Kiel
Working Papers

Kiel Institute
for the World Economy

Climate Policy, Technology Choice, and Multiple Equilibria in A Developing Economy

by Daiju Narita

No. 1590 | January 2010

Web: www.ifw-kiel.de

Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

Kiel Working Paper No. 1590 | January 2010

Climate Policy, Technology Choice, and Multiple Equilibria in A Developing Economy

Daiju Narita

Abstract:

Control of carbon dioxide emissions in developing countries is becoming a key issue in the international climate policy. A critical element for achieving substantial emission reduction in those countries is the installment of new energy technologies. Drawing on the framework of poverty-trap models in development economics, we discuss how climate policy affects the transition of energy technologies in a developing economy. We show that while a moderate carbon policy could promote transition to low-emission energy technology, too stringent policy in a relatively poor economy may rather hinder the process by reducing the economy's financing capacity as to building new energy infrastructure – there, the barrier is not the long-run costs of the new technology but the availability of financial resources for initial investment, which could be constrained not only by the domestic saving but also by the imperfection of credit market. The possibility of such a trapping may provide a justification for financial support towards the deployment of alternative energy technologies in low-income economies.

Keywords: Climate policy, technology choice, credit market imperfection, climate funds

JEL classification:O16, O33, Q54, Q56

Daiju Narita
Kiel Institute for the World Economy
24100 Kiel, Germany
E-mail:daiju.narita@ifw-kiel.de

Coverphoto: uni_com on photocase.com

Introduction

Climate change mitigation policies in developing countries are likely to have a significant meaning for the world in the coming decades, as the developing world already accounts for more than a half of the global anthropogenic carbon dioxide emissions and is expected to expand its share even more in the future. The challenge for those economies is sustainability of economic growth under constraints of climate change, in other words, how to reconcile the needs for controlling carbon dioxide emissions and their growing economic activities, which have their own merits of helping improve human welfare in those regions. Indeed, sustainable development is a word repeatedly mentioned in the text of the UN Framework Convention on Climate Change.

A number of leading studies suggest that the world may need a drastic emission reductions in the future, demanding to remove most emissions from fossil fuel combustion in the long term (e.g., Stern, 2007; IPCC, 2007). Since the use of fossil fuel is a fundamental component of the current world economy, the only avenue to reach the goal of near-zero emissions would be a comprehensive mobilization of new technologies that could replace the present energy system. This is not necessarily an infeasible proposition. For example, carbon capture and storage (CCS) would be a candidate technology to realize this transition on a global scale. CCS is essentially a collection of existing techniques and its global potential is thought to be large (IPCC, 2005) – in fact, optimists even estimate that CCS's total sequestration potential exceeds the size of fossil fuel resource, which is already more than all its global demand for the next couple of hundred years provided the current pace of consumption (House et al., 2006; Rogner et al., 2000). At a regional level, one can find even a wider range of alternatives to achieve a low-carbon energy system, and some of them already fill a significant proportion of regional energy demand, such as geothermal energy in Iceland, wind power in Denmark, and bioethanol in Brazil.

Alternative energy technologies are, however, often more expensive to operate than the conventional fossil-fuel energy technologies are, and in many cases, they are economically meaningful only in presence of policy incentives (CCS is an example). Although the developing countries are already subject to some climate policies, most importantly the Clean Development Mechanism (CDM), there is a shared concern among policymakers that existing policy instruments are not sufficient for the private sector to adopt new energy technologies in developing countries. In this context, financial mechanisms specifically targeting technology adoption in developing countries, such as technology funds, have been proposed. For example, the Bali Action Plan states that the international community should seek "improved access to adequate, predictable and sustainable financial resources and financial and technical support, and the provision of new and additional resources, including official and concessional funding for developing country Parties."[2]

Despite those discussions in the policy circles, however, little has been done as to finding theoretical rationale for those financial supports on technology in conjunction with general carbon-pricing mechanisms. This study is an attempt to theoretically interpret the meaningfulness of such technology financing policies with a special attention to credit market imperfection.

---

[2] As a follow-up of the Bali Action Plan, the Copenhagen Accord drafted in December 2009 explicitly notes $100 billion funding towards developing nations by developed nations and the establishment of the Copenhagen Green Climate Fund.

This paper approaches the question by using the framework laid out by theoretical studies of poverty traps. In development economics, a justification for external assistance for poor economies is found in the poverty trap models, in which an initially poor economy could be trapped in a low-income equilibrium among more than one possible steady states – there, multiple equilibria emerge due to non-convexities of economic structure (among others, a review of poverty-trap model studies is given by Azariadis and Stachurski, 2005; Sachs et al., 2004, and Sachs, 2005, apply this concept to real policy cases). Discreteness of alternative production technologies is a cause for such a trap (e.g., Murphy et al., 1989; Galor and Tsiddon, 1991, Iwaisako, 2002), as is the imperfection of financial market (e.g., Galor and Zeira, 1993; Matsuyama, 2004). This paper reframes these poverty-trap models to interpret the possible meaning of financial assistance on climate mitigation technology in developing economies. The key idea is that discreteness of dirty and clean production technologies could create more than one stable states, and in presence of an imperfect financial market, a spontaneous transition across technologies could be hindered. Here the barrier is not the long-run costs of the new technology but the availability of financial resources for the initial investment, which could be constrained not only by the domestic saving but also by the imperfection of the credit market. Such a financing gap could provide a reason for an international public lending mechanism additional to a carbon-pricing system, although this feature only appears under certain conditions.

A number of studies discussed the adoption of new technologies in the economics of climate change, and some of them focused on the shift in technology choice from polluting to non-polluting technologies (e.g., Requate and Unold, 2003; Chakravorty et al., 2008; Smulders and van der Werf, 2008; Tsur and Zemel, 2008, 2009). This paper is to be placed in this strand of literature yet highlights one new aspect, namely, the structure of technology financing regarding developing economies.

The Model

We discuss an overlapping-generations model for a small economy with a carbon policy. Suppose a small economy that is subject to a global carbon policy. The carbon policy imposes the economy an exogenous carbon price. The economy fulfills its policy commitment by purchasing outside carbon credits,[3] but its purchase of credits does not affect the carbon price. In presence of the global carbon policy, the climate is controlled at a moderate level and does not incur damage costs on the economy due to climate change. First, we assume that the economy is closed except for the carbon credit purchase: there is no cross-border capital movement (later, we will consider an alternative assumption).

