The international platform of Ludwig-Maximilians University's Center for Economic Studies and the Ifo Institute

CESifo Working Papers

www.cesifo.org/wp

The Effectiveness of Taxation and Feed-in Tariffs

Fabio Antoniou
Roland Strausz

CESIFO WORKING PAPER NO. 4788
CATEGORY 10: ENERGY AND CLIMATE ECONOMICS
MAY 2014

CESifo
Center for Economic Studies & Ifo Institute

CESifo *Working Paper No. 4788*

The Effectiveness of Taxation and Feed-in Tariffs

Abstract

We study (energy) markets with dirty incumbents and costly entry by clean producers. For intermediate entry costs, the market outcome exhibits inefficient production and inefficient entry. A policy mix of three popular regulatory instruments—taxation on polluters, feed-in tariffs for clean entrants, and taxation of consumption—cannot correct these two market failures. Feed-in tariffs and consumption taxes are ineffective instruments for implementing the first best. The second best requires feed-in tariffs or consumption taxes. For a given level of production, the instruments are ineffective in influencing the overall budget, but may be effective for other budgetary concepts.

JEL-Code: D210, D610, H230.

Keywords: taxation, feed-in tariffs, externalities, entry, pollution.

Fabio Antoniou
Humboldt-University Berlin
Institute for Economic Theory 1
Spandauer Str. 1
Germany – 10178 Berlin
fabio.antoniou@wiwi.hu-berlin.de

Roland Strausz
Humboldt-University Berlin
Institute for Economic Theory 1
Spandauer Str. 1
Germany – 10178 Berlin
strauszr@wiwi.hu-berlin.de

March 21, 2014
We thank Carsten Helm, Ulrich Kamecke, and Marco Runkel for helpful discussions and suggestions. Both authors gratefully acknowledge financial support by the BMBF in project "CReW".

1 Introduction

We point out that a currently popular[1] combination of regulatory instruments — taxation on polluters, feed-in tariffs for clean entrants, and taxation of consumption — is unable to achieve the joint policy goal of internalizing externalities of dirty incumbents and inducing efficient entry of clean producers. These instruments are therefore imperfect. As a result, we contradict the current policy debate, which argues that it represents the right policy mix for attaining these goals.

At first sight our results may seem surprising, because the classic Tinbergen rule of "one instrument per policy objective" suggests that the mentioned policy mix should be able to reach the two policy goals. Because there are actually three instruments, one may even see room for a third policy goal: balancing the budget to finance the intervention scheme. Indeed, the policy debate offers the following intuitive reasoning how to obtain these three goals: Use the tax on the polluting incumbent to address the externality problem, use the feed-in tariff to alleviate the entry problem, and, finally, use the consumption tax to balance the budget. The policy mix, therefore, seems to supply the perfect tool box for dealing with the two market imperfections.

We caution that the above reasoning is misleading and argue that the set of instruments is much less effective. We derive our results in a market setup with dirty incumbents and costly entry by clean producers. In this setup, the entrant's incentives to enter are suboptimally low, simply because he disregards the contribution to social welfare that is appropriated by the consumer surplus. Consequently, our market setup represents a minimalist setup for modeling the problem discussed in the policy debate: the externality problem of the dirty incumbents and too little incentives for entry by clean producers.

For this market setup, we first of all show that feed-in tariffs and consumption taxes are ineffective instruments for inducing the first best. More precisely, we show that a social planner is just as well off between using only a tax on polluters or only using a combination of feed-in tariff and consumer taxation. Put differently, if the social planner can attain the efficient outcome with the three instruments, she can also reach it with only a tax on polluters (or alternatively, only with a combination of feed-in tariff and consumer taxation). Hence, com-

[1]Feed-in tariffs are currently applied by more than 50 countries, including the US, Canada, most of the European countries, and China.

plementing a tax on polluters by a feed-in tariff, a consumption tax, or a combination of the two is redundant. The reason for this failure is a market interaction of the instruments, which prevents their use as independent policy instruments. As a consequence the usual Tinbergen logic fails.

We further show that, for intermediate entry costs, no set of instruments exist that induces efficient production and efficient entry. This establishes the imperfectness of the set of instruments for addressing the two policy goals. Since these policy instruments are in general unable to achieve the first best, we further study the second best. Intuitively, it trades off reductions in the incumbent's dirty production against inducing entry. In order to induce entry, the second best distorts upwards the production of the potential entrant to enable it to recover its entry costs. Interestingly, the second best overcorrects the polluter's output by inducing a production level below the efficient one. Overall production in the second best is nevertheless distorted upward. A social planner can achieve this second best with a tax on the incumbent's production and a feed-in tariff that subsidizes entry. Hence, only with regard to the second best, the feed-in tariff becomes an effective, albeit suboptimal instrument. In addition to these two instruments, the consumption tax is however still redundant in that it does not enable the social planner to attain a higher welfare than using only the polluter tax and the feed-in tariff. Since the second best allocation uniquely determines the budget, we also obtain that the consumption tax is also ineffective in balancing the budget of the overall set of instruments.

Our results caution against putting too much hope in the set of instruments as currently used in one way or another by many governments. For instance, the Scandinavian countries implement an explicit emissions tax, while the European Union implemented such a taxation scheme indirectly through its three phase program of tradable emissions permits. An alternative scheme with similar effects is a tax on energy produced by the polluters from which renewable sources are exempted. The latter has been implemented in the United Kingdom, Germany and the Netherlands. Quota obligations equivalent to market share requirements were established in Italy, Denmark, Belgium, Australia, Austria, Sweden, the United Kingdom and many U.S. states (Fischer and Newell, 2008). In the context of our setup, all these schemes are equivalent to the introduction of an explicit polluter tax.

Regarding the entry problem of the clean producers, the European Commission (2008 p.3) views feed-in tariffs as most effective dealing with entry costs: "Well-adapted feed-in tariff regimes are generally the most efficient and effective support schemes for promoting renewable electricity".[2] Underscoring this view, European Commission (§116b, 2013) proposes as a guideline for aiding immature technologies that "Aid is granted by way of a feed-in-premium".[3] Nowadays, feed-in tariffs are applied by more than 50 countries such as the U.S. where the individual states set their own tariffs, Canada, most of the European countries, with Germany being the leader, and China.[4]

Finally, the political arena is also much concerned about the funding of these intervention schemes and especially the feed-in tariffs. Some countries use a revenue-neutral system which recovers tariff expenditures by either a surcharge on the electricity price, or alternatively, by a general government tariff (Lehmann, 2013). The first has been applied by most of the countries and puts the burden solely to the electricity consumers. The second one, which has been implemented in the Netherlands, translates to a burden to all taxpayers.

Related literature: Although policy makers stress the common policy goal of efficient production and efficient entry of clean producers, environmental economics has not really focused on these two issues simultaneously. Studies on feed-in tariffs abstract from the discrete zero-one decision of entry and do not model a cost of entry of the clean energy producers (e.g., Schneider and Goulder, 1997; Fischer and Newell, 2008; Acemoglu et al., 2012; Reichenbach and Requate, 2012; Lehmann, 2013). These papers focus, instead, on the marginal effects on investment incentives and analyze how feed-in tariffs mitigate externalities due to learning by doing and spill-over effects in R&D.[5,6] Although we view these additional externalities as important, we point out that they capture a different problem than entry.

[2]See de Jager and Rathmann (2008), International Energy Agency (2008), and Deutsche Bank (2012) for similar views.

[3]Some authors distinguish feed-in *tariffs* from feed-in *premiums*, viewing a tariff as a guaranteed price of production, whereas the premium is a fixed markup over the market price. Although there is an important difference in its practical implementation, there is no real economic difference between the two and we use the wording "tariff" indiscriminately.

