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Climate Policy as Expectation Management? *

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Abstract:

It is believed that the primary economic solution to climate change is an introduction of a carbon pricing system anchored to the social cost of carbon, either as a form of tax or tradable permits. Potentially significant externalities accompanying the introduction of emission-reducing technologies, however, imply that the standard argument does not capture some important aspects for the designing of climate policy such as expectation-driven technology adoption. By using a simple model, we show some possible cases where carbon emission reduction progresses in a self-fulfilling prophecy by firms expecting others' future actions. In such circumstances, the carbon pricing system does not have much influence on determining the final outcome of economy-wide emission reduction. This highlights the danger of overemphasis on finding the "right" carbon price in policy making and the role of climate policy as expectation management.

Keywords: climate policy, technology choice, expectations, multiple equilibria

JEL classification: Q54, O33

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What role should the government play in climate policy?

The conventional view held by most economists is that the primary role of climate policy is to set a price for carbon dioxide emissions corresponding to their social costs, as a form of either tax or tradable permits. The basic idea behind this view is that carbon dioxide, a public good (or public "bad"), cannot be properly priced in the private market, and that the role of environmental policy is to devise some mechanism to adjust the price to the socially optimal level.[2] This logic supports a consequential but detached role of government that refrains from dictating how the private sector should act, a role resembling a rule-setter or a referee rather than a coach in a game.

This view, however, does not explain the entire picture of carbon dioxide reduction. As a case, in countries where significant policy of carbon dioxide emission control is already in place (exemplified by EU's emission trading scheme), carbon policy is a discernible factor for firms' investment decisions in energy infrastructure. A casual interpretation of the standard argument might suggest that the carbon price gives such companies an incentive to invest. In practice, however, the present level of the carbon price has only limited meaning for their investment decisions, as the average lifetime of power plants extends over several decades, and it is considered that the carbon price could considerably change within that period (e.g., Clarke et al., 2009). What is more important for their decisions would be their expectations about future benefits of clean technology, which are determined both by future carbon policy and by future

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[2] For example, Stern (2007) and Nordhaus (2008) might constitute two ends of a spectrum in opinion by estimating radically different optimal policy paths, but their difference comes primarily from the difference in social cost of carbon they estimate, not from any deviation from the conventional view by either of them.

adoption rates of clean technology by others. This implies that there is room for a more active role of government to align firms' expectations, like a coach guiding a team.[3]

In this paper, we examine how such expectations may drive the dynamics of carbon dioxide reduction. We discuss a simple dynamic model in which forward-looking firms make investment decisions on a clean technology. The clean technology has positive externalities, and firms benefit from alignment of technology choice with others'. Expectations held by firms have the central meaning in the model. They consist of two components. The first is the expectations about future carbon prices, incentives given directly by a public mechanism. The second is the expectations that others will adopt or abandon clean technology *for whatever reason* – indeed, it could be a sheer mood, such as optimism or pessimism, which could induce a bandwagon effect. The second factor would only become significant if externalities of technology adoption are sufficiently large, but one can easily conceive potential cases where clean technologies are associated with non-marginal externality effects of technology spillover and of network among suppliers. Under strong influence of either form of expectations, the current level of carbon price would have only limited power over companies making investment decisions. In such circumstances, it might not be wise to counter firms' pessimism by a mere adjustment of the carbon price, as only a very high carbon price would be able to force companies to adopt a technology with few existing users. Rather, it would be useful to introduce additional mechanisms to influence private firms' expectations, such as announcements of medium-term policy targets or technology-specific supporting schemes. Meanwhile, the flip side of this

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[3] A similar viewpoint is widely recognized in the field of development economics. A large amount of evidence from studies of economic development suggests that while the market mechanism is an important element to achieve economic efficiency, strong and discretionary interventions by government often play a decisive role in a favorable transformation of economic structure. See for example, Hoff and Stiglitz (2001) for a review.

argument is rather an optimistic picture, that is, a strongly punitive carbon pricing scheme may not be necessary if the government successfully manipulates firms' expectations about their future benefits.