The economy is composed of agents with two-period lifetimes. Agents are homogenous within each generation. Young agents supply labor, and old agents provide capital. A single final good is produced by the labor and capital offered by those agents. There are, however, two technological choices that can produce the same final good. Let $Y_t = F_0(K_t, L_t)$ be the gross output (exclusive of carbon costs) from the "dirty" production technology at time t. K_t denotes capital, and L_t signifies labor, which equals the population size of the young generation at time t.

---

[3] In fact, the choice of policy instrument does not matter in this context. It can also be a tax system involving the same level of social costs.

The per-worker gross output is expressed as $y_t \equiv Y_t / L_t = F_0(K_t / L_t, 1) \equiv f_0(k_t)$ where $k_t \equiv K_t / L_t$.

We assume a standard concave shape of $f_0(k)$, thus:

$$f_0'(k) > 0 > f_0''(k)$$

The dirty production technology produces carbon dioxide emissions proportional to the level of gross output. The economy needs to pay carbon costs proportional to the emission level (thus proportional to the gross output as well). Let α_t ($0< \alpha_t <1$) be the coefficient of carbon penalty in per-output terms. The total and per-worker net outputs from the dirty technology are written as:

$$F_a(K_t, L_t) = (1-\alpha_t)F_0(K_t, L_t) \text{ and } f_a(k_t) = (1-\alpha_t)f_0(k_t)$$

The economy has an alternative, "clean" production technology that does not produce emissions. To make the case illustrative, we assume that the clean technology has a scale effect that makes it competitive over the dirty one only beyond a certain size of production. A simple way to represent a scale effect is to introduce a setup cost, here denoted by B (>0), which needs be paid at each time.[4] The reasoning behind this assumption is that a clean energy technology (e.g., a centralized power grid system with CCS) may require larger-scale coordination in an economy than a conventional energy technology (e.g., the use of charcoal) does. The setup costs can be of various factors: the establishment of a legal or regulatory system for the clean technology, capacity building (training especially for technology management), construction of infrastructure, etc. The total and per-worker production functions are thus expressed as:

$$F_b(K_t, L_t) = \beta F_0(K_t, L_t) - B \text{ and } f_b(k_t) = \beta f_0(k_t) - B / L_t$$

where β is an efficiency parameter. We assume that besides the setup costs, the clean technology is preferred to the dirty technology *with* carbon costs but not to the dirty technology *without* carbon costs, i.e., $1-\alpha_t<\beta< 1$.

If the size of labor (or a generation) is assumed to be constant, i.e., $L_t = L$, then, $B / L_t = B / L \equiv b$ (>0), and

$$f_b(k_t) = \beta f_0(k_t) - b$$

The factor markets are competitive, and therefore the return to capital and the wage are determined for each technology choice as follows:

Return to capital r_t:

Dirty technology without carbon policy: $r_t = f_0'(k_t)$

---

[4] Barro and Sala-i-Martin (2004) discusses a model with a similar assumption as a variation of the standard Solow model. They attribute the base idea of their formulation to Galor and Zeira (1993).

Dirty technology with carbon policy: $r_t = (1-\alpha_t)f_0'(k_t)$

Clean technology: $r_t = \beta f_0'(k_t)\left(1 - \frac{b}{\beta f_0(k_t)}\right)$

Wage w_t ($\equiv w(k_t)$):

Dirty technology without carbon policy: $w_t = f_0(k_t) - k_t f_0'(k_t)$

Dirty technology with carbon policy: $w_t = (1-\alpha_t)[f_0(k_t) - k_t f_0'(k_t)]$

Clean technology: $w_t = \beta[f_0(k_t) - k_t f_0'(k_t)]\left(1 - \frac{b}{\beta f_0(k_t)}\right)$

For simplicity, we also take the following assumptions.[5] Capital depreciates fully in one period, and young agents allocate their wage obtained in the first period entirely to investment. Investment can take either of two forms: direct engagement in investment of production capital by running a project, or investment in the financial market (this assumption becomes important later in the cases of credit market imperfection). In the second period, they receive the return from investment and consume it fully.

The Small Closed Economy without Credit Market Imperfection

First, we consider a closed economy without any credit market imperfection. The domestic saving, which originates from agents' wage income, equals the amount of total investment. Without credit market imperfection, agents are indifferent between direct investment in production capital and investment in the financial market, and the structure of technology financing does not cause any effect in this case. For the beginning, we examine a simple case of an invariant carbon policy, i.e., $\alpha_t = \alpha$: henceforth we call it the Benchmark Case.

Agents choose an investment opportunity whose return is higher than the alternative.[6] Due to the scale effect, the economy chooses the dirty technology when k is low, and it chooses to the clean technology when k is high. There is in fact a critical level of per-worker capital k^c, which satisfies:

$$(1) \qquad (1-\alpha)f_0'(k^c) = \beta f_0'(k^c)\left(1 - \frac{b}{\beta f_0(k^c)}\right) \leftrightarrow f_0(k^c) = \frac{b}{\alpha+\beta-1}$$

Note that k^c is positive since $1-\alpha < \beta$ by definition.

---

[5] Matsuyama (2004) uses similar assumptions.

[6] Here we assume that agents know each other's preference, so the economy collectively moves to a state that maximizes the total return to investment.

Meanwhile, if the economy using the dirty technology satisfies the following condition, it means that it is on a path of economic contraction:

(2) $$k_{t+1} = (1-\alpha)[f_0(k_t) - k_t f_0'(k_t)] < k_t$$

If k_t=k^c satisfies the above condition (2), there is at least one steady state with the dirty technology (in other words, the economy may get stuck with the dirty technology):

(3) $$(1-\alpha)[f_0(k^c) - k^c f_0'(k^c)] < k^c$$

The economy may also have a steady state with the clean technology. If there is a k^{c2}>k^c that satisfies the following condition, there is a steady state for the clean technology.