[4]A detailed view of these policies across the U.S. states and several European countries can be found on the following links: <http://www.dsireusa.org/index.cfm>, <http://176.9.160.135/search-by-country>.

[5]Although not mentioned explicitly studies by Jaffe et al. (2005) and Helm and Schöttner (2008) also support promoting policies for similar reasons.

[6]Using data from *OECD* countries, Nesta et al. (2014) find empirical support for the hypothesis that current renewable energy policies foster green innovation. In a Nordic case study based on wind power, Boomsma et al. (2012) verify that the feed-in tariff encourages earlier investment.

In contrast, studies like Spulber (1985), Katsoulacos and Xepapadeas (1995) and Requate (1997) focus specifically on the problem of optimal entry under negative production externalities. They however do not address the role of different policy instruments in stimulating the entry of clean versus dirty producers.

Given our focus on the entry problem, we follow the latter approach (and much of the literature in industrial organization) and explicitly model the entry cost of clean producers. These entry costs may comprise the development costs of new technologies, the costs of setting up the new production facilities, or some alternative fixed costs.[7] In contrast to the existing literature on feed-in tariffs, we abstract from any spill-over effects. This enables us to attribute our results and insights about the underlying economic mechanisms unambiguously to the joint problem of efficient production and efficient entry, on which the policy debate focuses. It further allows us to differentiate our paper clearly from the aforementioned studies on feed-in tariffs. We however point out that spill-over effects would actually exacerbate our entry problem. Because next to the consumer surplus, the entrant will also not take into account the positive spill-over effects of its entry, spill-overs distort the entrant's entry decision further away from efficiency.

There is a vast literature in public economics on the effectiveness of different Pigou-tax bases when dealing with both single and multiple market failures. In the context of environmental externalities, Palmer and Walls (1997), Walls and Palmer (2001) and Fullerton and Wolverton (2000; 2005) point out that instead of taxing the polluter, a social planner may equivalently tax other participants. Fullerton and Wolverton (2005) combine this with revenue considerations of the government. This result is much in-line with our result that in order to implement the first best, the regulator may either only tax the polluter or equivalently use a combination of feed-in tariff and consumer taxation.

In line with the classic Tinbergen rule, dealing with multiple market failures usually requires a mix of different policy instruments. In the context of environmental externalities, Fischer and Newell (2008), Goulder and Parry (2008) and Garcia et al. (2012) for instance

[7]For example in the specific context of energy markets, practitioners view these fixed entry costs as taking the lion share of overall production costs of clean producers. For instance, US Energy Information Administration (Table 1, 2013) reports that the geothermal, wind, or solar generation of electricity involve no substantial variable costs and mainly fixed costs. Similarly, the European Wind Energy Association (2009) computes that the setup costs for establishing a wind powered plant typically accounts for the 75% of its total costs.

argue that multiple instruments are needed to address all the relevant dimensions. This stands in contrast to our insight that, when the first best is feasible in the presence of two imperfections, a single emission tax suffices to correct both market imperfections at the same time. Since this result no longer holds in the second best, our results are more in line with the literature on the second best use of multiple policy instruments such as Bennear and Stavins (2007).

Finally, there is a growing literature on the dynamic implications that may arise from the introduction of these policies (e.g., Grafton et al. 2012 and Hintermann and Lange 2013). Such dynamic considerations are however orthogonal to the issues we address and our model therefore abstracts from those ones. As already argued by Petrakis et al. (1997), entry in a dynamic environment effectively implies that the firm and the social planner compare the discounted profits to the entry costs. Hence, if the social planner and the entrant have a common discount factor, then adding dynamics to our framework would not lead to any additional effects. If, in contrast, the social planner has a smaller discount factor than the firm, then the entrant's entry choice is further distorted downwards, which, in our framework, effectively means that the entry problem is intensified.

2 Setup

Consider an industry that produces a homogeneous good x, for instance electricity. The representative consumer has a quasi-linear utility and obtains a utility $\Psi(x)$ from consuming a quantity x. His utility is increasing in consumption at a decreasing rate, i.e., $\Psi'(x) > 0$ and $\Psi''(x) < 0$. We normalize $\Psi(0) = 0$.

The industry consists of an incumbent sector. This sector produces the good with a cost function $C_i(x_i)$, which is increasing and convex, i.e., $C_i'(x_i) > 0$ and $C_i''(x_i) > 0$. Moreover, as an incumbent there are no entry costs, i.e., $C_i(0) = 0$. The incumbent sector uses a dirty technology in that a production x_i imposes a negative externality $E(x_i)$, which is increasing at a (weakly) increasing rate, i.e., $E'(x_i) > 0$ and $E''(x_i) \geq 0$. Moreover $E(0) = 0$.

In addition to the dirty technology, a new, clean technology is available, but its use requires an entry cost of $F \geq 0$. The clean sector produces with a cost function $C_e(x_e)$, which is increasing and convex, i.e., $C_e'(x_e) > 0$ and $C_e''(x_e) > 0$.[8] Since F represents the fixed cost of

[8]Note that convex cost functions also describe correctly production technologies with a constant marginal

production, we have $C_e(0) = 0$.

In order to guarantee internal solutions, we adopt the Inada conditions, $\Psi'(0) = C_i'(\infty) = C_e'(\infty) = \infty$, $\Psi'(\infty) = C_i'(0) = C_e'(0) = E'(0) = 0$.

Focusing on the externality and entry problem, we abstract from any competitive problems and assume that competition policy is effective so that firms act as under full competition.[9] Before analyzing the market outcome, we first characterize the efficient outcomes.

3 Efficient Outcomes

In this section, we derive the efficient production levels and an upper bound on the cost of entry below which it is efficient. In order to obtain these results, we compute, and subsequently compare, the levels of output that maximize social welfare with and without entry.

Given consumption x, production x_i of the incumbent, and production x_e of the entrant, social welfare gross of entry costs is

$$W(x, x_i, x_e) \equiv \Psi(x) - C_i(x_i) - C_e(x_e) - E(x_i).$$

Since feasibility requires $x = x_i + x_e$, efficient, first best production levels (x_i^{fb}, x_e^{fb}) solve

$$\max_{x_i, x_e} W(x_i + x_e, x_i, x_e) - F \cdot \mathbf{1}_{x_e > 0}$$

with $\mathbf{1}_{x_e>0}$ the indicator function, denoting whether the entry costs F are paid, which depends on whether entry ($x_e > 0$) takes place or not.

Hence, if entry is socially desirable, then the first best levels (x_i^*, x_e^*) satisfy

$$\Psi'(x_i^* + x_e^*) = C_i'(x_i^*) + E'(x_i^*) \text{ and } \Psi'(x_i^* + x_e^*) = C_e'(x_e^*). \tag{1}$$

If, in contrast, entry is not socially desirable, then the first best levels $(\hat{x}_i^*, \hat{x}_e^*)$ satisfy

$$\Psi'(\hat{x}_i^*) = C_i'(\hat{x}_i^*) + E'(\hat{x}_i^*) \text{ and } \hat{x}_e^* = 0. \tag{2}$$

Defining

$$F^* \equiv W(x_i^* + x_e^*, x_i^*, x_e^*) - W(\hat{x}_i^*, \hat{x}_i^*, 0),$$

a direct comparison of the welfare levels under (x_i^*, x_e^*) and $(\hat{x}_i^*, 0)$ yields the following result:

cost up to some fixed capacity.

[9]Clearly, this is an idealized starting point, but presents a clear benchmark and allows us to isolate the problems that are only due to the externality and entry problem and not confounded by other economic problems such as imperfect competition.

