortgages
- Qualified Energy Conservation Bonds
- Manufacturing Tax Credits for manufacturers of energy efficient appliances; tax credits for gas stations/fueling centers that install allternative fuel pumps; tax credits for alternative fuels
- Federal appliance standards
- Cap-and-trade (at the state level)
- State-level Renewable Portfolio Standards
Significant government programs
Federal
- DOE's Office of Energy Efficiency and Renewable Energy programs, including: Wind (including Wind Powering America), Solar (including SunShot Initiative), Bioenergy, Geothermal Technology, Hydrogen & Fuel Cell Technologies, Vehicle Technologies, Buildings, Energy Efficiency and Conservation Block Grant, and Weatherization and Intergovernmental programs
- Renewable Fuel Standard Program
- DOE Section 1703 and Advanced Technology Vehicles Manufacturing Loan Programs
- Energy Star
- Federal support to states for RE and EE programs: DOE's State Energy and EPA's State Climate and Energy Partnership Programs
- Renewable portfolio standards in a majority of states (at least 33 have RPS standards or goals in place)
- California cap-and-trade program created regulations and market mechanisms to reduce the state's GHG emissions to 1990 levels by 2020, with mandatory caps beginning for significant emissions sources
- Regional Greenhouse Gas Initiative (RGGI): mandatory cap-and-trade program for fossil fuel-fired power plants, consisting of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont.
- California's Alternative and Renewable Fuel and Vehicle Technology Program; California Solar Initiative, Go Solar California
- New York State Energy Plan; Western Climate Initiative

Table 1: United States' green growth policies

Important laws and policies
- Energy Transition (2011): policy document phasing out nuclear energy by 2022, renewable energy and energy efficiency targets
- Energy Concept (2010) : road map and commitment to reduce GHG emissions by 40% by 2020 and 80-95% by 2050
- Integrated Energy and Climate Programme ("IEKP", 2007): defined primary and secondary legislation and support programs for GHG reduction
- Adherence to EU Energy and Climate Package ("20/20/20"), including:
- EU Emission Trading Directive
- EU Effort Sharing Decision: binding annual GHG reduction targets for sectors not covered by EU ETS
- EU Renewable Energy Directive: binding national targets for raising the share of renewable energy in energy mix by 2020
- EU Energy Service Directive
- EU Energy Efficiency Directive
- 2007 Biofuels Quota Act (mandates minimum percentage of biofuel-petroleum blend) and the 2011 Fuel Quality Ordinance
- Renewable Energies Heat Act (2009)
- Energy Saving Ordinance (2009): regulates energy performance of new buildings and provides energy certification of buildings
- Energy Industry Act (2005)
Tools used
- Direct funding to R&D in renewable energy and energy efficiency
- Feed-in tariff for renewable energy, together with "market premium" allowing plant operators to sell renewable energy directly back into the grid and keep the premium
- Concessional lending/subsidies for renewable energy projects and energy efficiency improvements
- Insurance against non-discovery risk for geothermal energy
- Quotas for minimum percentage of biofuel in fuel
- New vehicle tax depending on vehicle CO2 emissions and type/size of engine
- Energy performance standards for buildings, appliances
- Participation in EU Emissions-Trading Scheme
- Taxes on electricity and fuel use, but controversial exemption of energy-intensive industries if they commit to annual energy efficiency improvements
- State (Länder) support to renewable energies (varies by state)
Significant government programs
- Sixth Energy Research Programme (EUR 3.5 billion for research on low-carbon technologies)
- German Special Fund on Energy and Climate ("EKF")
- KfW Renewable Energies Programme
- KfW Offshore Wind Energy Programme
- Energy Efficiency Fund

Table 2: Germany’s green growth policies

Important laws and policies
- Renewable Energy Law (2006)
- 12th Five Year Plan (2011-2015): energy efficiency, carbon emissions reduction and new energies are priorities
- 12th Five Year Plan for Energy Development
- 12th Five Year Plan for Solar Power
- 12th Five-Year Work Plan on Controlling GHG Emissions
- Energy Saving and New Energy Vehicle Development Plan (2011-2020)
- National Medium and Long-Term Development Plan for Renewable Energy (2007)
- Medium and Long-Term Energy Conservation Plan (2004)
Tools used
- Feed-in tariffs for solar, wind (at the national and provincial levels)
- Fiscal incentives to support R&D or manufacturing in renewable energies (including VAT and income tax breaks, exemptions from custom duties and import VATs)
- Concessional lending for renewable energy projects
- Subsidies to green technologies (including to solar PV manufacturers)
- Mandated energy reductions for largest firms (~17,000)
- National cap on energy consumption, coal output
- Forthcoming national emissions trading system (envisaged for 2016-2020, following the pilot projects)
- Forthcoming fuel economy standards for automotive industry
- Direct funding to R&D
Significant government programs
- Pilot cap-and-trade programs in Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, and Guangdong and Hubei provinces, covering 256 million people and accounting for 3.5% of global economy
- Solar Roofs Program and Golden Sun Program: provide investors with financial incentives and scientific and technological support for solar energy projects
- Large R&D programs, parts of which support clean tech development:
- National Basic Research Program ("Program 973")
- MOST's innovation fund for small technology-based firms
- MOST’s National High-Tech R&D Program ("863")
- Key Technologies R&D Program
- Top 10,000 Enterprises Energy Efficiency Program
- City-based pilot projects to construct low-carbon transport systems