(4) $$\beta[f_0(k^{c2}) - k_t f_0'(k^{c2})]\left(1 - \frac{b}{\beta f_0(k^{c2})}\right) > k^{c2}$$

In fact, whether there is k^{c2} satisfying (4) with a given *b* depends on the level of *β*, which leads to the following Lemma.

LEMMA: *If* $\exists k^{c2} > 0$ *that satisfies* $[f_0(k^{c2}) - k_t f_0'(k^{c2})](1 - b / f_0(k^{c2})) > k^{c2}$ and k^{c2}>k^c *(henceforth we call it Condition A), there is a critical level of* β=β^* *for every level of α below which there is no steady state with the clean technology and beyond which there is a steady state with the clean technology.*
(For the proof, see the Appendix).

In fact, the solutions when β^* does not exist are trivial (there is no possibility of sustainable use of the clean technology, so the economy always ends up with the dirty technology), and in the following, we limit our analysis to the cases which fulfill Condition A (i.e., $\exists k^{c2} > 0$ that satisfies $[f_0(k^{c2}) - k_t f_0'(k^{c2})](1 - b / f_0(k^{c2})) > k^{c2}$ and k^{c2}>k^c). The functional shape of f_0 and the level of *b* are the only determinants for the satisfaction of the condition.

The dynamics of economy are different depending on whether the conditions hold. Figure 1 illustrates three possibilities that the system could have. Indeed, the economy might have two equilibria, the ones with the dirty technology and with the clean technology. It is also possible that it has a unique equilibrium either with the dirty or clean technology. These are summarized in the following Proposition.

PROPOSITION 1: *(Benchmark Case) In the closed economy with a constant α and without credit market imperfection, the economy follows either of the following three cases if Condition A holds. (I) If condition (3) is not satisfied and* $\beta \geq \beta^*$*, the economy always reaches a steady state with the clean production technology regardless of the initial level of k (II) If* $\beta < \beta^*$*, the economy always reaches a steady state with the dirty production technology regardless of the initial level of k (III) If condition (3) is satisfied and* $\beta \geq \beta^*$*, the economy reaches a steady state either with the clean technology or with the dirty technology depending on the level of initial k.*

Figure 2 shows a phase diagram of the system. The graph indicates that a higher level of carbon price (represented as α) can facilitate a shift from the dirty to clean technology in certain circumstances, but not always so. The carbon price should be high enough to give incentive for the adoption of clean technology (for a shift from II to I), but too much carbon penalty deprives the economy of the capacity to make a spontaneous shift to the new technology (a shift from I to III occurs). The effect of carbon penalty is, however, dependent on the efficiency of clean technology as well. If the clean technology is not efficient (expensive), carbon policy does not realize a technological shift but only reduces the net output of the economy.

One should note that Figure 2 does explain the dynamic shift of system with a temporal change of parameter α. However, the carbon policy parameter could in fact be time-variant as well. Most climate-economy integrated assessment models suggest that the optimal global carbon price shows a rising trend (e.g., Nordhaus, 2008). In the current model, it is clear that a rising carbon price accentuates the gap structure if it exists. The following Corollary summarizes this feature.

COROLLARY: *If* α_t *increases over time and if (III) of Proposition 1 applies, any* k_0 *leading to the dirty technology equilibrium in the Benchmark Case does not lead to the clean technology steady state. Meanwhile, if* α_t *increases over time and if (a) in Proposition 1 applies, and a switch of technology may take place at a lower* k_t *than in the Benchmark Case.*

The Small Closed Economy with Credit Market Imperfection

Let us now examine the case of a closed economy with credit market imperfection. For this case, we need to formulate the borrowing behavior by agents. It would be fair to assume that agents can partially self-finance their investment in addition to utilizing borrowed money, and as the wage grows, the proportion of self-financing should rise. Here, we take the following modeling approach after Matsuyama (2004). Agents make investment through a form of running a project. The price of the project is normalized as 1, and we assume that agents need to borrow some amount of money in all instances – thus we set $w(k_t) < 1$ and confine our examination to cases in which $k_t < 1$. In other words, the agents borrow some amount of money for making investment but the ratio of borrowed money to the total per-worker investment decreases as they become rich.

Credit market imperfection produces a mismatch between the return to project investment and the return from investment in the financial market, which is determined by the market interest rate i_t. Let us now define the degree of capital market imperfection θ ($0< \theta <1$). When agents borrow, they repay only up to θr_t, which may cause a failure of repayment for a part of money of which the borrowers have commitment. The lower is θ, the higher is the imperfection of credit market. Agents must entirely self-finance projects if θ is zero (in other words, the financial market does not exist), and the credit market functions perfectly (i.e., the borrowers can fully repay their money regardless of the amount that they borrow) if θ is 1. This formulation is a general way to model credit market imperfection exhibited as various forms (e.g., collateral requirement, transaction costs).

The borrowers can borrow money only if they can make a full repayment. In a mathematical formulation, the condition is expressed as:

(5) $\theta r_{t+1} \geq i_{t+1}(1-w(k_t))$ or $r_{t+1} \geq i_{t+1}(1-w(k_t))/\theta$ (borrowing constraint)

Another condition for borrowing is the profitability constraint, which represents agents' preference in starting a project: they begin a project only when the return to project investment is at least as high as the market interest rate. Mathematically:

(6) $r_{t+1} \geq i_{t+1}$ (profitability constraint)

First, we consider that the capital market imperfection exists in the finance of both of two production technologies in an equal degree. In a closed economy, the amount of capital investment is determined by the amount of domestic saving, Lw_t. Hence, the fraction w_t of agents become borrowers, while the fraction 1-w_t of agents become lenders. When the borrowing constraint is binding, they strictly prefer borrowing. However, because of the constraint of domestic saving and the imperfection of credit market, 1-w_t of agents are simply denied credit by credit rationing. Here, a raise of interest rate by lenders does not enhance repayment by borrowers, and therefore the lenders limit lending rather than increasing the interest rate.

(7a) $i_{t+1} = \theta r_{t+1}/(1-w(k_t))$ if $k_t < k^d(\theta)$
(7b) $i_{t+1} = r_{t+1}$ if $k_t \geq k^d(\theta)$

where $k^d(\theta)$ is a value that satisfies $1-w(k^d(\theta)) = \theta$.