Proposition 1 *Entry is socially desirable and first best levels exhibit* (x_i^*, x_e^*) *if* $F \leq F^*$. *Otherwise entry is not desirable and first best levels exhibit* $(\hat{x}_i^*, 0)$*, where*

$$x_i^* < \hat{x}_i^* < x_i^* + x_e^* = x^*.$$

Hence, entry is only socially efficient if the cost of entry is small enough and F^* represents the exact threshold level below which this is the case. Moreover, the efficient level of the incumbent is smaller with entry than without entry, whereas overall efficient level of production is larger with entry. These results are all in line with standard intuition.

4 Inefficient Market Outcome

In this section we consider the outcome of an unregulated market and identify the distortions from the first best.

Let p represent the market price for electricity. Consumers maximize their net consumer surplus $\Phi(x) \equiv \Psi(x) - px$. Hence, the consumers' demand function $D(p)$ obtains from the first order condition $p = \Psi'(x)$. The incumbent maximizes $\Pi_i(x_i) = px_i - C_i(x_i)$. Consequently, the supply function $S_i(p)$ obtains from the first order condition $p = C_i'(x_i)$. Given entry, the entrant maximizes $\Pi_e(x_e) = px_e - C_e(x_e)$. The supply function $S_e(p)$ follows from the first order condition $p = C_e'(x_e)$. Our Inada conditions together with our convexity assumptions imply that the first order conditions are sufficient and lead to well-defined and positive demand and supply for any $p > 0$.

Given that entry occurs, the competitive equilibrium price p^c satisfies $D(p^c) = S_i(p^c) + S_e(p^c)$ and the equilibrium outcome is $x^c = D(p^c)$, $x_i^c = S_i(p^c)$, $x_e^c = S_e(p^c)$ with

$$p^c = \Psi'(x^c) = C_i'(x_i^c) = C_e'(x_e^c). \tag{3}$$

In this market equilibrium, the profit of the entrant is $\Pi_e^c = p^c x_e^c - C_e(x_e^c) - F$ and is positive if $F \leq F^c$, where

$$F^c \equiv p^c x_e^c - C_e(x_e^c).$$

Proposition 2 *A competitive market equilibrium with entry exists only if* $F \leq F^c$. *In this equilibrium, the incumbent's output is larger than in the first best* $(x_i^c > x_i^*)$*; the entrant's output is smaller than in the first best* $(x_e^c < x_e^*)$*; and the overall output is larger than in the first best* $(x^c > x^*)$. *Moreover, it holds* $F^c < F^*$.

The proposition identifies the usual distortions in a market with a negative externality. Overall production x^c is too large compared to the first best, because the market fails to internalize the negative externality. Consequently, the polluting firm produces too much at the expense of the entrant, which produces too little from an efficient point of view. The proposition, moreover, shows that the entrant's incentives to enter the market are distorted downward ($F^c < F^*$). The reason of this downward distortion is that the entrant's profit is smaller than its contribution to total welfare. In particular, it cannot extract its contribution to the consumer surplus.

Depending on the entry costs F, we may therefore classify the different market failures as follows:

1. For low entry costs, $F \leq F^c$, the market leads to an externality problem, but not an entry problem.
2. For intermediate entry costs, $F \in (F^c, F^*)$, the market leads to both an externality problem and an entry problem.
3. For high entry costs, $F \geq F^*$, the market leads to an externality problem, but not an entry problem.

5 The Policy Instruments

In this section we introduce the policy instruments by which the regulator can address the externality and entry problem. In particular, the regulator may use three regulatory instruments: 1. a (specific) tax t_c on the incumbent's production; 2. a feed-in tariff t_e to subsidize the entrant's production; 3. a (specific) tax, t_c, on the consumer's consumption. We discuss first the effect of the policy instruments (t_i, t_e, t_c) on the market outcome.

The instruments affect the market outcome, because they change the effective prices which market participants face. Given a market price p, the tax t_i on the incumbent implies that the incumbent effectively faces a price $p - t_i$ for each unit sold. As a result, his profit maximizing supply is $S_i(p - t_i)$, where $C_i'(S_i(p - t_i)) = p - t_i$. Similarly, the feed-in tariff t_e effectively raises the entrant's return to $p + t_e$ for each unit so that, conditional on entering the market, it optimally supplies $S_e(p + t_e)$, where $C_e'(S_e(p + t_e)) = p + t_e$. Finally, the consumption tax

t_c raises the consumers' price to $p + t_c$. Hence, market demand is $D(p + t_c)$ and satisfies $\Psi'(D(p + t_c)) = p + t_c$. For a given set of regulatory instruments (t_i, t_e, t_c), the equilibrium price with entry, p^r, satisfies

$$D(p^r + t_c) = S_i(p^r - t_i) + S_e(p^r + t_e).$$

Consequently, we say that the *instruments* (t_i, t_e, t_c) *implement an allocation* (x_i, x_e) *with* $x_e > 0$ if and only if there exist some price p^r such that

$$x_i + x_e = D(p^r + t_c); x_i = S_i(p^r - t_i); x_e = S_e(p^r + t_e); \Pi_e^r(x_e) = (p^r + t_e)x_e - C_e(x_e) - F \geqslant 0. \quad (4)$$

As discussed in the introduction, a social planner may also have budgetary concerns. Given a set of instruments and an equilibrium price p^r, the *overall budget* of the policy mix is

$$B \equiv t_c D(p^r + t_c) + t_i S_i(p^r - t_i) - t_e S_e(p^r + t_e). \quad (5)$$

Condition (4) restricts the policy outcomes (x_i, x_e) that are implementable, and thereby limits the effectiveness of the instruments. The following lemma gives a characterization of these limitations. It will play a crucial role for our subsequent results.

Lemma 1 *Instruments* (t_i, t_e, t_c) *implement the allocation* (x_i, x_e) *with* $x_e > 0$ *if and only if*

(i) $t_c = \Psi'(x_i + x_e) - C_i'(x_i) - t_i = \Psi'(x_i + x_e) - C_e'(x_e) + t_e$;

(ii) Entrant's profits are $\Pi_e^r = C_e'(x_e)x_e - C_e(x_e) - F \geq 0$;

(iii) Consumers' net surplus is $\Phi^r = \Psi(x_i + x_e) - \Psi'(x_i + x_e)(x_i + x_e)$;

(iv) Incumbent's profits are $\Pi_i^r = C_i'(x_i)x_i - C_i(x_i)$;

(v) The budget equals $B = [\Psi'(x_i + x_e) - C_i'(x_i)]x_i + [\Psi'(x_i + x_e) - C_e'(x_e)]x_e$.

The lemma follows directly from condition (4) and expresses the remaining degree of freedom in the use of the instruments when implementing a certain allocation. The result obtains because given a set of instruments (t_i, t_e, t_c) the equilibrium price p^r adapts so that demand equals overall supply. Hence, the market interaction of the instruments limits their use for implementing certain allocations.