The discussion here deals with coordination failure. Although coordination failure itself is not a new subject in the context of climate change,[4] an aspect associated with coordination failure, generation of multiple equilibria and its dynamic implications, has been largely ignored in previous studies on climate policy. An important exception is Karp (2008), who discusses existence of multiple equilibria due to the externality of climate change damage and argues that a tradable permit system could eliminate indeterminacy among equilibria. Our paper is to highlight a different type of multiple equibria regarding climate policy, namely that from externalities of clean technology. Here in this model, unlike in Karp's, multiplicity of feasible paths could remain even under a price-based system of carbon regulation, and it opens up room for expectations to influence dynamics. In fact, this viewpoint is not particularly unusual as a casual argument. For example, it is well known that some clean technologies have not been implemented even with presumed cost saving (e.g., IEA, 2008). Also, firms generally take into account the clarity of policy signals in technology investment. This paper is an attempt to bridge the informal observations about investment behavior on clean technologies and the more formal economic arguments centered on the carbon pricing mechanism.

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[4] For example, Barrett (2006) discusses effects of technology externalities in the making of international climate treaties. In a broader sense, most studies of self-enforcing environmental treaties (e.g., Barrett, 2003) might be placed into this category of research.

Possibility of system indeterminacy in presence of a carbon price

We consider a model of a small economy with a climate policy in place. The model is a reframed version of the "history versus expectations" model discussed by Krugman (1991),[5] which is originally used for investigating shifts of labor force between the agricultural and manufacturing sectors in a pre-industrial economy. In the version below, the sector difference is replaced with the difference in technologies with regard to emission intensities. Here, the climate policy requires carbon dioxide emitters to buy tradable permits whose price is determined exogenously (purchased internationally, but the purchase makes no influence on the international price). The international climate policy is strong enough to keep climate change below a level that does not cause significant damage on the economy.

The economy is composed of N (fixed) firms with identical size and cost structures. Firms have perfect access to the international financial market whose interest rate r (>0) is constant. The firms have two technology choices, the "dirty" and "clean" technologies, which have different emission potentials. Firms can freely choose technologies in consideration of future benefits and current installation costs. The switching of technology requires setup (or moving) costs of firms at the time of introduction. Let the total setup costs for all firms switching technology denote SC. The setup costs comes from various factors such as the construction of new equipment and the training of employees.

For clarity of discussion, we introduce the assumption that the use of the clean technology is only meaningful in presence of some emission penalty, in other words, firms using the clean

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[5] A more generalized version of the model is discussed by Matsuyama (1991).

technology produce less emissions than those with the dirty one do, but the clean technology is less efficient in gross output (i.e., output exclusive of the effect on emissions). Let the penetration rate of the clean technology be x ($0 \le x \le 1$). The clean technology has a scale effect that benefits the users of the technology as the number of adopting firms increases.[6] The effect could have two components. The first is the emission saving $\kappa(x)$ (per firm: $\kappa > 0$, $\kappa' \ge 0$) from the emission level of the dirty technology ε ($\ge \kappa(1)$). With the carbon penalty c per unit emission, carbon costs for individual firms with the dirty and clean technologies are εc and $[\varepsilon - \kappa(\mathrm{x})]c$, respectively. As x rises, $[\varepsilon - \kappa(x)]c$ declines (or $\kappa(x)$ rises). The second is the loss of gross output $l(x)$ (per firm: $l > 0$, $l' \le 0$) from the output level of the dirty technology $\bar{y}$ ($> l(0)$).

The national income of the economy (Y) is expressed as the combination of gross output, carbon costs, and the initial setup (or moving) costs (SC) regarding technology switching between the dirty and clean technologies. Hence:

$$Y = N\bar{y} - Nl(x)x - N[\varepsilon - x\kappa(x)] \cdot c - SC$$

The social planner would seek to maximize the present value of output flow. But actual economic decisions are made by the private firms that do not internalize externalities. The firms make their technology choice by weighing the initial setup costs and the present-value expected increase of profit by switching its technology – they switch technologies when the present-value net expected return exceeds the initial costs. Let us define the “shadow value of having the clean production

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[6] Such positive externality could be either of technology spillover or of network externality. Installation of carbon capture and storage (CCS) would be a good example in this context. Introduction of CCS involves construction of common infrastructure, such as pipelines for carbon dioxide gas transport, and a complex chain of operations linking multiple companies or industries.

technology instead of the dirty technology" as q. The shadow value represents the present value of per-firm net benefit of having the clean technology and is expressed as:

$$(1)\qquad q(t)=\int_t^\infty(\kappa_s c_s - l_s)e^{-r(s-t)}ds$$

Note that the parameters κ, c and l could be time-dependent (the subscript s is put to the parameters in (1) to signify that they represent values at time s). Also note that q depends on the expected future levels of x, in other words, the level of q reflects how others firms will behave in the future. If the economy is at equilibrium as it progresses, this shadow value q should be matched with the marginal (instantaneous) cost of technology switching.