As the condition (7a) shows, the interest rate is lowered when the borrowing constraint is binding. However, since the two production technologies are equally affected by the imperfection, one level of interest rate is tied with the same level of return to investment for both production technologies. In other words, the lenders always have the same preference of technology choice as the borrowers (project investors). As the k_{t+1} schedule is only indirectly related to the market interest rate (through its relationship with the return to project investment), the credit market imperfection does not influence the configuration of economy as to technological shift. We summarize it as follows.

PROPOSITION 2: *In the closed economy with a constant α and with credit market imperfection for both of the two technologies, the economy in which Condition A holds has the same* k_{t+1} *schedule as in the Benchmark Case, while credit market imperfection may lower the market interest rate.*

A more contrasting case is that credit market imperfection exists for financing the clean technology but not for the dirty one. There is good reason to assume that the function of credit market is weaker for the clean technology than for the dirty technology. First, it is possible that the implementation of the clean technology takes a form of large projects and thus needs more borrowing per project than the dirty technology does. Second, the clean technology is likely to involve technical complexity and also an intricate chain of coordination among various entities, and therefore it may be harder for lenders to monitor projects.

In this case, lenders' preference may not match with borrowers'. Due to credit market imperfection, the clean technology needs to have a higher return than the dirty technology to get credit at the same market interest rate. In other words, with the borrowing condition in effect, lenders have a preference for the dirty technology if the return to project investment is the same for both technologies. The conditions for the investment in the clean technology are:

$$(8a)\quad (1-\alpha)f_0'(w(k_t)) \le \beta f_0'(w(k_t))\left(1-\frac{b}{\beta f_0(w(k_t))}\right)\cdot\frac{\theta}{1-w(k_t)} \qquad (k_t < k^d(\theta))$$

$$(8b)\quad (1-\alpha)f_0'(w(k_t)) \le \beta f_0'(w(k_t))\left(1-\frac{b}{\beta f_0(w(k_t))}\right) \qquad (k_t \ge k^d(\theta))$$

In fact, the condition (8a) implies that the technology shift starts at a greater k than in the perfect credit market case. Figure 3 shows an example case in which the credit market imperfection causes the shift of mode from (I) to (III) as described in the Benchmark Case. The arrow shown in Figure 2 indicates the shift of boundary between phases because of the imperfection. This leads to Proposition 3 below:

PROPOSITION 3: *In the closed economy with a constant α and with credit market imperfection only for financing the clean technology, there is at least one set of (α, β) that would belong in Phase (I) under the conditions of the Benchmark Case but belongs in Phase (III) with credit market imperfection.*

As Figures 2 and 3 imply, in case that the credit market functions imperfectly in financing the clean technology, the credit problem alone may create a trap. Foreign aid (including an indirect form of it as a reduction of carbon price) is a way to overcome the technology trap. At the same time, public or external intervention may also focus on ameliorating the financing system rather than filling all the financing gap by external money. Some public schemes in fact potentially remedy the problem of imperfect credit market. For example, a development bank might have a better capacity than smaller financial institutions to evaluate and monitor energy technology projects, and its involvement in lending can reduce monitoring costs for other institutions.[7] In such a way, public lending may help mitigate the problem of credit market imperfection even if the amount of loan is small.

The Small Open Economy

Developing economies are generally not entirely closed, and thus it is worthwhile to consider an open economy case as well. In a small open economy, the capital is no longer constrained by the domestic saving and could be financed by foreign investment. The market interest rate therefore equals the world rate, i.e., $i_t = i$ (>0, constant). But since the size of economy is small, an inflow of capital does not affect the level of the world interest rate. It is clear that with a perfect global credit market, a financing gap as we observed in the closed economy case does not appear in the open economy, as the economy has unlimited access to the global financial market. Thus, here we only consider the case with an imperfect global credit market.

---

[7] This effect is in fact observed in some actual cases, for instance, the role of the Japanese development bank during the high-growth period (World Bank, 1993, Chapter 5).

Again in this case, credit market imperfection may exist for either or both of the clean and dirty technologies. However, here let us focus on a simpler case – credit market imperfection only exists for implementation of the clean technology.[8] In this case, when the economy adopts the clean technology, k_{t+1} is determined either by the borrowing or profitability condition with a given market interest rate i, depending on the level of k_t. Meanwhile, for the dirty technology, the profitability condition is the sole constraint determining the level of k_{t+1}. In this case, the return to investment is constrained by the fixed interest rate. Hence, technology choice is made according to which technology gives a higher k_{t+1} with a given initial level of k_t.

$$\text{(9a)} \quad r_{t+1} = \beta f_0'(k_{t+1})\left(1 - \frac{b}{\beta f_0(k_{t+1})}\right) = i(1 - w(k_t))/\theta \qquad (k_t < k^d(\theta))$$

$$\text{(9b)} \quad r_{t+1} = \beta f_0'(k_{t+1})\left(1 - \frac{b}{\beta f_0(k_{t+1})}\right) = i \qquad (k_t \geq k^d(\theta))$$

$$\text{(9c)} \quad r_{t+1} = (1-\alpha) f_0'(k_{t+1}) = i$$

The k_{t+1} schedule for the clean technology may take various patterns, and here we only discuss the condition for transition from the dirty to clean technology. As Figure 4 shows, there is a critical level of k (k^{**}) below which the clean technology cannot be financed (because there is an upper bound of r that could be realized with the clean technology), while the clean technology is preferred beyond that level. The k_{t+1} schedule is an increasing function of k in the vicinity of k^{**}. The discontinuity of the k_{t+1} schedules for the dirty and clean technologies can again create a multiple-equilibria structure. To summarize:

PROPOSITION 4: *In the open economy with a constant α and with credit market imperfection only for financing the clean technology, it follows either of the following three cases if Condition A holds. (i) The economy can make a transition from the dirty production technology to the clean production technology (ii) The economy stays with the dirty production technology if it is the initial technology choice, and it may switch from the clean technology to the dirty technology with some range of the initial levels of k (iii) The economy stays with the initial technology choice (either the dirty or clean technology).*

Figure 5 shows an example of phase diagram (configurations would differ depending on the levels of β and b). In the open economy, the carbon price does not have to be reduced to facilitate a technological shift. A gap can be overcome if the capital market imperfection is mitigated (eliminated) by direct public lending or various mechanisms to remove informational problem. A technology fund might be useful from this standpoint. The above discussion also implies an advantage of foreign direct investment (FDI), since investors and operators in FDI projects are by definition the same entities and therefore the informational problem of capital financing should be low.