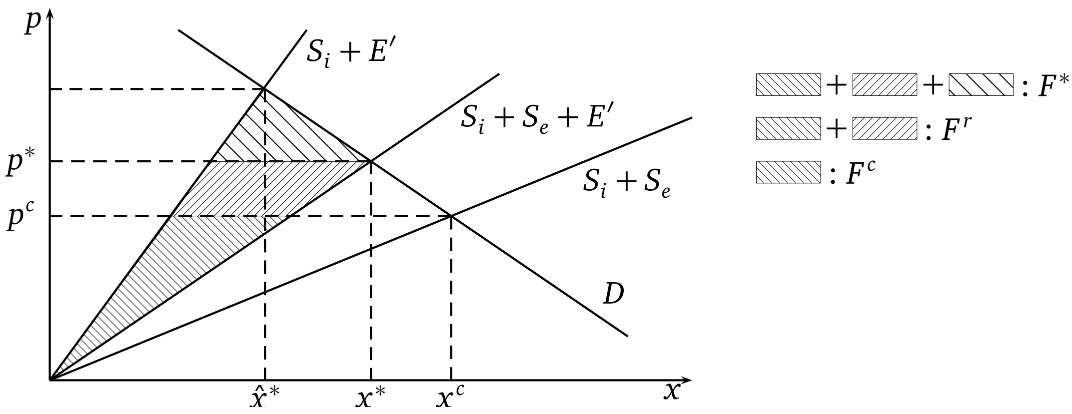

Figure 1: Efficient and Market Outcomes

6 First Best: Failures and Redundant Instruments

In this section we show two of our main results. First, the three regulatory instruments are imperfect in that they are unable to achieve the efficient solution in general. Second, the feed-in tax and the consumption tax are redundant in that they do not help to achieve efficient outcomes. To establish these results, we first define

$$F^r \equiv C_e'(x_e^*)x_e^* - C_e(x_e^*).$$

We may then adapt Lemma 1 to obtain the following result.

Proposition 3 *It holds $F^c < F^r < F^*$. Moreover,*

(i) For $F \in (F^r, F^*)$ a set of instruments implementing the efficient outcome fails to exist.

(ii) For $F \notin (F^r, F^*)$ a set of instruments which implements the efficient outcome exists. For any such set of instruments, it holds $t_c^* = t_e^* = E'(x_i^*) - t_i^*$ and the net consumer surplus, profits, and the budgets are uniquely determined. Moreover, one such set of instruments exhibits $t_i = E'(x_i^*)$ and $t_e = t_c = 0$.

The proposition states first of all that the entrant's incentives to enter are higher in a regulated market that implements the efficient outcome than in the unregulated market, but still too low from an efficiency point of view. As already explained in our discussion of Proposition 2, the entrant's incentives to enter the market are too small as compared to the first best, because its profits are smaller than its contribution to total welfare. Figure 1 illustrates this more clearly. The market equilibrium in an unregulated market obtains where demand D equals the aggregate supply function $S_i + S_e$. This yields the equilibrium price p^c and total output x^c. At this outcome, the entrant's profit gross of entry costs, F^c, is the area between the curves $S_i + E'$ and $S_i + S_e + E'$ up to p^c, because the difference between these curves equals the entrant's marginal costs. For the efficient outcome however, the demand curve D equals the sum of aggregate supply function $S_i + S_e$ *plus* the marginal externality E'. As a result, the efficient output x^* is smaller than the unregulated market outcome x^c and the efficient outcome obtains for the larger price p^*. The entrant's gross profit, F^r, corresponds again to the area in between the curves $S_i + E'$ and $S_i + S_e + E'$ but now up to the higher price p^*. As a result, $F^c < F^r$. Yet, also at the price p^*, the entrant does not extract its entire contribution to overall welfare. As illustrated by the triangle in Figure 1, the consumers extract a part of the entrant's contribution in the form of a larger consumer surplus. Consequently, it follows $F^c < F^r < F^*$.

Statement (i) of the proposition substantiates our claim that the three regulatory instruments are imperfect. They are, in general, unable to achieve the joint policy goals of efficient production levels and efficient entry. In particular, the first best outcome can only be achieved, when the entry problem is non-existent $F \notin (F_e^c, F^*)$ or small $F \in (F^c, F^r)$.

Statement (ii) of the proposition explains the sense in which the feed-in tariff and the consumption tax are redundant for implementing efficient outcomes. First of all, if the efficient outcome is not attainable with only an incumbent tax t_i, it is also not attainable by using the feed-in tariff and the consumption tax as additional instruments. Moreover, these two instruments do not help in alleviating the budget or adjusting the profits or net consumer surplus.

These results follow because when implementing the efficient outcome, the instruments leave only a small degree of freedom in their use. In particular, the feed-in tariff must coincide with the consumption tax. Moreover, the feed-in tariff and the incumbent's tax must add up to the marginal externality at the first best output level. Hence, the freedom in the use of instruments to induce efficient outcomes is highly restrictive. In particular, any set of policy instruments for which the feed-in tariff differs from the consumption tax, does not induce an efficient outcome.

Consistent with usual results, efficiency obtains with the usual tax scheme where only the incumbent is taxed by the marginal externality, $t_i = E'(x_i^*)$, while consumers are not taxed at all and the entrant receives no feed-in tariff, $t_e = t_c = 0$. Yet, an alternative way to implement the efficient outcome is not to tax the incumbent at all, $t_i = 0$, but equate the consumer tax and the feed-in tariff to the marginal externality: $t_e = t_c = E'(x_i^*)$.[10] Hence, if the efficient outcome is attainable, then a regulator may also dispense with taxing the externality and attain it by using only a feed-in tariff with a matching consumption tax. In addition, when the incumbent tax, for some reason, does not match the marginal externality, a regulator may use an appropriate feed-in tariff and matching consumption tax to correct for this.[11]

For intermediate entry costs, $F \in (F^r, F^*)$, the instruments fail to implement the efficient outcome. We therefore conclude that the set of instruments is imperfect. There are two possible ways to pursue. First, we can ask whether there exists a different set of instruments which enables the implementation of efficient outcomes. Second, we can lower our goals and change our focus from first best efficiency to second best outcomes by asking the question what is the constrained optimal use of these imperfect instruments.

7 Second Best: Characterization

In this section, we study the constrained efficient use of the three instruments, when they cannot implement the efficient outcome but no alternative set of instruments exist. We characterize second best outcomes, which maximize social welfare over those outcomes that are implementable by the three instruments. The second best outcome solves a trade-off between inducing entry and regulating the externality and we derive it by comparing the welfare maximizing implementable allocation without and with entry. We show that also with respect to the second best the three policy instruments exhibit a redundancy. The second best is attainable by using only two of the three instruments. Moreover, the redundant third instrument is ineffective in regulating the scheme's budget.

It is straightforward to see that the second best without entry $(\hat{x}_i^{sb}, \hat{x}_e^{sb})$, coincides with the efficient outcome without entry as defined in (2): $(\hat{x}_i^{sb}, \hat{x}_e^{sb}) = (\hat{x}_i^*, 0)$. Indeed, this outcome maximizes social welfare among all outcomes without entry. It is attainable, because the regulator can always prevent entry by a negative feed-in tariff.

[10] In a different setup, this degree of freedom is also noted in Walls and Palmer (2001) and Fullerton and Wolverton (2005).

[11] For instance, the draft of the Guidelines on environmental and energy aid for 2014-2020, mentions in paragraph (108) that "the EU ETS and national CO2 taxes internalise [...] may not (yet) ensure the achievement of the related, but distinct EU objectives for renewable energy [...] the Commission therefore presumes that a residual market failure remains, which aid for renewable energy can address."

We next address the welfare maximizing implementable outcome with entry, (x_i^{sb}, x_e^{sb}). This outcome is a solution to the constrained maximization problem

$$\max_{x_i, x_e} W(x_i + x_e, x_i, x_e) \quad \text{s.t. } C_e'(x_e)x_e - C_e(x_e) - F \geq 0.$$

Disregarding the constraint yields the outcome $x_i = x_i^*$ and $x_e = x_e^*$ as defined in (1). It violates the constraint if $F > F^r$. Since the problem is concave, the constraint then binds at the optimum. From this observation we obtain the following insight.