The per-firm setup costs *sc* (*SC* per switching firm) would have some floor level (lower-bound price of installment) but at the same time could also be proportional to the number of firms switching[7] – this feature suppresses an instant technology switching by all firms and thus makes the case more realistic and a dynamic analysis more illustrative. A simple representation of these assumptions is a function with a linear term of the number of firms switching and a constant. The first term could be expressed as $\dot{x}$ multiplied by a constant (note that N is fixed), if we assume that at each time point, firms switching technologies move into either of the directions in unison, as individual firms clearly benefit from bandwagoning.[8] As the setup costs exist in both

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[7] This is the case when, for instance, installation costs of equipment reflect the supply curves of inputs. A supportive fact for this assumption is that the construction costs of new fossil-fuel power plants in recent years have risen rapidly mainly due to a demand increase in emerging economies (e.g., "Price of new power plants rises sharply," New York Times, July 10, 2007).

[8] If firms were rational and perfectly knew others' motives for movements at each step, nonconformist shifts countering others' choices would be suppressed because such shifts do not benefit the firms. The assumption of such perfect knowledge is consistent with that of most game-theoric studies, but it is certainly not obvious that firms

directions of technology shift, i.e., from the dirty to clean ones and from the clean to dirty ones,[9] the costs are defined as $sc = \alpha_c \dot{x} + \beta_c$ (dirty → clean) or $sc = -\alpha_d \dot{x} + \beta_d$ (clean → dirty), where α_c, α_d, β_c and β_d are positive constants. At equilibrium, these should be matched with q, therefore:

(2) $\alpha_c \dot{x} + \beta_c = q$ (dirty → clean) or

(2′) $\alpha_d \dot{x} - \beta_d = q$ (clean → dirty)

Meanwhile, the functional form of (1) leads to the following differential equation on q:

(3) $rq = (\kappa c - l) + \dot{q}$

The equations (2) or (2′) and (3) determine the dynamics of the system. General solutions for such a model would involve multiple stationary states in the interior of the system that produce complex dynamic patters.[10] But the model is presented for the purpose of illustration, and finding complete solutions for this particular model does not carry central importance to the discussion. As for simplification of the model, a representation of technology externality as a linear function (in line with Krugman) would significantly reduce complexity of the model and allow us clear interpretations of results. From this standpoint, we narrow our scope to one illustrative case with the assumptions of $\kappa(x) = \phi x + \chi$, $l(x) = l^*$, $\phi c + \chi c - l^* > 0$, $\chi c - l^* < 0$ ($\varphi, \chi, l^*, c > 0$). With

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would in fact move in such a way without possessing a means to know that others have perfect knowledge. This question is addressed in the general literature of game theory and of its applications to economics (See for example, Aumann and Brandenburger, 1995).

[9] The assumption of switching costs from the clean to the dirty technology is partly a logical necessity, but historical evidence also supports such a possibility. For example, deployment of the electric vehicle (EV) technology has been attempted by many as commercial projects (partly as a response to some perceived economic benefits, such as avoidance of oil price volatility), but initiatives have been successively scaled back and later terminated.

[10] Matsuyama (1991) investigates this aspect by using a similar model

these formulations, the clean technology is advantageous over the dirty one with a full penetration (x=1) but disadvantageous with a zero penetration (x=0) – it sets up two equilibria for the system, and then the question is whether and how the system moves to either of these equilibria.

The paths of x and q are obtained by tracing them backwards from two long-run equilibria (where x=0 or 1). The roots of the system defined by (1) and (2) are

$$(4) \qquad \rho_c = \frac{1}{2}\left[r \pm \sqrt{r^2 - \frac{4\phi c}{\alpha_c}} \right] \quad \text{(if q>0)} \qquad \text{or}$$

$$(4') \qquad \rho_d = \frac{1}{2}\left[r \pm \sqrt{r^2 - \frac{4\phi c}{\alpha_d}} \right] \quad \text{(if q<0)}$$

Note that $r^2 - \frac{4\phi c}{\alpha_c}$ or $r^2 - \frac{4\phi c}{\alpha_d}$ can be both positive and negative. If positive, the system has two real positive roots. If negative, the system has two complex roots with positive real parts.