Table 3: China’s green growth policies

Important laws and policies
- National Action Plan on Climate Change (2008), consisting of eight missions, including the National Solar Mission
- Integrated Energy Policy (2006)
- National Electricity Policy (2005)
- Energy Conservation Act (2001)
- Air (Prevention and Control of Pollution) Act (1981)
- Environment (Protection) Act (1986)
Tools used
- Renewable portfolio standard
- Renewable Energy Certificates for wind, solar and biomass power plants (but market near collapse)
- Generation-Based Incentives for wind and solar (providing payment per kWh) targeting large-scale IPPs (on and off)
- Accelerated depreciation for wind investments, targeting smaller investors (currently on pause)
- Set of feed-in tariffs, varying by state and source type
- State-level feed-in-tariff for wind power for 13+ states
- National feed-in-tariff only for federal or inter-state power generators (few)
- Gujarat has a feed-in-tariff for solar-generated electricity, with at least two other states possibly following suit
- Fiscal incentives (e.g. reduction of tariffs on solar imports and concessional lending)
- Subsidies to R&D in renewable energy
- (Planned) Insurance for solar power producers against default by state utilities ("Solar Payment Security Account")
- (Planned) Pilot Emissions Trading Schemes in three states
Significant government programs
- Jawaharlal Nehru National Solar Mission
- National Mission for Enhanced Energy Efficiency
- National Clean Energy Fund (funded by coal tax)
- Solar Cities Development Programme (forthcoming)

Table 4: India's green growth policies

In addition to a 40% GHG reduction target, Germany has an extensive array of initiatives. These include R&D support of several billions of euros (focusing on wind energy, PV renewable energy systems, integration of renewable energies, geothermal, solar thermal power plants, and low-temperature solar thermal energy installations), long-term low-interest loans (for solar PV, biomass, wind energy, hydropower, or geothermal, and electricity or heat from other renewables), an energy and climate fund (spent on various support programmes relating to energy efficiency, renewable energy, energy storage and grid technology, energy-efficient renovation, national and international climate protection as well as electro-mobility), a climate protection initiative (with projects in areas such as refrigeration technology and biomass research), and a climate technology initiative (aiming to mobilize bilateral technology cooperation with countries that have German export potential).

Chinese efforts have gone heavily into PV projects, mainly directed for the world market. This was a key source of Solyndra's financial difficulties, discussed in the next section. Under the second phase of its Golden Sun Program, the Chinese government allocated a total of 13 billion yuan ($2 billion) to support the domestic PV market in 2012, with 7 billion yuan ($1.1 billion) earmarked to subsidize solar PV demonstration projects. Since 2009, a parallel program provides financial incentives of up to 20 yuan/W. China Development Bank provides billions of dollars in concessional lending to renewable energy. In 2010 the Development Bank had credit lines worth RMB 282 billion (around US$ 45 billion) available for the renewable energy industry. Some Chinese provinces and municipalities are particularly active and have their own fiscal incentives to promote new plant investment in the solar industry. Beijing, for example, provides upfront subsidies for qualified demonstrative PV projects.[6]

In the U.S., many of the incentives for investment in green technology were put in place (or strengthened) with the American Recovery and Reinvestment Act of 2009. The Act contained loan

[6] The financial incentives in solar energy have led to over-capacity, and China's PV sector was facing severe financial difficulties in 2013. They also produced trade disputes with the U.S. and the EU.

guarantees, tax incentives and other subsidies amounting to $20 billion for research and investment in green technologies. In June 2013, President Obama announced an ambitious Climate Action Plan, which included an additional $8 billion in loan guarantees for advanced fossil energy projects that reduce GHG emissions.[7] India employs a range of tax incentives (tax holidays, accelerated depreciation, reduced VAT), low-interest loans, and pilot projects. One thing that is common across all these countries is the prevalence of policies that encourage the use and development of new technologies instead of protectionist trade policies that close off markets to foreign companies. On balance, therefore, these policies aim to move incentives in the right direction.

How well do these programs work in practice? The short answer is that we do not know. There are concerns that the ambitious policies in Germany and China have not been well designed, encouraging excessively solar power in Germany and solar cells in China. Policy makers do not seem to be paying enough attention to designing policy instruments targeted on offsetting externalities in the most effective way. Unlike carbon pricing, which is easy to do in view of the nature of the GHG externality, encouraging innovation spillovers is complicated and requires considerable care. In many countries, policy focuses more on subsidizing supply of renewable energy than boosting R&D spending or improving the national innovation system. Similarly, principal-agent problems present a huge challenge to policy design.

In the next section, I review a celebrated failure, Solyndra, as a prelude to a discussion of appropriate design for green industrial policies.

III. Solyndra: economics and politics

In May 2010, President Obama visited a company in Fremont, California, praising it as a "symbol of progress." The company was Solyndra, a solar cell company founded in 2005 and the first to get funding under an expanded loan-guarantee program to develop green technologies, part of Obama's 2009 American Reinvestment and Recovery Act. "The true engine of economic growth will

[7] http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

always be companies like Solyndra," Obama said (Greene 2012). The Obama administration would eventually sign off on $535 million in loan guarantees to Solyndra, to supplement $450 million raised from private investors.

By August 2011 Solyndra had gone bankrupt. Its collapse raised questions in the eyes of many observers about the desirability of "picking winners," as the Obama administration had apparently done. It also highlighted the risks of political favoritism and cronyism, which many thought had played a role in the administration's continued support of Solyndra.

The reason behind Solyndra's collapse seems clear in retrospect. Solyndra's technology for producing photovoltaic cells relied on CIGS (copper indium gallium selenide) as the semiconducting material, instead of silicon which was vastly more common in the industry. CIGS was cheaper than silicon but less efficient at converting solar energy. Solyndra was founded at a time when silicon prices were rising rapidly. The competitive case for Solyndra relied heavily on silicon prices remaining high. But from early 2008 on, silicon prices tumbled as precipitously as they had risen earlier, thanks in large part to new capacity coming online in China. Within a year, spot prices for silicon collapsed from more than $450/kg to less than $100/kg (Figure 1). At such prices, Solyndra's technology had no chance to compete with conventional silicon-based photovoltaic cells. Meanwhile, PV capacity expanded six-fold globally between 2007 and 2010 (Table 5). The company failed even though it had met its own technological and cost-reduction goals.