Proposition 4 *For $F \in (F^r, F^*)$, the second best allocation (x_i^{sb}, x_e^{sb}) with entry exhibits*

(i) $C_e'(x_e^{sb})x_e^{sb} - C_e(x_e^{sb}) = F$;

(ii) $\Psi'(x_i^{sb} + x_e^{sb}) = C_i'(x_i^{sb}) + E'(x_i^{sb})$;

(iii) $x_e^{sb} > x_e^*$, $x_i^{sb} < x_i^*$ and $x^{sb} = x_i^{sb} + x_e^{sb} > x_i^* + x_e^* = x^*$;

(iv) it is implementable with the set of instruments $(t_i^{sb}, t_e^{sb}, t_c^{sb})$, where $t_e^{sb} = C_e'(x_e^{sb}) - \Psi'(x_i^{sb} + x_e^{sb}) + t_c^{sb} \geq t_c^{sb} = E'(x_i^{sb}) - t_i^{sb}$.

For $F > F^r$, the output x_e^* is too small to yield enough profits to compensate for the entry costs F. The second best with entry, therefore, exhibits an output of the entrant that is distorted upward so that the fixed costs is covered, $(x_e^{sb} > x_e^*)$. It then remains to determine the incumbent's output level that given the entrant's output x_e^{sb}, deals with the externality efficiently. As the quantity of the entrant rises, the marginal benefit from consumption decreases. As a result, the output of the incumbent is lower than in the first best $(x_i^{sb} < x_i^*)$, because at the incumbent's efficient production level, the marginal benefit from consumption equals the social marginal costs. Finally, overall production in the second best with entry is larger than the corresponding one in the first best.

Proposition 4(iv) further characterizes the set of policy instruments that implements the second best allocation. In particular, it shows that a polluter tax t_i alone is unable to attain the second best. Consequently, a positive feed-in tariff is needed. A specific set of instruments which achieves the second best, is the usual incumbent tax that equals the marginal externality $(t_i^{sb} = E'(x_i^{sb}))$ together with a positive feed-in tariff $(t_e^{sb} = C_e'(x_e^{sb}) - \Psi'(x_i^{sb} + x_e^{sb}) > 0)$. A further consumption tax is not needed $(t_c^{sb} = 0)$ so that the second best is attainable with only two of the three instruments. Moreover, it is interesting to note to what extent the required set of instruments differs from the set of instruments that implements the first best as described in Proposition 3(ii). Under the second best the optimal mix between the consumption tax and the tax on the incumbent follows the same rule as in the first best, i.e., the sum of the

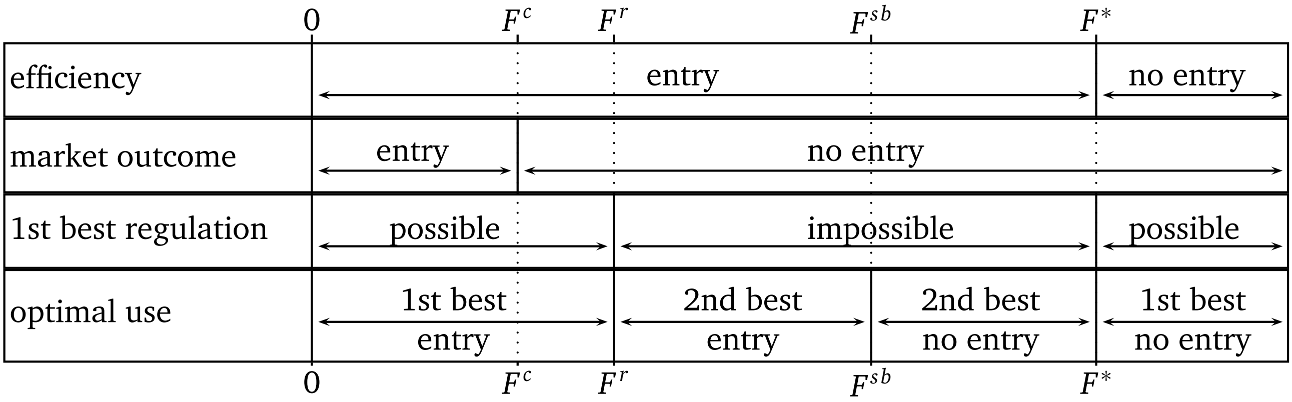

Figure 2: Outcomes

two taxes must be equal to the marginal externality at the targeted pollution level. Yet, the feed-in tax must exceed rather than equal the consumption tax.

Defining

$$F^{sb} \equiv W(x_i^{sb} + x_e^{sb}, x_i^{sb}, x_e^{sb}) - W(\hat{x}_i^*, \hat{x}_i^*, 0) < F^*,$$

we can compare the welfare levels associated with $(\hat{x}_i^*, 0)$ and derive the optimal regulation (x_i^{sb}, x_e^{sb}) in the second best.

Proposition 5 *For $F \in (F^r, F^{sb}]$ the optimal use of instruments is to induce entry and outcome (x_i^{sb}, x_e^{sb}). For $F \in (F^{sb}, F^*)$ the optimal use does not induce entry and outcome $(\hat{x}_i^*, 0)$.*

Figure 2 collects our results. Comparing the first and second row reveals how the market distorts entry downward. The reason for this downward distortion is that, in a market, the entrant can extract only a part of the efficiency gains from entry while incurring its full cost. It is therefore less willing to enter. The third line shows that the three instruments are unable to achieve the first best for intermediate entry costs, while the fourth line demonstrates for these intermediate costs, whether under an optimal use of the instruments entry occurs.

8 General effectiveness of the policy mix

Until now we considered the effectiveness of the instrument mix to implement either first or second best allocations. In this section, we study the general effectiveness of the instruments to induce some market outcome with entry. This study allows us to argue that the at first sight intuitive argument presented in the introduction — the tax on the polluting incumbent is to address the externality problem, the feed-in tariff is to alleviate the entry problem, and the consumption tax is to balance the budget — is misleading, because the three instruments exhibit an inherent dependency.

To show this, the next proposition states to what extent the restrictions of Lemma 1 limit the effectiveness of the policy instruments with entry in general.

Proposition 6 *Suppose an outcome (x_i, x_e) with $x_e > 0$ is implementable by a set of instruments (t_i, t_e, t_c) and yields net consumer surplus Φ, profit levels Π_e, Π_i, and a budget B. Then,*

(i) (x_i, x_e) is also implementable by only a tax t_i' and a feed-in tariff t_e' and yields the same net consumer surplus Φ, profit levels Π_e, Π_i, and budget B.

(ii) (x_i, x_e) is also implementable by only a tax t_i' and a consumption tax t_c' and yields the same net consumer surplus Φ, profit levels Π_e, Π_i, and budget B.

The proposition shows a general redundancy in the policy instruments. With respect to the market outcome, net consumer surplus, individual profits, and the overall budget, it suffices to use only two of the three instruments. Given that the regulator uses a tax t_i either the feed-in tariff t_e or the consumer tax t_c is superfluous. Hence, the regulator can do just as well by using only two instruments instead of three.

The proposition, moreover, implies that we cannot use the three policy instruments independently for regulating the externality, ensuring entry, and budget concerns. The proposition therefore explains in what sense the Tinbergen logic of the introduction fails and that the intuitive argument presented in the introduction — the tax on the polluting incumbent is to address the externality problem, the feed-in tariff is to alleviate the entry problem, and the consumption tax is to balance the budget — is incorrect.

Finally, we want to note that the budget irrelevance of the instruments as identified in Proposition 6 depends on the exact concept of the budget. In some countries that implement the incumbent tax through a permit system, politicians seem more concerned with financing only the feed-in policy through the consumption tax. To address this concern we define a policy mix (t_i, t_e, t_c) as *feed-in budget balanced* if it implements an allocation (x_i, x_e) so that

$$t_e x_e = t_c(x_i + x_e). \tag{6}$$

For a policy mix that is feed-in budget balanced, the total expenditures associated with the feed-in tariff match the overall revenues from the consumption tax.