Figure 1 illustrates the dynamics of two cases. Let us first examine the case with real roots (Figure 1(i)). Two paths could be drawn from A_c or A_d and reach either of the two equilibria (G^c_0 and G^d_0 for c=c_0). The equilibrium with x=1 is preferable to that with x=0 for the social planner as well as for the firms, but both equilibria might be attained as the dynamics evolve through a succession of private decisions without a coordination mechanism. A positive q exceeding the instantaneous setup (moving) costs sets an incentive for individual private firms to switch to the clean technology, while the a negative q greater in magnitude than the instantaneous switching costs to the dirty technology induces firms to abandon the clean technology and switch to the dirty one. The graph shows that each value of x could correspond to at most one point on either of the trajectories (ranges I and III, where x progresses towards 0 or 1, respectively). Or, there is no corresponding point for x on the trajectories, which means the penetration rate could remain stable (range II). In other words, the initial state uniquely determines the long-run penetration rate of the clean technology – either a full penetration (x=1), a zero penetration (x=0) or no change in adoption rate. With a higher level of carbon penalty ($c=c^*$), the path to full technology adoption starts with a lower x, and the path to a full technology abandonment also starts with a lower x relative to the lower penalty case (paths $G^c{}_1$ and $G^d{}_1$). This feature is consistent with the intuition that a higher carbon price should promote the clean technology and should discourage a continuous use of the dirty one. If the carbon penalty gradually increases from c_0 to c^* on the graph (this rising pattern of carbon penalty is consistent with most climate-economy integrated assessment models, e.g., Nordhaus, 2008), the paths should be traced as illustrated in the diagram ($G^{c\prime}$ and $G^{d\prime}$). It is worth noting that the future levels of carbon penalty do not have to be the real ones but could be only *perceived* ones. Only anticipation about future penalties can change the dynamics of technology penetration.

Meanwhile, expectations play an even more prominent role in the case with complex roots. In this case, the trajectories show oscillatory patterns, and their arms could cover wide ranges of x. When the two arms have an overlap over a span of x (an example shown in Figure 1 (ii)), the initial state does not determine the direction the path moves – in fact, there are numerous feasible paths that the economy can take. In such a circumstance, it is agents' expectations about future technology penetration that determine the growth (or decline) of technology penetration, as exogenous factors (such as the carbon penalty) do not condition the economy to follow a unique path.[11] In other words, even if there is a feasible path leading to the full penetration of the clean technology (for example, Z_c on the graph), sheer pessimism about future adoption by others could prevent the economy from taking the path and instead could make it follow the trajectory to the zero adoption (Z_d). It is worthwhile to note that given the formulation of ρ_c (ρ_d), a high level of carbon penalty is a factor that may shift the system towards a one with complex roots, therefore the system would become more indeterminate.

One obvious solution to this indeterminacy problem is to raise the carbon price to the level at which firms can gain relative benefits from clean technology even if its penetration rate is zero, in other words, to force the firms to switch technologies through a very high carbon price. Such a drastic raise of carbon price, however, is not likely to be the best policy choice. As the carbon pricing mechanism is in effect an indirect taxation scheme, a high price itself is a factor to reduce economic efficiency with a large deadweight loss (given that the same amount of emission reduction could in principle be obtained at a lower carbon price). In fact, as suggested by some examples of major energy technologies such as the hydrogen-based energy system, the level of price incentive may need to be very high for forcing companies to adopt a technology with few existing users with whom they could share infrastructure or technical information. A better approach would be to influence firms' expectations about technology penetration through schemes such as technology standards and targets. In fact, a reverse argument of the above suggests rather a bright prospect of expectation-oriented policy schemes: a strongly punitive carbon pricing scheme may not be necessary if the government successfully manipulates firms' expectations about their future benefits.

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[11] This is essentially the same argument as Krugman's (1991), which is applied to a different context.

In the second case, the firms take the low-equilibrium path not because they think that future climate policy will be weak, but because they fear that others will not adopt the clean technology for whatever reason. A possible criticism against such an expectation model is that pessimism could not be sustained for a long period since the existence of a favorable equilibrium is public knowledge. This is a legitimate argument and could indeed be the case. One can, however, point out some factors why the expectation aspect should not be overlooked in the context of climate policy in particular. As for climate change mitigation, there are many potential beliefs that could discourage companies from investment, such as the false understanding that climate change will never become significant, or the prospect that tough regulations could be blocked through political bargaining. After all, the need for actions against climate change has not been a common perception by major energy companies for a long time (e.g., Levy, 2005), and in a way, is still not. One should be reminded that such pessimistic perceptions do not have to be the majority view among companies for determining the path. Dynamics could change if only those minority perceptions could induce the majority to think that others would desert the emission-reducing technology.