---

[8] Credit market imperfection for the dirty technology in addition to the clean technology adds complexity to the system, generating even more complex solutions.

Conclusion

We examined dynamic aspects of climate policy in a developing economy with a two-technology overlapping-generations model in which the technology choice shifts with the economy's income level. The starting point of discussion is the idea that if a clean technology is economically feasible at some high income level, poor countries should also be able to deploy it when their income level becomes high enough. Under certain conditions, however, poor economies may not be able to make a transition to the new technology resulting from non-convexity of economic structure. Cost structure or efficiency associated with technologies is a factor determining the existence of a trap, but credit market imperfection alone may create a trap as well – in this sense, multiple equilibria could arise not only in a closed economy but also in an open economy where investment is not constrained by domestic saving. A higher carbon price may facilitate the transition to the new technology in some cases, but a too high carbon price can inhibit a transition to the clean technology. A possible remedy for such a stagnation is a reduction of the carbon price, or some mechanisms to reduce the imperfection of credit market. In this context, some of the proposed technology-financing schemes such as technology funds might play a role. For example, a development bank might have a better capacity than smaller financial institutions to evaluate and monitor energy technology projects, and its involvement in lending can reduce monitoring costs for other institutions.

This model is simple and has limitations in its applicability. First, the model primarily considered a small developing economy and is not meant to explain climate policy for the entire world. Current estimates suggest that the long-run costs of climate change mitigation will be one percent of the world GDP at most (e.g., World Bank, 2010) against the long-run historical trend of global GDP growth of a few percents, and it is therefore unlikely that climate change mitigation alone will lead to a contraction of the global economy and consequently limit the capacity of investment in new energy technologies worldwide. It is also worth noting that at a global level, carbon policy should be rather regarded as an endogenous function representing interactions between the climate system, the economic output and the carbon policy itself. It would be interesting, however, to examine potential consequences of a strong global climate policy under a scenario that the global baseline growth rate slows down in the next decades (as did in the year of 2009) and that climate policy has a clear influence on global economic growth – but this question is left to future investigations. Second, some of the assumptions regarding technology may not hold in some cases. For example, some innovative energy technologies can be implemented without large-scale coordination or fixed costs. In such a case, the carbon pricing whose level is set simply to equal the social cost of carbon would be the most appropriate policy scheme.

Despite the above limitations, since climate policy is rarely discussed in a way as is in this study, the paper should provide a useful perspective in sharpening policy debates about how to reconcile the concurrent needs for economic growth and carbon dioxide control.

Acknowledgments

The author thanks seminar participants at the Kiel Institute for the World Economy for useful comments. Financial support by the German Research Foundation (the “Future Ocean” Cluster of Excellence program) is gratefully acknowledged.

Appendix

Define the following function $\Gamma(k)$ ($\beta>0$):

$$\Gamma(k) \equiv \beta\left[f_0(k) - kf_0'(k)\right]\left(1 - \frac{b}{\beta f_0(k)}\right) - k = \beta\left[f_0(k) - kf_0'(k)\right] - b + \frac{kf_0'(k)b}{f_0(k)} - k$$

$$\Gamma'(k) = -\beta kf_0''(k) + \frac{f_0''(k)kb}{f_0(k)} + \frac{f_0'(k)}{\left(f_0(k)\right)^2}\left(f_0(k) - kf_0'(k)\right)b - 1$$

As $f_0''(k)<0$ by definition, $\Gamma'(k)$ is greater with a greater β for any $k<0$. This means that $\Gamma(k)$ with a larger β always dominates $\Gamma(k)$ with a smaller β. If $\beta \rightarrow 0$, clearly $\Gamma(k)<0$ for any $k>0$. If $\beta \rightarrow 1$ and there is at least one k what satisfies $\Gamma(k)>0$ (i.e., Condition A holds), there is a critical level of $\beta = \beta^{0*}$ below which $\Gamma(k)<0$ for all $k>0$.

Meanwhile, $f_0(k^c) = \dfrac{b}{\alpha + \beta - 1}$ implies that k^c increases with a lower β. If $\beta \rightarrow 1$ and a steady state exists for the clean technology, there is at least one k which satisfies $\Gamma(k)>0$ and $k>k^c$ for a β in the neighborhood of $\beta=1$. If there is $\beta = \beta^{1*} > \beta^{0*}$ below which all k satisfying $\Gamma(k)>0$ are less than k^c, we define $\beta^* \equiv \beta^{1*}$. Otherwise, $\beta^* \equiv \beta^{0*}$. □

References

Azariadis, C. and J. Stachurski. 2005. "Poverty Traps," Handbook of Economic Growth, in: P. Aghion and S. Durlauf (eds.), Handbook of Economic Growth, edition 1, volume 1, chapter 5 Elsevier.

Barro, R.J. and X. Sala-i-Martin. 2004. Economic Growth (2nd ed.), MIT Press.

Chakravorty U., M. Moreaux, and M. Tidball. 2008. Ordering the Extraction of Polluting Nonrenewable Resources, American Economic Review 98(3): 1128-1144.

Galor, O. and D. Tsiddon. 1991. Technological Breakthroughs and Development Traps, Economics Letters 37(1), 11-17.

Galor O. and J. Zeira. 1993. Income Distribution and Macroeconomics, Review of Economic Studies 60(1), 35-52.

House, K.Z., D.P. Schrag, C.F. Harvey, and K.S. Lackner. 2006. Permanent Carbon Dioxide Storage in Deep-Sea Sediments. PNAS 103(33): 12291-12295.

IPCC. 2005. Special Report on Carbon Dioxide Capture and Storage.

IPCC. 2007. Fourth Assessment Report.