For policy instruments that are feed-in budget balanced, we obtain the following characterization.

Proposition 7 *Suppose a schedule (t_i, t_e, t_c) implements an allocation (x_i, x_e) with $x_i > 0$. Then there exists a policy mix (t_i', t_e', t_c') which is feed-in budget balanced and implements (x_i, x_e). In particular, a policy mix with consumption tax $t_c' = (t_e - t_c)x_e/x_i$, polluter tax $t_i' = t_i + t_c - t_c'$. and feed-in tariff $t_e' = t_e - t_c + t_c'$ represents such a policy mix.*

Although the proposition holds for any allocation (x_i, x_e) with $x_i > 0$, its interpretation is markedly different depending on whether or not it is applied to the first best allocation (x_i^*, x_e^*). With respect to the first best allocation, the proposition effectively implies that feed-in budget balanced policy instruments cannot use feed-in tariffs or consumer taxation. To see this, recall from Proposition 3(ii) that any set of instruments which implements the first best requires $t_c = t_e$. Given $x_i^* > 0$, such policy instruments only satisfy the feed-in budget balanced condition (6) if $t_c = t_e = 0$. Hence, any feed-in budget balanced set of policy instruments that implements the first best must use only a tax t_i (which then equals the marginal externality) and does not use a feed-in tariff or consumer tax.

In contrast, the proposition identifies a specific role for consumer taxation when implementing an allocation (x_i, x_e) for which $\Psi'(x_i + x_e) \neq C_e'(x_e)$. Such allocations are necessarily inefficient, but restricting to feed-in budget balanced instruments, they do require a specific non-zero consumer tax. This consumer tax is at most as large as the feed-in tariff.

9 Concluding Remarks

The currently popular combination of regulatory instruments — taxation on polluters, feed-in tariffs for clean entrants, and taxation of consumption — is, in general, unable to solve both externality and entry problems. Consequently this set of instruments is not the right one for addressing these two problems. In contrast, a tax on polluters that equals the marginal externality together with a lump-sum subsidy conditional on entry that covers the entry costs is an example of a set of instruments that induces the first best. From a policy viewpoint such fixed, quantity independent transfers may seem suspicious and difficult to implement.[12] It would however be naive to view the feed-in tariff as an adequate alternative to such a lump sum transfer. The feed-in tariff is distortive, because it affects marginal considerations whereas the lump sum payment does not.

If regulation is restricted to the exclusive use of the three aforementioned instruments, then regulation will, in general, only be second best. This second best policy is suboptimal in that it either distorts entry downwards or overshoots in reducing production of the dirty incumbents together with overproduction by the entrants.

We stress that we obtain such results already in our surprisingly parsimonious setup that captures the essence of the externality and entry problem in a most elementary way. The plainness of our setup allows us to identify clearly the basic economic force that the market interaction of the policy instruments restricts their effectiveness as independent policy measures.

We also point out that entry costs are an essential part of any framework where entry is a problem; the fact that potential entrants do not enter must mean that the benefits of entry – the profits – do not outweigh some kind of entry costs. For our arguments it does not matter whether these profits or costs are uncertain or dynamic. It is also immaterial whether the entry costs reflect the development cost of some new technology or some other more mundane entry cost.

Introducing additional aspects, such as for example imperfect competition, asymmetric information, spill-over externalities, or transboundary pollution, may lead to additional effects which, when strong enough, can affect our results. We consider any such extensions worthwhile, but point out that our insight of the basic limitations of the instruments due to their market interaction is a robust feature that will also play a role in more complicated setups.

[12]As already noted in the introduction, the European Commission (§116b, 2013) advocates the use of feed-in tariffs to promote immature technologies and discourages the use of direct subsidies.

Appendix

This appendix collects the formal proofs.

Proof of Proposition 1: Follows from a straightforward comparison of the optimal welfare level with and without entry. In order to show $x_i^* < \hat{x}_i^* < x^*$, define the function $\tilde{x}_i(a)$ implicitly by

$$\Psi'(\tilde{x}_i(a)+a) = C_i'(\tilde{x}_i(a)) + E'(\tilde{x}_i(a)). \tag{7}$$

Note that $x_i^* = \tilde{x}_i(x_e^*)$ and $\hat{x}_i^* = \tilde{x}_i(0)$. By the implicit function theorem it follows

$$\Psi''(\tilde{x}_i(a)+a)(\partial\tilde{x}_i/\partial a+1) = C_i''(\tilde{x}_i(a))\partial\tilde{x}_i/\partial a + E''(\tilde{x}_i(a))\partial\tilde{x}_i/\partial a \tag{8}$$

so that

$$\frac{\partial\tilde{x}_i}{\partial a} = \frac{\Psi''}{C_i''+E''-\Psi''} < 0,$$

where the inequality follows because C_i and E are convex and Ψ is concave. Hence, $\tilde{x}_i$ is strictly decreasing so that $x_i^* = \tilde{x}_i(x_e^*) < \tilde{x}_i(0) = \hat{x}_i^*$. Note that since $C_i'' > 0$, $E'' > 0$ and $\partial\tilde{x}_i/\partial a < 0$ the right hand side in (8) is negative. Since $\Psi'' < 0$ we must have $\partial\tilde{x}_i/\partial a+1 > 0$. Hence, the term $\tilde{x}_i(a)+a$ is increasing in a so that it follows $\hat{x}_i^* = \tilde{x}_i(0)+0 < \tilde{x}_i(x_e^*)+x_e^* = x^*$. Q.E.D.

Proof of Proposition 2: We first show $x_i^c > x_i^*$. We distinguish two cases: 1. If $x_e^c > x_e^*$, then it follows by applying (3), convexity of $C_e(x_e)$, and (1) the chain of inequalities $C_i'(x_i^c) = C_e'(x_e^c) > C_e'(x_e^*) = C_i'(x_i^*)+E'(x_i^*) > C_i'(x_i^*)$. This inequality implies by the convexity of $C_i(x_i)$ that $x_i^c > x_i^*$. 2. If, instead, $x_e^c \leq x_e^*$, then $x_i^c \leq x_i^*$ would imply $x^c \leq x^*$, by which we obtain the contradiction

$$0 = 2\Psi'(x^*) - C_e'(x_e^*) - C_i'(x_i^*) - E'(x_i^*) < 2\Psi'(x^*) - C_e'(x_e^*) - C_i'(x_i^*) \leq 2\Psi'(x^c) - C_e'(x_e^c) - C_i'(x_i^c) = 0,$$

where the last equality follows from the FOCs which define (x^c, x_i^c, x_e^c).

We next show $x_e^c < x_e^*$. Suppose not, then $x_e^c \geq x_e^*$ and $x_i^c > x_i^*$ imply $x^c = x_i^c + x_e^c > x_i^* + x_e^* = x^*$ so that $\Psi'(x^*) = C_e'(x_e^*) \leq C_e'(x_e^c) = \Psi'(x^c)$, which due to the concavity of Ψ can only hold if $x^* \geq x^c$, a contradiction.

To show $x^c > x^*$ note that, due to $x_e^c < x_e^*$ and the convexity of C_e, it follows $\Psi'(x^c) - \Psi'(x^*) = C_e'(x_e^c) - C_e'(x_e^*) < 0$. Hence, $\Psi'(x^c) \leq \Psi'(x^*)$. Concavity of Ψ then implies $x^c \geq x^*$.