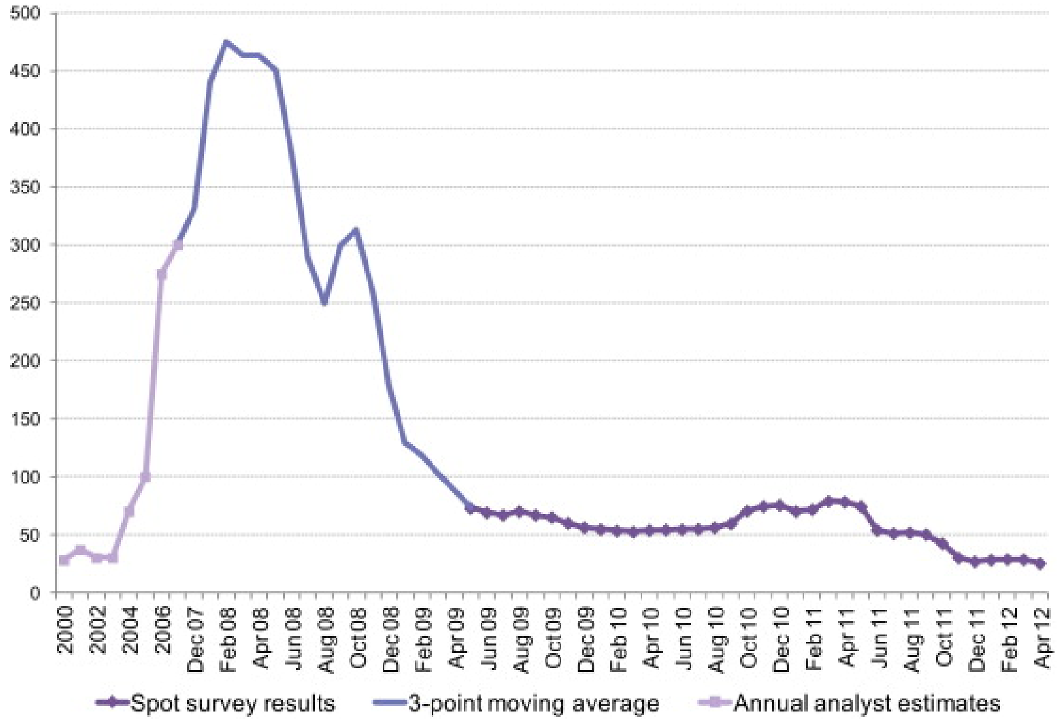

Figure 1: Solar-grade silicon prices ($/kg.)

Source: Bazilian et al. (2013)

Year	China	Taiwan	Japan	Germany	US	Others	World
2005	128	88	833	339	153	241	1,782
2006	342	170	926	469	178	374	2,459
2007	889	387	938	777	269	542	3,801
2008	2,038	813	1,268	1,399	401	1,207	7,126
2009	4,218	1,411	1,503	1,496	580	2,107	11,315
2010	10,852	3,639	2,169	2,022	1,115	4,248	24,047

Table 5: Annual PV Production by Country, 1995–2010 (MW)

Source: Deutch and Steinfeld (2013)

Much of the subsequent furor focused on two questions. First, did the Department of Energy (DOE), which administers the loan-guarantee program, exercise sufficient due diligence with regard to the commercial viability of Solyndra's technology? Second, did Solyndra and its private backers exercise undue political influence to get the DOE to finance the company despite the evident risks? These two questions go to the heart of the argument against industrial policy, which rests on the government's lack of omniscience and its propensity to political capture. Solyndra's failure provides an apparent vindication of these concerns.

However, there is little that we learn about industrial policy and its uses and abuses from Solyndra's bankruptcy alone. Under an optimally-designed program of industrial policy, some firms that receive public support will necessarily fail. In fact, if every subsidized firm were to prove financially successful, this would likely indicate that the program was vastly under-performing.

The reason is that green technologies are subject to significant ex-ante uncertainty. The uncertainty may be due to unforeseen scientific and technological developments, or potentially unpredictable price and other commercial trends (as in the case of Solyndra). In the face of uncertainty, it is optimal to finance a larger group of projects than will prove viable ex post.

For concreteness, suppose the public agency faces a continuum of applicants indexed by $z \in [0,1]$, with ex-ante failure probabilities given by $p(z)$. Let $p(z)$ be weakly increasing in z, with $p(0)=0$ and $p(1)=1$. (As long as $p(z)$ is not <u>strictly</u> increasing in z, we can have a range of projects for which the failure probability remains zero.) Let each project require public funding of amount K, and provide net return of π if successful (and 0 otherwise). The total budget, B, required to fund all projects that are worthwhile can be expressed as $B = \int_0^k f(z)K dz$, where k denotes the marginal project funded and $f(z)$ is the probability distribution function of z. The marginal project, in turn, is defined as the one that just breaks even in economic terms. Let r stand for the public agency's opportunity cost of funds and assume $\pi > r$, such that there are at least some projects worth funding. Then k is implicitly determined by the equation $[1-p(k)]\pi = r$. In this equilibrium, $p(k) > 0$ and there will be many projects that are funded yet have positive probability of failure. The portfolio of projects will more than pay for itself in aggregate, even though some investments will likely fail ex post.

This is of course what every fund manager or venture capitalist knows. The true measure of success is not whether some projects fail, but how the portfolio fares overall. A portfolio that screened out all projects with positive probability of failure would entail too small an investment (*B)* and too low an overall return. As Thomas Watson, the founder of IBM, supposedly advised cautious managers, "if you want to succeed, raise your error rate."

For publicly subsidized projects, there is an additional layer of considerations. In the absence of some kind of market failure, the public sector does not have any comparative advantage in undertaking such activities and should not be in the business of subsidizing or funding private projects. On the other hand, if green technologies both produce technological externalities and help counteract the under-pricing of carbon, as I have argued above, commercial profitability or breaking even is not the appropriate benchmark for success.

Suppose each successful project yields θ in external benefits per unit of capital invested, in addition to the private return of π. Now the marginal project k is defined implicitly by $[1-p(k)](\pi + \theta) = r$, and has a higher default probability than in the previous case. The marginal project will in fact be one that makes losses on a commercial basis. The portfolio as a whole may bring below-market, even negative, returns if the externalities are sufficiently strong. In view of these considerations, a public program to encourage green technologies cannot be evaluated by the financial performance of the overall portfolio, much less by the success or failure of individual projects.