Iwaisako, T. 2002. Technology Choice and Patterns of Growth in An Overlapping Generations Model, Journal of Macroeconomics 24: 211-231.

Matsuyama, K. 2004. Financial Market Globalization, Symmetry-Breaking and Endogenous Inequality of Nations, Econometrica 72(3), 853-884.

Murphy, K., Shleifer, A., and R.W. Vishny. 1989. Industrialization and the Big Push, Journal of Political Economy 97(5), 1003-1026.

Nordhaus, W. 2008. A Question of Balance: Weighing the Options on Global Warming Policies, New Haven, CT: Yale University Press, 2008.

Requate, T. and W. Unold. 2003. Environmental Policy Incentives to Adopt Advanced Abatement Technology: Will the True Ranking Please Stand Up? European Economic Review 47: 125-146.

Rogner, H.-H. et al. 2000. Energy resources. Energy and the challenge of sustainability. World Energy Assessment Report. (Goldemberg, J., Anderson, D., Holdren, J. P., Jefferson, M., Jochem, E., Nakicenovic, N., Reddy, A. K. N., Rogner, H.-H. et al. (eds.), UNDP, UNDESA, WEC, New York, NY, USA.)

Sachs, J.D., J.W. McArthur, G. Schmidt-Traub, M. Kruk, C. Bahadur, M. Faye, and G. McCord. 2004. Ending Africa’s Poverty Trap, Brookings Papers on Economic Activity 35(1): 117-240.

Sachs, J.D. 2005. The End of Poverty, New York: Penguin Press.

Smulders, S. and E. van der Werf. 2008. Climate Policy and the Optimal Extraction of High- and Low-Carbon Fossil Fuels, Canadian Journal of Economics 41(4): 1421-1444.

Stern, N. 2007. The Economics of Climate Change, Cambridge University Press.

Tsur Y. and A. Zemel. 2008. Regulating Environmental Threats. Environmental and Resource Economics 39, 297-310.

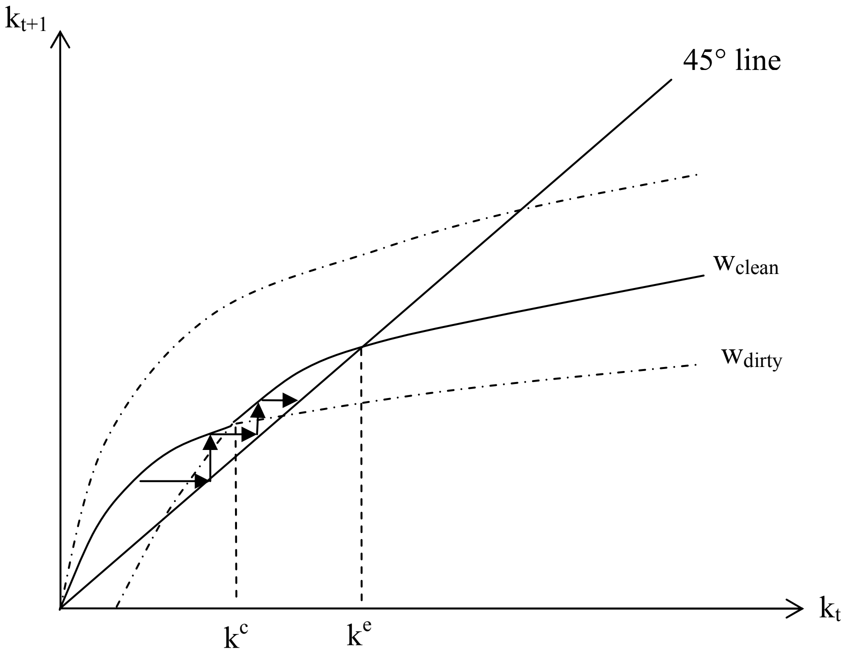
Tsur, Y. and A. Zemel. 2009. Market Structure and the Penetration of Alternative Energy Technologies, Hebrew University of Jerusalem Discussion Paper No. 2.09.

World Bank. 1993. The East Asian Miracle: Economic Growth and Public Policy. World Bank Policy Research Report, Washington D.C.: World Bank.

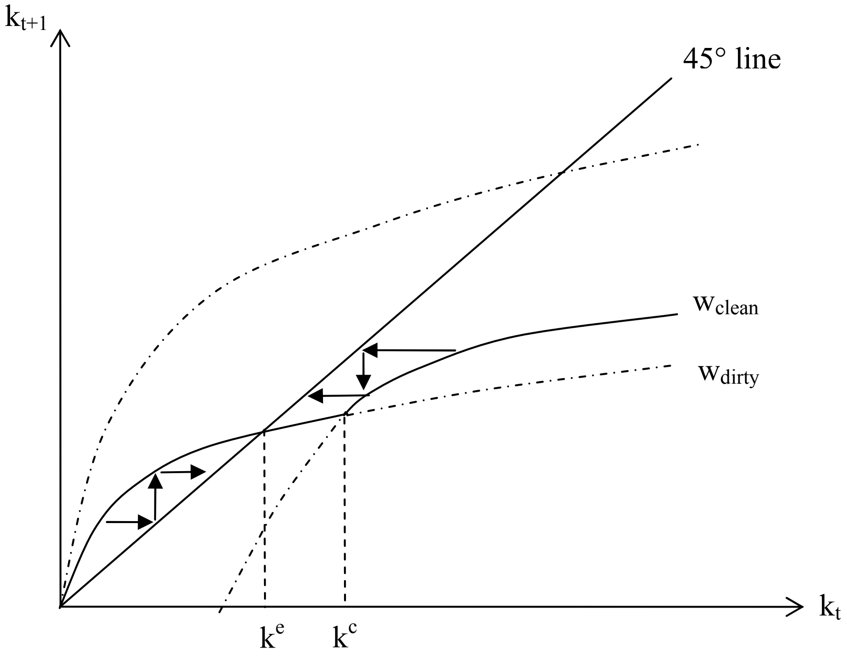
World Bank, 2010. World Development Report 2010: Development and Climate Change, Washington D.C.: World Bank.