To show $F^c < F^*$ define $p^* \equiv \Psi'(x^*) = C_i'(x_i^*) + E'(x_i^*)$. Since $\hat{x}^* > x_i^*$ and x_i^* is such that $C_i'(x_i^*) + E'(x_i^*) = p^*$, we have $C_i'(x) + E'(x) > p^*$ for all $x \in (x_i^*, \hat{x}^*)$ due to convexity.

Moreover, since $\hat{x}^* < x^*$ and x^* is such that $\Psi'(x^*) = p^*$, we have $\Psi'(x) > p^*$ for all $x \in (\hat{x}^*, x^*)$, due to the concavity of Ψ. Consequently

$$\int_{\hat{x}^*}^{x^*} [\Psi'(x) - p^*]dx + \int_{x_i^*}^{\hat{x}^*} [C_i'(x) + E'(x) - p^*]dx > 0.$$

Using this inequality it then follows

$$F^c = p^c x_e^c - C_e(x_e^c) < p^* x_e^c - C_e(x_e^c) \leq p^* x_e^* - C_e(x_e^*) = \int_0^{x_e^*} [p^* - C_e'(x)]dx \tag{9}$$

$$= p^* x_e^* - \int_0^{x_e^*} C_e'(x)dx = p^*(x^* - x_i^*) - \int_0^{x_e^*} C_e'(x)dx \tag{10}$$

$$< p^*(x^* - x_i^*) - \int_0^{x_e^*} C_e'(x)dx + \int_{\hat{x}^*}^{x^*} [\Psi'(x) - p^*]dx + \int_{x_i^*}^{\hat{x}^*} [C_i'(x) + E'(x) - p^*]dx \tag{11}$$

$$= \int_{\hat{x}^*}^{x^*} \Psi'(x)dx + \int_{x_i^*}^{\hat{x}^*} [C_i'(x) + E'(x)]dx - \int_0^{x_e^*} C_e'(x)dx \tag{12}$$

$$= \int_0^{x^*} \Psi'(x)dx - \int_0^{x_i^*} [C_i'(x) + E'(x)]dx - \int_0^{x_e^*} C_e'(x)dx - \int_0^{\hat{x}^*} \Psi'(x)dx + \int_0^{\hat{x}^*} [C_i'(x) + E'(x)]dx \tag{13}$$

$$= W^* - \hat{W}^* = F^*, \tag{14}$$

where the two inequalities in the first line follow from $p^* > p^c$ and revealed preferences, respectively. Q.E.D.

Proof of Lemma 1: By definition, the instruments (t_i, t_e, t_c) implement an allocation (x_i, x_e) with $x_e > 0$ if and only if there exist some price p^r such that (4) holds. The conditions in (4) are equivalent to the set of conditions

$$\Psi'(x_i + x_e) = p^r + t_c \tag{15}$$

$$C_i'(x_i) = p^r - t_i \tag{16}$$

$$C_e'(x_e) = p^r + t_e, \tag{17}$$

$$\Pi_e^r(x_e) = (p^r + t_e)x_e - C_e(x_e) - F \geqslant 0. \tag{18}$$

"⇒" Suppose (t_i, t_e, t_c) implements the allocation (x_i, x_e). Then there exists a p^r such that (15)- (17) holds from which it follows:

Statement (i) follows from rewriting and combining (15) and (16) as follows $t_c = \Psi'(x_i + x_e) - p^r = \Psi'(x_i + x_e) - C_i'(x_i) - t_i$ and rewriting and combining (15) and (17) as follows $t_c = \Psi'(x_i + x_e) - p^r = \Psi'(x_i + x_e) - C_e'(x_e) + t_e$.

Statement (ii) follows because entrant's profits are $\Pi_e^r = (p^r + t_e)x_e - C_e(x_e) - F = C_e'(x_e)x_e - C_e(x_e) - F \geqslant 0$, where the equality follows from (17). Non-negativity follows by (18).

Statement (iii) follows because consumer's net surplus is $\Phi^r = \Psi(x_i + x_e) - (p^r + t_c)(x_i + x_e) = \Psi(x_i + x_e) - \Psi'(x_i + x_e)(x_i + x_e)$.

Statement (iv) follows because incumbent's profits are $\Pi_i^r = (p^r - t_i)x_i - C_i(x_i) = C_i'(x_i)x_i - C_i(x_i)$, where the last equality follows from (16).

Statement (v) follows from using statement (i), since it thereby follows $B = t_c(x_i + x_e) + t_i x_i - t_e x_e = [t_c + t_i]x_i + [t_c - t_e]x_e = [\Psi'(x_i + x_e) - C_i'(x_i)]x_i + [\Psi'(x_i + x_e) - C_e'(x_e)]x_e$.

"$\Leftarrow$" Suppose (i) to (v) holds, then (18) holds by (ii). We therefore only have to show existence of a price p^r so that (15)-(17) hold. Take $p^r = \Psi'(x_i + x_e) - t_c$ so that (15) holds per construction. By (i) it then follows $p^r - t_i = \Psi'(x_i + x_e) - t_c - t_i = \Psi'(x_i + x_e) - \Psi'(x_i + x_e) + C_i'(x_i) = C_i'(x_i)$ so that also (16) holds. Moreover, by (i) it follows $p^r + t_e = \Psi'(x_i + x_e) - t_c + t_e = \Psi'(x_i + x_e) - \Psi'(x_i + x_e) + C_e'(x_e) = C_e'(x_e)$ so that also (17) holds. Q.E.D.

Proof of Proposition 3: $F^c < F^r < F^*$ follows from the proof of Proposition 2, since the right hand side of equation (9) equals F^r. Statement (i) follows directly from Lemma 1(ii). Statement (ii) follows directly from Lemma 1(i) and (ii) combined with the conditions for efficiency described in (1). Q.E.D.

Proof of Proposition 4: (i) follows directly, because of the binding constraint at the optimum.

(ii) is the first order condition of maximizing $W(x_i + x_e^{sb}, x_i, x_e^{sb})$ with respect to x_i.

To show (iii) note first that for $F > F^r$ the constraint at $x_e = x_e^*$ is violated. From this it follows $x_e^{sb} > x_e^*$, because the left hand side of the constraint is increasing in x_e, due to $C_e''(x_e)x_e + C_e'(x_e) - C_e'(x_e) = C_e''(x_e) > 0$. It follows moreover $x_i^{sb} = \tilde{x}_i(x_e^{sb}) < \tilde{x}_i(x_e^*) = x_i^*$ with $\tilde{x}_i(.)$ as defined in (7), where we showed that $\tilde{x}_i(.)$ is decreasing but by less than 1. As a result $x^{sb} = x_i^{sb} + x_e^{sb} > x_i^* + x_e^* = x^*$.

It remains to show (iv). From Proposition 4(ii) and Lemma 1 it follows $t_i^{sb} = \Psi'(x^{sb}) - C_i'(x_i^{sb}) - t_c^{sb} = E'(x_i^{sb}) - t_c^{sb}$ and $t_e^{sb} = \Psi'(x^{sb}) - C_i'(x_i^{sb}) + t_c^{sb}$. Hence, by Lemma 1, the set of instruments $(t_i^{sb}, t_e^{sb}, t_c^{sb})$ implements (x_i^{sb}, x_e^{sb}). Recall that $x_e^{sb} > x_e^*$ and $x^{sb} > x^*$ and x_e^* is such that $C_e'(x_e^*) = \Psi'(x^*)$. Convexity of C_e and concavity of Ψ then imply $C_e'(x_e^{sb}) > \Psi'(x^{sb})$ so that $t_e^{sb} > t_c^{sb}$. Q.E.D.