We have one detailed study that takes such a portfolio approach to public support in green technology and the results are quite instructive. In 2001, the U.S. National Research Council (2001, NRC) evaluated DOE initiatives in two areas – energy efficiency and fossil energy – between 1978 and 2000. The DOE had invested about $22.3 billion in these areas (or about 26 per cent of its total expenditures on energy R&D). The NRC identified many projects that had failed, but came to the conclusion that the portfolio's net benefits for the U.S. economy had been positive overall. In energy efficiency net benefits amounted to $30 billion – not at all bad for an investment of roughly $7 billion over 22 years (valuations are in 1999 dollars). (Note that the NRC did not attempt to estimate benefits that spilled over to other nations.) Interestingly, much of the net economic benefits could be attributed to "three relatively modest projects in the building sector."

Returning to the Solyndra case, we can conclude that its failure did not necessarily warrant the outcry and the immediate search for culprits that went on display. Many observers and Congressional representatives were too quick to jump to the conclusion that something must have gone wrong, and that somebody must be guilty. Solyndra's offices were searched by FBI agents and the company's top executives were hauled before Congress (where they took the Fifth Amendment).

Aside from the specific mistakes that may have been committed in this particular case (see below), what precipitated the reaction is that the logic outlined above had not been an explicit part of the loan-guarantee program's design and communication strategy. The DOE program served a mixed-set of objectives. It never had a clear set of yardsticks for measuring and evaluating performance other than recouping the loan guarantees. Stimulating demand and employment, spearheading new technologies, competing with China, and environmental benefits all played a role in selling the program to Congressional interests and the broader public. The White House talked about positioning "the United States as a global leader in developing and manufacturing cutting-edge clean energy technologies," "continued growth in the renewable energy sector," spurring "innovation and investment in our nation's energy infrastructure," and creating "American jobs."[8] President Obama himself would state the case in explicitly national-competitiveness terms in October 2011, following the failure of Solyndra: "… if we want to compete with China, which is pouring hundreds of billions of dollars into this space, if we want to compete with other countries that are heavily subsidizing the industries of the future, we've got to make sure that our guys here in the United States of America at least have a shot" (cited in Datla, p. 10).

The idea that a successful program would have to incur many individual failures along the way, even if well understood by the specialists, was not clearly articulated or explained. Partly as a

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[8] http://www.whitehouse.gov/sites/default/files/blueprint_secure_energy_future.pdf

result, the Solyndra failure was treated as an indication of a broader, systematic problem rather than as something that was within the normal parameters of the program.

Once it is understood that failure is part and parcel of a successful industrial policy effort, the question becomes how the cost of failures can be minimized. We cannot pick winners; this is a fact of life that is not a deterrent to industrial policy on its own. But we can, in principle, stop backing evident losers. The better we get at the task of letting losers go, the better our industrial policy. As elaborated further in the next section, this task requires clear benchmarks for success, close monitoring, and explicit mechanisms for reversing course. How well did the administration do on this score in the Solyndra case?

There are many indications that Solyndra's progress – or lack thereof – was not sufficiently scrutinized. It appears that the company was selected early on as a showcase for the administration's efforts and pushed through the approval process in record time. Silicon prices had already begun their precipitous drop before the loan guarantee was approved, which should have raised some concerns. As a subsequent Congressional report put it,

> "the lack of available competitor information for Solyndra and the rapidly dropping price of polysilicon and panel prices should have prompted DOE to reconsider the Solyndra loan guarantee or, at the least, postpone the Solyndra closing so it could examine how the Solyndra loan guarantee would be impacted by the Chinese pricing pressures."[9]

And as Solyndra's financial difficulties mounted, it seems that DOE officials justified the losses by arguing that this was common in all start-ups. In July 2010, the Office of Management and Budget (OMB) sent DOE specific questions relating to Solyndra's financial status and productivity. The DOE apparently never responded, despite repeated OMB requests.[10]

Similarly, a memo prepared for the President on the DOE loan guarantee program by Lawrence Summers, among others, in October 2010 did mention the need for "clear policy principles

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[9] http://energycommerce.house.gov/sites/republicans.energycommerce.house.gov/files/analysis/20120802solyndra.pdf, p. 132.

[10] Ibid., p. 135.

– and associated metrics for evaluation" as one of the options to be considered. But Solyndra was not mentioned as a potentially problematic case, and no action seems to have been taken in response.[11]

More damagingly, the administration invested substantial political capital in the company's success, making a potential cut in support difficult to contemplate. The provisional loan commitment to Solyndra in March 2009 was marked by joint appearances by Energy Secretary Steven Chu and Vice President Joseph Biden (Datla 2012). And, as noted previously, President Barack Obama himself showed up at the company's headquarters in California in May 2010 to publicly celebrate Solyndra's apparent success.

Then there were Solyndra's own political activities, which were substantial. As the New York Times notes, **"**Solyndra spent nearly $1.9 million on lobbying activities over a period of 43 months from 2008 to 2011."[12] This is a large number, which placed the Solyndra in the top tier of lobbyists among comparable energy companies.[13] The scale of lobbying for a firm of its size and with such financial difficulties should have been a warning sign. Moreover, the principal private investor in Solyndra, George Kaiser, was an important fundraiser for Obama and he clearly had access to the White House. Congressional investigators found that Kaiser had discussed Solyndra with the White House staff in February 2010 in Vice President Biden's office.[14] The Obama administration would maintain throughout that the loan guarantees were approved by the DOE purely on the merits of the case.

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[11] To illustrate some of the potential problems that may arise, the memo discussed another project, the Shepherd's Flat loan guarantee. For the text of the memo see http://abcnews.go.com/Blotter/obama-talks-big-clean-energy-money-removed-key/story?id=12048872#.UaN5XndFVK0.

[12] http://www.nytimes.com/gwire/2011/09/16/16greenwire-solyndra-spent-liberally-to-woo-lawmakers-unti-81006.html.

[13] To compare Solyndra's lobbying expenditures to other energy firms' lobbying activities in 2011, see http://www.opensecrets.org/lobby/indusclient.php?id=E07&year=2011 and http://www.opensecrets.org/lobby/indusclient.php?id=E01&year=2011.