Climate policy as expectation management?

The model is a simple representation of technology switching by firms in response to a price-based climate policy. The model shows that under certain conditions, the path of emission reduction could progress as a self-fulfilling prophecy, in which firms' perception about future outcomes, i.e., optimism or pessimism, plays a role in determining the trajectory. While the carbon pricing generally drives firms towards more emission reduction, it may not help eliminate

– in fact may even amplify – the ambiguity of emission reduction paths. A remedy for the problem is an introduction of policy schemes to align firms’ expectations about future penetration of clean technology. This insight would provide a support for non-price-based mechanisms of climate policy, such as the EU’s targets for renewable energy.

The aim of this paper is to highlight the potential importance of expectations and not to argue that all carbon-pricing schemes are destined to be nullified by the bandwagon dynamics. It is also important to note that general solutions from more general model settings could of course look different from this model’s. Some important arguments made by previous studies of indeterminacy dynamics were not addressed in the model: for example, findings by some studies imply that indeterminacy may not emerge if the system is subject to some randomness and there is some likelihood that the use of either of technologies become the dominant strategy through a random development of the system (Morris and Shin, 1998; Frankel and Pauzner, 2000). Such factors omitted in the model could make expectations less relevant. On the other hand, however, it is fair to assume that complexity of the actual energy system should leave more grey zones where expectations drive dynamics than a simple model does. As a future research, it would be interesting to examine more complex cases, such as that of competing mitigation technologies. In general history of technology, examples of technology lock-in are prevalent, such as the wide adoption of the QWERTY keyboard despite its obvious inefficiency (David, 1985).

Finally, it is worthwhile to stress that this paper’s discussion does not mean that we should reject the idea of market-based solution of climate change mitigation. It does suggest, however, that there might be a missing perspective in the conventional view of climate policy, that is, the effectiveness of market-based climate policy partly rests on people’s expectations. In a way, climate policy should be *expectation management*.

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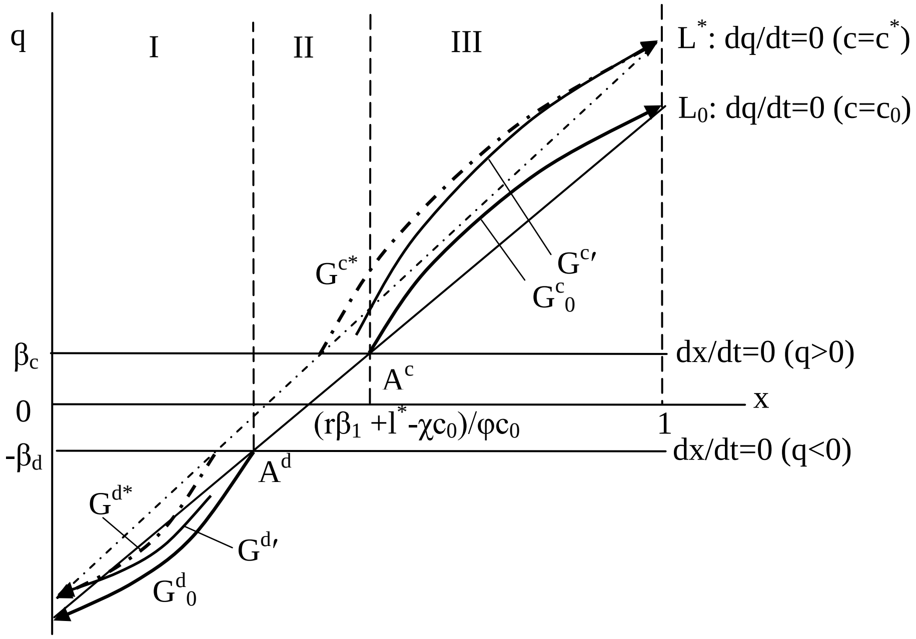
Figure 1. Possible dynamic structures of the system

(i) The roots are real



(ii) The roots are complex (when arms overlap over a range of x)