Proof of Proposition 5: Maximum welfare without entry equals $W(\hat{x}_i^*, \hat{x}_i^*, 0)$, whereas maximum welfare with entry equals $W(x_i^{sb} + x_e^{sb}, x_i^{sb}, x_e^{sb}) - F$. Hence, optimal regulation involves entry when $F < F^{sb}$. Since $W(x_i^{sb}+x_e^{sb},x_i^{sb},x_e^{sb}) < W(x_i^*+x_e^*,x_i^*,x_e^*)$ we have $F^{sb} = W(x_i^{sb}+x_e^{sb},x_i^{sb},x_e^{sb}) - W(\hat{x}_i^*,\hat{x}_i^*,0) = W(x_i^{sb}+x_e^{sb},x_i^{sb},x_e^{sb}) - W(x_i^*+x_e^*,x_i^*,x_e^*) + F^* < F^*$. Q.E.D.

Proof of Proposition 6: Suppose (t_i,t_e,t_c) implements the outcome (x_i,x_e) with net consumer surplus Φ, profit levels Π_e, Π_i, and a budget B. By Lemma 1 any other set of instruments (t_i',t_e',t_c') that implements (x_i,x_e) must also yield the same net consumer surplus Φ, profit levels Π_e, Π_i, and a budget B. We therefore only have to show that the specific set of instruments exist.

To see instruments exist that satisfy (i). Set $t_c' = 0$, $t_i' = \Psi'(x_i+x_e) - C_i'(x_i)$ and $t_e' = C_e'(x_e) - \Psi'(x_i+x_e)$. It then follows by Lemma 1 that also $(t_i',t_e',0)$ implements (x_i,x_e).

To see instruments exist that satisfy (ii). Set $t_e' = 0$, $t_c' = \Psi'(x_i+x_e) - C_e'(x_e)$, and $t_i' = \Psi'(x_i+x_e) - C_i'(x_i) - t_c' = C_e'(x_e) - C_i'(x_i)$. It then follows by Lemma 1 that also $(t_i',0,t_c')$ implements (x_i,x_e). Q.E.D.

Proof of Proposition 7: Since (t_i,t_e,t_c) implements (x_i,x_e), it follows by the definition of (t_i',t_e',t_c') and Lemma 1 that

$$t_i' = t_i + t_c - t_c' = \Psi'(x_i+x_e) - C_i'(x_i) - t_c' \text{ and } t_e' = t_e - t_c + t_c' = C_e'(x_e) - \Psi'(x_i+x_e) + t_c'.$$

It then follows from Lemma 1 that also (t_i',t_e',t_c') implements (x_i,x_e). It remains to show that (t_i',t_e',t_c') is feed-in budget balanced. This follows from $t_e'x_e = (t_e - t_c + t_c')x_e = (t_c'x_i/x_e + t_c')x_e = t_c'x_i + t_c'x_e = t_c'(x_i+x_e)$. Q.E.D.

References

[1] Acemoglu, D., Aghion, P., Bursztyn, L., Hemous, D., 2012. The Environment and Directed Technical Change. *The American Economic Review*, 102: 131-166.

[2] Bennear, L.S., Stavins, R.N., 2007. Second-Best Theory and the Use of Multiple Policy Instruments. *Environmental and Resource Economics*, 37: 111-129.

[3] Boomsma, T.K., Meade, N., Fleten, S-E., 2012. Renewable Energy Investments under Different Support Schemes: A Real Options Approach,. *European Journal of Operational Research*, 220: 225-237.

[4] de Jager, D., Rathmann, M., 2008. Policy Instrument Design to Reduce Financing Costs in Renewable Energy Technology Projects. Work performed by ECOFYS, Ultrecht, The Netherlands. Paris, France: International Energy Agency – Renewable Energy Technology Deployment.

[5] Deutsche Bank, 2012. Global Climate Change Policy Tracker, Continued Progress on Mandates, but the Emissions Challenge Remains. Retrieved March, 2014, <https://www.db.com/cr/de/docs/Global_Policy_Tracker_20120424.pdf>.

[6] European Commission (COM), 2008. Commission Staff Working Document, Brussels, 57, 23 January 2008.

[7] European Commission (COM), 2013. Draft Guidelines on environmental and energy aid for 2014-2020, December 2013.

[8] European Wind Energy Association 2009. The economics of wind energy. Retrieved March, 2014, <www.ewea.org>.

[9] Fischer, C., Newell, R.G., 2008. Environmental and Technology Policies for Climate Change Mitigation. *Journal of Environmental Economics and Management*, 55: 142-162.

[10] Fullerton, D., Wolverton, A., 2000. Two Generalizations of a Deposit-Refund Systems. *The American Economic Review*, 90: 238-242.

[11] Fullerton, D., Wolverton, A., 2005. The Two-Part Instrument in a Second-Best World. *Journal of Public Economics*, 89: 1961-1975.

[12] Garcia, A., Alzate J.M., Barrera J., 2012. Regulatory Design and Incentives for Renewable Energy. *Journal of Regulatory Economics*, 41: 315-336.

[13] Goulder, L.H., Parry I.W.H., 2008. Instrument Choice in Environmental Policy. *Review of Environmental Economics and Policy*, 2: 152-174.

[14] Grafton, Q., Kompas T., Van Long, N., 2012. Substitution Between Biofuels and Fossil Fuels: Is There a Green Paradox? *Journal of Environmental Economics and Management*, 64: 328-341.

[15] Helm, C., Schöttner, A., 2008. Subsidizing technological innovations in the presence of R&D spillovers. *German Economic Review* 9: 339-353.

[16] Hintermann, B., Lange, A., 2013. Learning Abatement Costs: On the Dynamics of the Optimal Regulation of Experience Goods. *Journal of Environmental Economics and Management*, 66: 625-638.

[17] International Energy Agency (IEA), 2008. Deploying Renewables: Principles for Effective Policies, ISBN 978-92-64-04220-9.

[18] Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A Tale of Two Market Failures: Technology and Environmental policy. *Ecological Economics,* 54: 164-174.

[19] Katsoulacos, Y., Xepapadeas, A., 1995. Environmental Policy under Oligopoly with Endogenous Market Structure. *Scandinavian Journal of Economics*, 97: 411-420.

[20] Lehmann P., 2013. Supplementing an Emissions Tax by a Feed-in Tariff for Renewable Electricity to Address Learning Spillovers. *Energy Policy*, 61: 635-641.

[21] Nesta, L., Vona, F., Nicolli, F., 2014. Environmental Policies, Competition and Innovation in Renewable Energy. *Journal of Environmental Economics and Management*, Forthcoming.

[22] Palmer, K., Walls, M., 1997. Optimal Policies for Solid Waste Disposal Taxes, Subsidies, and Standards. *Journal of Public Economics*, 65: 193-205.

[23] Petrakis, E., Rasmusen, E., Roy, S., 1997. The Learning Curve in a Competitive Industry. *RAND Journal of Economics,* 28: 248-268.

[24] Reichenbach, J., Requate, T., 2012. Subsidies for Renewable Energies in the Presence of Learning Effects and Market Power. *Resource and Energy Economics,* 34: 236-254.

[25] Requate, T., 1997. Green Taxes in Oligopoly if the Number of Firms is Endogenous. *Finanzarchiv,* 54: 261-280.

[26] Schneider, S.H., Goulder, L.H., 1997. Achieving Low-Cost Emissions Targets. *Nature*, 389: 13-14.

[27] Spulber, D.F., 1985. Effluent Regulation and Long-Run Optimality. *Journal of Environmental Economics and Management*, 12: 103-116.

[28] US Energy Information Administration, 2013. Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013. Retrieved March, 2014 <http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf>.

[29] Walls, M., Palmer, K., 2001. Upstream Pollution, Downstream Waste Disposal, and the Design of Comprehensive Environmental Policies. *Journal of Environmental Economics and Management*, 41: 94-1082.