[14] See http://energycommerce.house.gov/sites/republicans.energycommerce.house.gov/files/analysis/20120802solyndra.pdf, p. 145.

So there is plenty to criticize in the manner in which DOE managed Solyndra -- and the loan guarantee program as a whole. The lesson, however, is not that the administration should not have subsidized a company that eventually failed. There is no economic reason that the government should recover every loan. In view of the environmental and technological externalities, there is not even a case for insisting that the loan portfolio as a whole should make a profit or break even. The real lesson is that there were no safeguards in place against political manipulation and to ensure DOE could pull the plug if circumstances warranted it. Worse yet, the administration made it harder to reverse course by committing itself to the project politically.

The DOE's loan guarantee program would eventually grow (by May 2013) to encompass 28 companies. Proponents would argue that, Solyndra notwithstanding, these companies had collectively created more than 20,000 jobs (Bump 2013) and played a role in "kickstart[ing] a fresh, promising, and environmentally responsible sector of the economy" (Oremus 2013). Many of the firms had begun to pay back their loans. Tesla Motors, which had received a $465 million loan guarantee in 2009, had seen its shares soar, and had repaid its loan early. Solyndra is clearly only part of a bigger picture. However, it will be years before we can reach a clear judgement as to whether the loan guarantee program as a whole was a success or not.

IV. Better rules for industrial policy

The theoretical justification for industrial policies to promote green industries is strong. But such policies can be exploited by powerful insiders and overwhelmed by informational asymmetries between the private and public sectors, as the Solyndra case well highlights. Skeptics rely on these arguments to argue for a hands-off approach. However these pitfalls are not special to industrial policy. Virtually any area of government policy is subject to similar challenges.

For example, education policy is motivated by arguments about educational externalities and social cohesion, even though there is much debate about how well it works, whether these ends are adequately served, and the extent to which insiders such as teacher unions distort its implementation. Health policy is driven also by a combination of social concerns and moral hazard/adverse selection considerations, but few would deny the role of organized political groups in shaping it. Infrastructure and telecom policy are rooted in problems of natural monopoly, but insiders and lobbyists play a large role in their formulation. Stabilization policy is motivated by Keynesian theories and is marked by virulent debates about its effectiveness.

In all these cases, there are strong a priori, theoretical justifications for policy intervention, but inconclusive empirical evidence on whether policy works "on average." However, debates typically focus not on whether the governments should have active policies in these areas but on how the requisite policies should be designed – whether government should run schools or simply finance them, or the appropriate mix between monetary and fiscal policies, for example. Green industrial policy needs to be approached in the same manner, as an important government function, that can be carried out better or worse. The useful debate to be had is not whether green industrial policies should exist but how they should be designed.

A serious debate about the design of industrial policy would bring it out of the shadows and allow it to be carried out in an explicit manner. It would save it from being carried out surreptitiously, as an appendage to other governmental functions and hostage to related, but distinct objectives such as employment or competitiveness.

Industrial policies must be built on three key ideas. First, the requisite knowledge on the existence and location of technological spillovers, market failures, and constraints that impede green investments is diffused widely within society across businesses, entrepreneurs and scientific communities. Second, private investors and others who are the beneficiary of public support have strong incentives to "game" the government, by bending the rules to their advantage through their informational advantage and political muscle. Third, the intended beneficiary of industrial policies is neither bureaucrats nor business, but society at large.

Each of these ideas has specific implications for the institutional design of green industrial policies. We can summarize these implications as (i) embeddedness; (ii) discipline; and (iii) accountability. I take up each design principle in turn.

(i) Embeddedness

When economists think about optimal policy design in the context of industrial policy, they typically hone in on models of regulation based on agency theory. In these models, the principal (the regulator) aims to alter the behavior of an agent (the firm) to pursue a public objective (an investment of a particular kind). The central feature of the setup is that the agent has some private information (e.g., its costs). In light of this asymmetry in information, the principal has to cede "informational rents" to the agent, and cannot obtain its unconstrained (i.e., perfect-information) optimum. Effectively, the principal has to offer the agent a reward to dissuade it from mimicking a less efficient counterpart (Laffont and Tirole 1993).

In this top-down model of interaction between the bureaucracy and business, communication between the two is neither assumed, nor required. From the standpoint of minimizing rent-seeking and lobbying, this can be viewed as a distinct advantage. The policy maker need not consult with business people, and can keep them at arm's length. Any direct interaction is unnecessary from the standpoint of carrying out the public purpose and hence can be judged as illegitimate. The autonomy that is built into the framework insulates the bureaucracy from pressure from below and protects them for it.

By the same token, the principal-agent perspective severely limits the flow of information from below. This is a serious shortcoming, especially in an area such as green technology where uncertainty is multifaceted and may often take Knightian characteristics. The agency framework assumes the principals already have a very good idea of what needs to be done to achieve public goals, and all that needs to be done is to provide the agents (firms) with the right incentives to carry out the requisite investments. But as Charles Sabel puts it,

> “what if … there are no principals … with the robust and panoramic knowledge needed for this directive role? Then the problem for reform is at least as much determining ways actors can discover together what they need to do, and how to do it, as determining which actors ought to be the principals in public decision making.” (Sabel 2004)

The principal-agent model presumes the existence ex ante of a well-defined social objective function -- well-defined in the sense of not just what is being maximized, but also the types of instruments and strategies that are available. Businesses cannot communicate information about the constraints they face other than through their actions. Neither can they communicate directly any new opportunities that may arise, or advance proposals as to how these might be pursued with the help of the public sector.

An appropriate industrial policy framework needs to make room for learning by government officials on all these counts. That in turn requires a significant amount of interaction and communication between the public and private sectors. This is what the term “embeddedness” refers to. It was used first in the industrial-policy context by Peter Evans (1995), who described South Korea’s developmental state as one in which the bureaucracy exhibited “embedded autonomy.” The South Korean bureaucracy, he argued, operated along Weberian, meritocratic lines, but it was not insulated from the private sector. Quite to the contrary, it was “embedded in a concrete set of social ties that binds the state to society and provides institutionalized channels for the continual negotiation and renegotiation of goals and policies” (Evans 1995, p. 12). As Evans wrote, “[a] state that was only autonomous would lack both sources of intelligence and the ability to rely on decentralized private implementation” (1995, p. 12).