Figure 1. Dynamics of the closed economy case (no credit market imperfection)

(I)



(II)



(III)

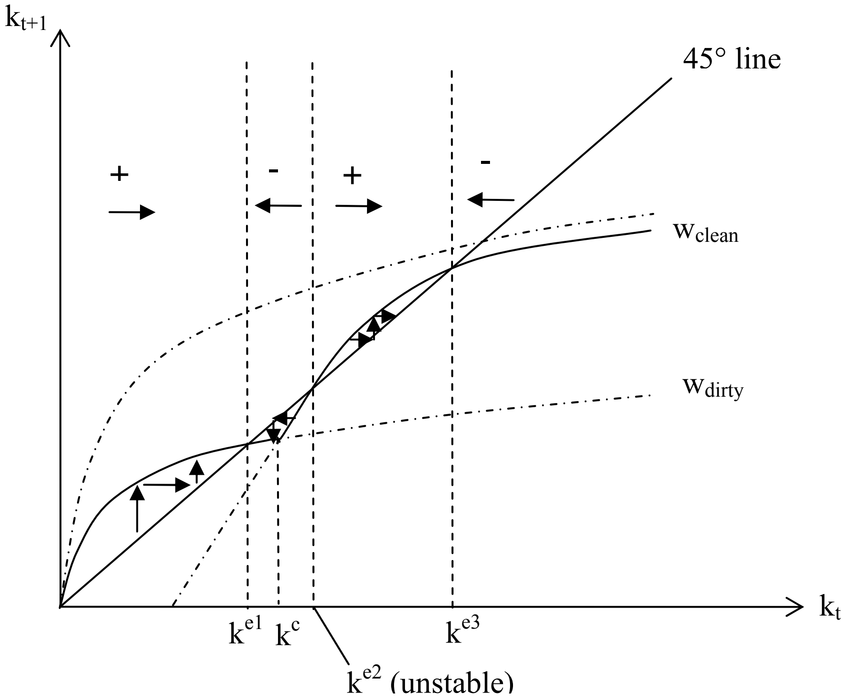


Figure 2. Phase diagram for the closed economy case

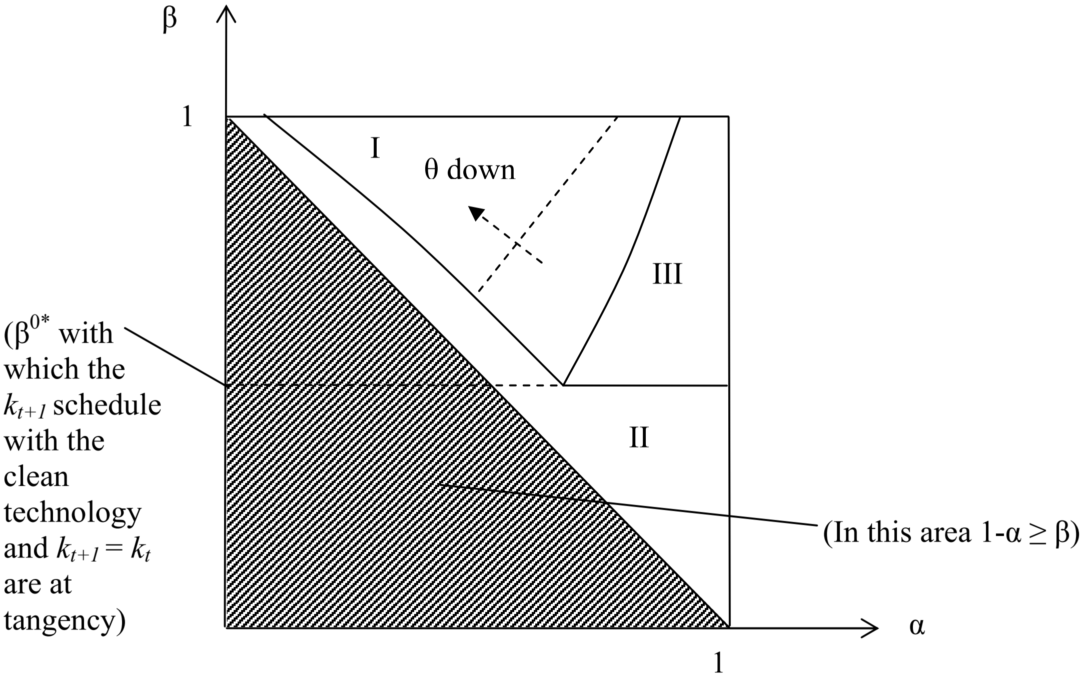


Figure 3. Example of dynamics for the closed economy with credit market imperfection for the clean technology