Clearly, the embeddedness that is required is one that falls far short of bureaucrats being beholden to and in the pockets of business. Government agencies need to be embedded in, but not in bed with, business. The right model lies between arm’s-length and capture. It is one of strategic collaboration and coordination between the private sector and the government with the aim of learning where the most significant bottlenecks are and how best to pursue the opportunities that this interaction reveals. There are multiple institutional settings within which this kind of collaboration can occur: deliberation councils, supplier development forums, search networks, regional collaborative innovation centers, investment advisory councils, sectoral round-tables, private-public venture funds, and so on.

This way of looking at green industrial policy highlights another important implication: the right way of thinking about it is as a process of discovery, by the government no less than the private sector, instead of a list of specific policy instruments. This perspective focuses attention on learning where the constraints and opportunities lie and responding appropriately, rather than on whether the governments should employ tax breaks, R&D subsidies, credit incentives, loan guarantees, and so on. It is important, of course, to evaluate the effectiveness of these specific instruments. But the prior, meta-question on green industrial policy is whether a government has put in place the appropriate processes and institutions of engagement with the private sector.

(ii) Discipline

The embedded nature of green industrial policy makes the need for disciplining devices against abuse all the more imperative. Firms and industries that receive help from the government must know that they cannot game the system, and that underperformance will result in the removal of assistance. Carrots must be matched by sticks. This was indeed a key ingredient of East-Asian style industrial policy. In South Korea firms that did not meet their export targets saw their subsidies cut, and in some cases even became targets of government recrimination in the form of aggressive tax audits, for example.

In democracies, discipline has to take a form that is different than the one in which it came in the "hard states" of East Asia (as exemplified by South Korea and Taiwan during the 1960s and 1970s, especially). It has to be less ad-hoc and firm-specific, and more institutionalized. But since each case is different and the nature of green technology is inherently uncertain, a certain element of discretion is unavoidable. The trick is to exercise discretion in a manner that can be justified by the facts on the ground.

A principled discipline requires first and foremost clarity in objectives. If the objectives of a program to support green technologies have not been explicitly specified ex ante, it will be difficult to know whether the program is working or needs revision. This seems to be a rather obvious principle, but it is frequently flouted in practice. For example, the DOE loan guarantee program was touted on account of its contribution variously to jobs, global competitiveness, technological benefits, external spillovers, and contribution to curbing climate change. It is certainly possible to meet one or more of these objectives while failing on account of the others. Technological benefits and spillovers can be reaped without attaining competitiveness at the same time, as was possibly the case with Solyndra. Similarly, jobs may be created without gains either in technology or competitiveness.

Politicians may naturally want to kill multiple birds with one stone. But multiplicity of goals – or confusion about them – does not contribute to discipline. It becomes possible to justify any range of results after the fact, by latching on to the least problematic aspects of performance. The greater the multiplicity of goals and the hazier their definition, the less the ability to recognize failure, remove support, and change course.

What then are appropriate goals for green industrial policy? As discussed in the introduction, public support is justified by the need to foster private investment in green technologies and contribute to reduction of GHG emissions, in view of the likely market failures in both areas. This is a largely technological goal. It has to be distinguished from employment creation, competitiveness, profitability, and other commercial aspects. A promising new technology may be worth supporting even if it does not generate many jobs; employment objectives are better served through other policies. And it may be worth supporting even if the pioneering investor ends up bankrupt; if the technological learning and spillovers from the pioneer spawn a new industry, its own commercial failure is of little consequence.

Unlike jobs and commercial profitability, however, a technological objective is very difficult to monitor. Within firms and industries, probably the best single observable indicator would be cost.

The progress of, say, a solar-cell firm in meeting its technological objectives can be measured by its rate of cost reduction in producing energy. Therefore cost-reduction targets make much more sense in general than employment or investment targets. (Interestingly, by this measure, Solyndra's performance was quite solid.) But other measures of technological development can be used as well, many of which necessarily require judgment and discretion. Patenting activity, cluster development, and indicators of beneficial spillovers to other firms can all be scrutinized. Ultimately, monitoring overall technological progress needs to rely on periodic audits by professional specialists who can render their independent judgment.[15]

The next step is evaluation, which goes beyond tracking observable indicators and monitoring performance. Evaluating whether a program is meeting its objectives requires an explicit counterfactual: what would have happened in the absence of the program? Technically the most sophisticated (and credible) evaluations of public programs are based on randomized trials, regression discontinuity, or instrumental variables methods (Jaffe 2002; Van Reenen 2013). The first of these approaches compares firms that were randomly selected to receive support with those that did not. The second compares outcomes just above and below the threshold of qualification for public support. The third identifies the program effect through an exogenous component of variation in qualification. These techniques can be quite useful in some settings, when the intervention is relatively specific and the potential number of beneficiaries is large. Criscuolo et al. (2012) provide a useful application to regional state aid in Britain. As Jaffe notes (2002), building such evaluation protocols into support programs from the outset are an important safeguard.

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[15] As Jaffe et al. (2004, 14) note for the U.S.: "systematic assessment efforts are woefully lacking. Because success is uncertain and difficult to measure, most agencies engaged in support of research and technology adoption have resisted efforts to measure their output against quantitative benchmarks, as is required in the United States by the Government Performance and Results Act" (reference omitted). See Martin et al. (2009) for an interesting study on Britain, which finds negotiated targets on carbon abatement produced fewer gains than a non-discretionary tax because of the tendency of the regulators to set targets that were too flexible ex post, and ultimately too lax.

But in many instances, such techniques are not easily applicable, either because of small numbers of support beneficiaries or because the program components differ too much across recipients to render comparison meaningful. Inability to undertake evaluations that are rigorous enough to satisfy journal referees should not stop governments from implementing certain monitoring routines which are useful early-warning signals and can flag blatant program failures. A particularly useful practice would be to establish explicit cost, productivity and other targets ex ante. Such targets cannot eliminate the influence of unforeseen, exogenous changes (such as unexpected technological and market developments) that take place once the project is rolled out. But at least they allow outcomes to be evaluated against a particular benchmark – the baseline established by ex-ante expectations. Significant under-performance relative to that benchmark would then call for either the abolition of support or an explicit countervailing argument as to why unanticipated developments warrant continued support.

As long as there remains fuzziness about objectives, targets, and results – which seems inevitable, in light of the nature of green industrial policies – firms will always try to make a case for continued subsidies – either before the program agency or through political lobbying. As Matsuyama (1990) shows in a related context, the threat to remove support when a firm does not perform as expected is often not credible. Appropriate rules can help alleviate the dynamic inconsistency that bureaucracies face in these circumstances. For example, automatic sunset clauses would reverse the burden of proof by requiring positive action to renew support schemes, and make it harder for failing projects to be propped up. The requirement that agencies must provide an explicit accounting – preferably of a public kind – for continuing support when initial targets are not met would raise the bar similarly.

Experience with central banking shows that it is professionalism and reputation that ultimately safeguard an institution's independence from day-to-day politics rather than formal or legal independence. A similar reality holds for agencies in charge of industrial policies as well. The vaunted Defense Advanced Research Projects Agency (DARPA) provides an apt illustration in the

United States. DARPA has been behind some of the most dramatic technological breakthroughs of our time, including the Internet, GPS and satellite imagery. Few doubt its capacity to experiment with highly speculative technologies – as well as pull back from efforts that are not paying off. It works closely with private sector firms in so-called "dual use" technologies. But it is not known for being manipulated by commercial firms or politicized. It has been insulated and protected by the technical competence and esprit de corps of its staff and, ultimately, by its repeated successes (Greenwald 2013).

In summary, discipline requires clear objectives, measurable targets, close monitoring, proper evaluation, well-designed rules, and professionalism. With these institutional safeguards in place, it becomes easier to revise policies and programs along the way, and to let losers go when the circumstances warrant it.

(iii) Accountability

Embeddedness and discipline are two sides of the same coin, establishing the acceptable boundaries of the relationship between public agencies and the private sector. They facilitate communication and collaboration between the two while ensuring that public officials retain sufficient autonomy and have the ability to deploy a stick when needed. However, the purpose of green industrial policy is to further the public good at large, not the interests of the two parties in this relationship, bureaucrats and private firms. Therefore a third element of the institutional architecture must be public accountability. Public agencies must explain what they are doing and how they are doing it. They must be as transparent about their failures as their successes. Accountability not only keeps public agencies honest, it also helps legitimize their activities.

Accountability is an integral feature of democracy. One of the puzzles of East Asia is how state bureaucracies maintained their integrity and public-spiritedness despite the absence of democratic controls. One explanation is that there were alternative mechanisms of accountability in place. In South Korea, bureaucrats setting and implementing export targets during the 1960s and

1970s were closely monitored by higher-ups, including most notably President Park Chung-hee himself. In Singapore, one may surmise that the very high level of pay (and, relatedly, professionalism and skill) of officialdom prevents corruption and abuse. In China, despite rampant corruption, regional competition for investment and fiscal revenue compels local officials to remain business-friendly.

Even within democracies, accountability can be improved in a number of ways. The appointment of a high-level political champion for green industrial policies not just helps with coordination, but also identifies a clear figure who can be held politically responsible. A vice-president, minister, or other political official with visibility can serve in such a role. Transparency can be enhanced by a pro-active communication strategy. Agencies can publish, among others, minutes of meetings with firms and industry groups, regular reports on activities and budgets, and periodic audits by independent experts. The greater the openness and transparency at the outset, the less likely that industrial policies will be overwhelmed by real or imagined scandals down the line.

V. Concluding remarks

It will take concerted effort by governments to avert the threat of catastrophic climate change. One plank of the needed strategy is industrial policy, to stimulate and facilitate the development of green technologies. The fact that many governments are already embarked on such policies for reasons of international competitiveness or job creation provides a mixed opportunity. On the one hand, it engages governments in certain useful activities that they might not have been interested in on account just of climate change or control of GHGs. On the other, it makes it difficult for the policies to be targeted on the right targets and designed appropriately.

In practice, we are unlikely to get purely green industrial policy, focusing directly on the development and diffusion of green technologies instead of competitiveness, commercial, employment, or fiscal motives. Indirect, but politically salient objectives such as “green jobs” will likely continue to present a more attractive platform for promoting industrial policy than alternative energy or clean technologies. This may result in investment in the “wrong” industries – wind turbines, say, being built in countries like Britain rather than in developing nations. Occasionally, such objectives will clash directly with technological goals, as in the case of American and European protectionism in solar panels.

In the second-best setting of green growth, what ultimately matters is whether the global supply of green technologies expands (good) or contracts (bad). From a global standpoint, it would be far better if national competitiveness concerns were to lead to a subsidy war than a tariff war. The former expands the global supply of clean technologies while the latter restricts it. So far, that is largely what we have been getting. But there is no guarantee that we can extrapolate this trend into the future. A pragmatic approach would consist of improving the general practice of industrial policy, along the lines sketched out in the previous section, while gently nudging policy makers in the direction of greater awareness of how it can be better targeted on purely environmental concerns.

REFERENCES

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous, "The Environment and Directed Technical Change," American Economic Review, 102(1), 2012, 131–166.

Aghion, Philippe, Antoine Dechezleprêtre, David Hemous, Ralf Martin and John Van Reenen, "Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry," Centre for Climate Change Economics and Policy Working Paper No. 120, Grantham Research Institute on Climate Change and the Environment Working Paper No. 102, November 2012.

Bazilian, Morgan, Ijeoma Onyeji, Michael Liebreich, Ian MacGill, Jennifer Chase, Jigar Shah, Dolf Gielen, Doug Arent, Doug Landfear, and Shi Zhengrong, "Re-considering the economics of photovoltaic power," Renewable Energy, Volume 53, May 2013, Pages 329–338.

Bosetti, Valentina, Carlo Carraro, Romain Duval, Massimo Tovani "What Should We Expect from Innovation? A Model-Based Assessment of the Environmental and Mitigation Cost Implications of Climate-Related R&D," Fondazione ENI Enrico Mattei, 2010.