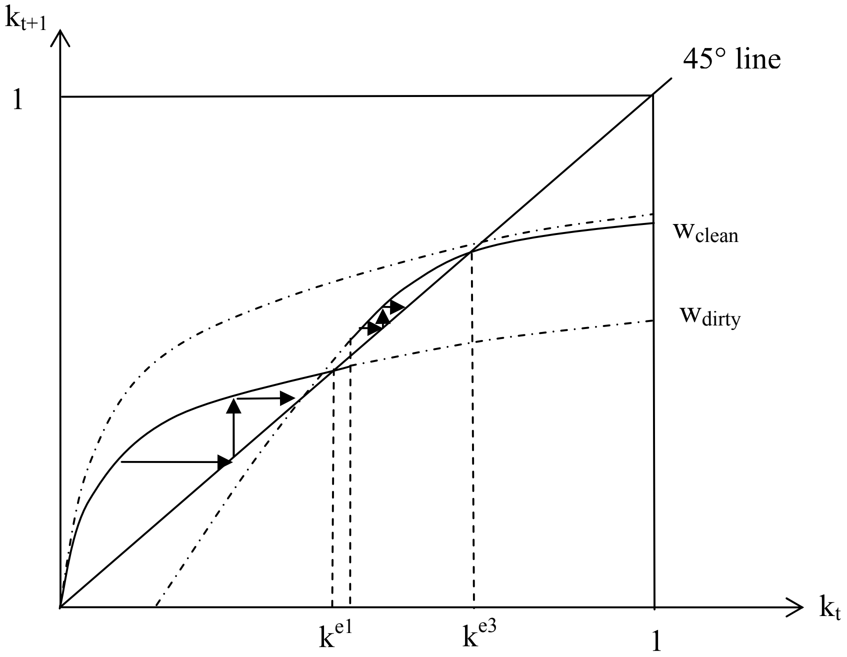
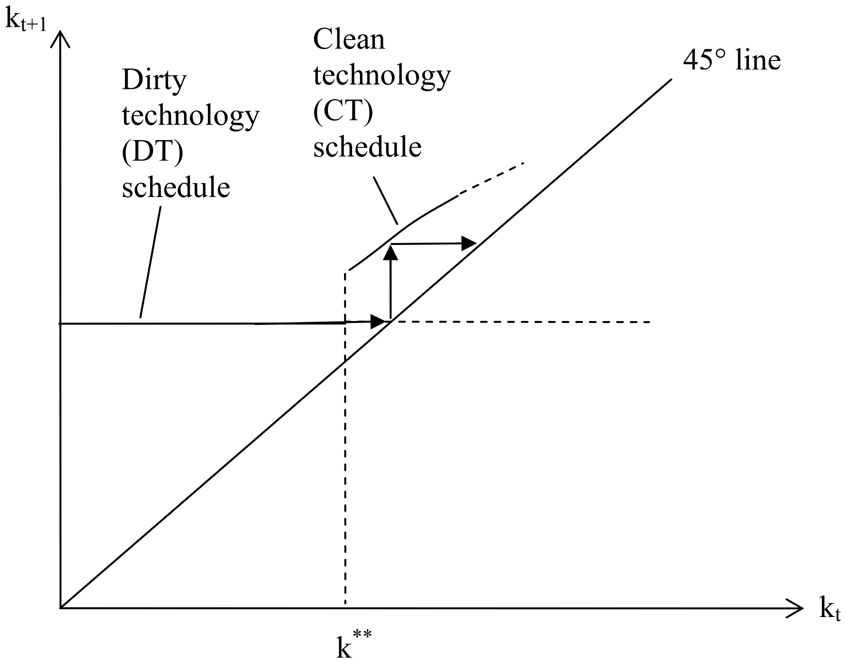
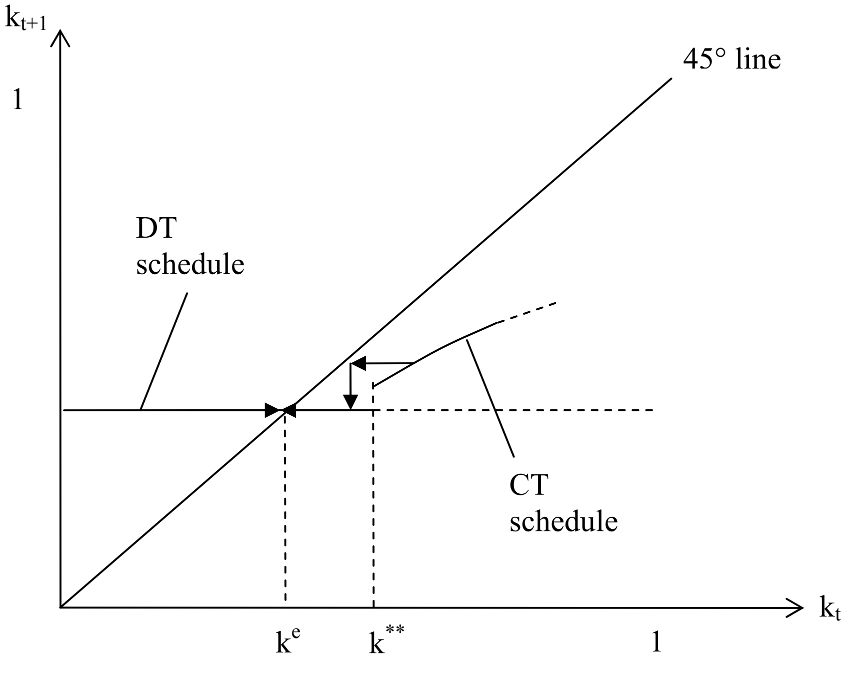


Figure 4. Transitional dynamics in the open economy case

(i)



(ii)



(iii)

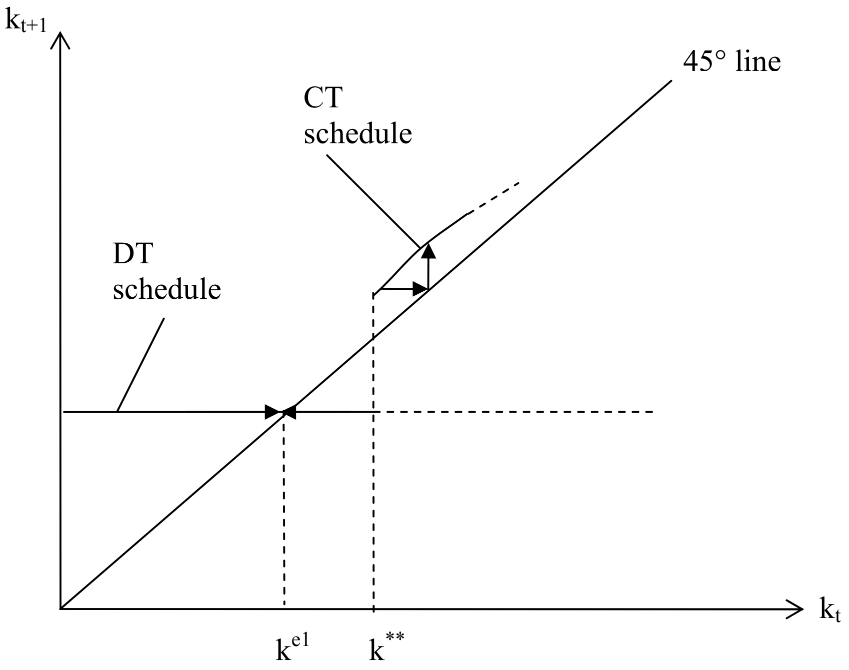

k_{t+1}
45° line
CT
schedule
DT
schedule
k_t
k^{e1}
k^{**}

Figure 5. An example of phase diagram for the open economy case