Bowen, Alex, and Samuel Fankhauser, "The green growth narrative: paradigm shift or just spin?" Global Environmental Change, Volume 21, Issue 4, October 2011, pp. 1157–1159.

Block, Fred R., and Matthew R. Keller, eds., State of Innovation: The U.S. Government's Role in Technology Policy, Paradigm Publishers, 2011.

Bump, Philip, "Solyndra Was This Much of an Outlier in the Energy Department's Portfolio," The Atlantic Wire, May 6, 2013 (http://www.theatlanticwire.com/national/2013/05/energy-department-loan-guarantee-charts/64932/.

Criscuolo, Chiara, Ralf Martin, Henry G. Overman and John Van Reenen, "The Causal Effects of an Industrial Policy," CEP Discussion Paper No 1113, January 2012.

Datla, Anjani, "Shaping the Future of Solar Power: Climate Change, Industrial Policy, and Free Trade," Harvard Kennedy School case written under the direction of Robert Lawrence, January 2012.

de Serres, A., F. Murtin and G. Nicoletti, "A Framework for Assessing Green Growth Policies," *OECD Economics Department Working Papers*, No. 774, OECD, 2010.

Deutch, John, and Edward Steinfeld, A Duel in the Sun The Solar Photovoltaics Technology Conflict between China and the United States, A Report for the MIT Future of Solar Energy Study, MIT, 2013.

Evans, Peter, Embedded Autonomy: States and Industrial Transformation, Princeton University Press, Princeton, NJ 1995.

Fankhauser, Sam, Alex Bowen, Raphael Calel, Antoine Dechezleprêtre, David Grover, James Rydge and Misato Sato, "Who will win the green race? In search of environmental competitiveness and innovation," Centre for Climate Change Economics and Policy Working Paper No. 111, and Grantham Research Institute on Climate Change and the Environment Working Paper No. 94, September 2012.

Freund, Caroline, "Solar Panels: When Trade, the Environment, and Geopolitics Collide," June 12, 2013, http://www.piie.com/blogs/realtime/?p=3620.

Greene, Ronnie, "Recurring red flags failed to slow Obama administration's race to help Solyndra," Public Integrity, updated January 23, 2012 (http://www.publicintegrity.org/2011/09/13/6434/recurring-red-flags-failed-slow-obama-administrations-race-help-solyndra).

Greenwald, Ted, "Secrets of Darpa's Innovation Machine," Forbes Magazine, February 15, 2013 http://www.forbes.com/sites/tedgreenwald/2013/02/15/secrets-of-darpas-innovation-machine/.

Hallegatte, Stéphane, Geoffrey Heal, Marianne Fay, and David Treguer, "From Growth to Green Growth: A Framework," World Bank WPS5872, November 2011.

International Monetary Fund, Energy Subsidy Reform: Lessons and Implications, January 28, 2013 (http://www.imf.org/external/np/pp/eng/2013/012813.pdf).

Jaffe, Adam B., "Building Program Evaluation into the Design of Public Research-Support Programmes," Oxford Review of Economic Policy, vol. 18, no. 1, 2002.

Jaffe, Adam B. Richard G. Newell, and Robert N. Stavins, "Technology and Environmental Policy: A Tale of Two Market Failures," Resources for the Future Discussion Paper 04-38, October 2004.

Karp, Larry, and Megan Stevenson, "Green Industrial Policy: Trade and Theory," Policy Research Working Paper 6238, October 2012.

Laffont, Jean-Jacques, and Jean Tirole, A Theory Of Incentives In Procurement And Regulation, MIT Press, Cambridge, MA, 1993.

Martin, Ralf, Laure B. de Preux, and Ulrich J. Wagner, "The Impacts of the Climate Change Levy on Business: Evidence from Microdata," Centre for Economic Performance Discussion Paper No 917, London School of Economics, March 2009.

Matsuyama, Kiminori, "Perfect Equilibria in a Trade Liberalization Game," The American Economic Review, Vol. 80, No. 3, June 1990, pp. 480-492.

Mazzucato, Mariana, The Entrepreneurial State, Demos, London, 2011.

National Research Council, Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000, Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, Board on Energy and Environmental Systems, Division on Engineering and Physical Sciences, 2001 (http://www.nap.edu/catalog/10165.html).

Oremus, Will, "Tesla, the Anti-Solyndra, Just Repaid Its Government Loans Nine Years Early," Slate, May 22, 2013 (http://www.slate.com/blogs/future_tense/2013/05/22/tesla_pays_off_doe_loan_9_years_early_first_us_car_company_to_repay_government.html).

Rodrik, Dani, The New Global Economy and Developing Countries, Overseas Development Council, Washington, DC, 1999.

Rodrik, Dani, One Economics, Many Recipes: Globalization, Institutions, and Economic Growth, Princeton University Press, Princeton, NJ, 2007.

Rodrik, Dani, Normalizing Industrial Policy, Commission on Growth and Development Working Paper No. 3, Washington, DC, 2008.

Sabel, Charles, "Beyond Principal-Agent Governance: Experimentalist Organizations, Learning and Accountability, in Ewald Engelen and Monika Sie Dhian Ho (eds.), *De Staat van de Democratie. Democratie voorbij de Staat*. WRR Verkenning 3 Amsterdam: Amsterdam University Press, 2004, 173-195.

Schmitz, Hubert, Oliver Johnson, and Tilman Altenburg, "Rent Management – The Heart of Green Industrial Policy," IDS WORKING PAPER, Volume 2013, No 418**,** April 2013.

Steer, Andrew, "Resource Depletion, Climate Change and Economic Growth," paper prepared for the Global Citizen Foundation Project on "Towards a Better Global Economy," February 2013.

Van Reenen, John, "Evaluation of State Aid," Centre for Economic Performance, LSE, presentation before DG-COMP, April 23rd 2013.

Wu, Mark, and James Salzman, "The Next Generation of Trade and Environmental Conflicts: The Rise of Green Industrial Policy," unpublished paper, April 2013.