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Thure Traber • Claudia Kemfert

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German Institute for Economic Research
Mohrenstr. 58
10117 Berlin
Tel. +49 (30) 897 89-0
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Refunding ETS-proceeds to Spur the Diffusion of Renewable Energies: An Analysis Based on the Dynamic Oligopolistic Electricity Market Model EMELIE

Thure Traber[1] and Claudia Kemfert

Abstract

We use a quantitative electricity market model to analyze the welfare effects of refunding a share of the emission trading proceeds to support renewable energy technologies that are subject to experience effects. We compare effects of supporting renewable energies under both perfect and oligopolistic competition with competitive fringe firms and emission trading regimes that achieve 70 and 80 percent emission reductions by 2050. The results indicate the importance of market power for renewable energy support policy. Under imperfect competition welfare improvements is maximized by refunding ten percent of the emission trading proceeds, while under perfect competition the optimal refunding share is only five percent. However, under both behavioral assumptions we find significant welfare improvements due to experience effects which are induced by the support for renewable energy.

Keywords: emission trading; renewable energy support; experience effects; imperfect competition

[1]Corresponding author, German Institute for Economic Research (DIW Berlin) , Mohrenstr. 58, D-10117 Berlin, Germany; Email: ttraber@diw.de, Tel.: +49-30-89789409, Fax: +49-30-89789113.

1 Introduction

After the liberalization of energy markets in the last decade, the electricity sector tended to suffer from at least two market failures. On the one hand market structures on the supply side are not likely to establish sufficient competition, and on the other hand, externalities particularly due to carbon dioxide emissions give rise to environmental concerns. In Europe, the environmental externalities have subsequently been adressed by the establishment of the European Emission Trading System (ETS) which applies a cap to allowed emissions and internalizes the externality through emission allowance prices.

The grandfathering of the emission allowances has, however, been rightfully critizised for its creation of large windfall profits for the industry, thus strengthening the position of incumbents in the electricity market. For instance, Sijm et al. (2006) use the model COMPETES for an assessment of the magnitude of the windfall profits and calculate a multi billion euro windfall profit for firms in Belgium, France, Germany and the Netherlands alone. Starting in 2013, however, energy firms have to fully pay for their allowances which creates a potentially huge budget for the government. Given the additional problem of market power, it is obvious to consider the use of parts of the proceeds of the emission market to improve the situation of the distorted output market. Moreover, the emission trading directive 2009/29/EC of the European Union demands that at least fifty percent of the proceeds from auctioning emission allowances have to be allocated to support low carbon technologies or energy efficiency programs.

In a situation where market power meets environmental externalities, the economic literature suggests to add an output subsidy if an emission tax is chosen or to reduce the tax to below the Pigouvian level. Ebert (1992), and Requate (1993) analyze first and second best taxes and tax/subsidy schemes for symmetric Cournot oligopolies. Simpson (1995) investigates the optimal emission tax in the presence of an asymmetric duopoly and finds that the optimal tax level might fall short of or exceed the marginal damage depending on the different costs of the duopolists. More recently, Gersbach and Requate (2004) have analyzed a tax/tax-refunding system which may establish the social optimum by linking the refund to market shares under static conditions. In addition, if investment decisions are taken into account, they show that the social optimum can be achieved if the refund is based on both market shares and investment shares.

A further problem for the optimal design of environmental policy is introduced when technological knowledge is not fixed but depends on R&D effort, learning by doing or experience effects in general. A good overview of the nature of the problem is given in Jaffe et al. (2005) who find that "in the presence of weak or nonexistent environmental policies, investments in the development and diffusion of new environmentally beneficial technologies are very likely to be less than would be socially desirable. Positive knowledge and adoption spillovers and information problems can further weaken innovation incentives." In the same vein, Parry et al. (2003) investigate, with analytical and numerical treatments, the welfare gains of keeping the optimal abatement level if innovations in abatement technologies are possible. They find that the results depend crucially on the discount rate, the optimal abatement level without innovation, and the speed at which innovations take place. More recently, Gerlagh et al. (2009) analyze the timing of policies in an optimal control framework with R&D induced technological change. They find that if the regulator has the possibility to encourage R&D, he should do so. On the contrary, if the regulator has no instrument to support R&D but only an emissions tax available, the authors suggest fixing the tax above the Pigouvian level to induce more innovations.

Unlike previous research, we focus on the impact of market power on the level of an environmentally motivated subsidy when experience effects are significant and the environmental externality is internalized by an emission market. We analyze effects of partial refunding ETS proceeds to investment in renewable energy technologies with the model EMELIE EUR-25 documented in Traber and Kemfert (2009), and simulate the welfare maximizing refunding share under conditions of both imperfect and perfect competition for two likely ETS reduction targets.

In the next section we proceed with the presentation of the algebraic formulation of the model which is followed by section 3 on model data and calibration. In section 4 we first present and discuss the effects of the refunding on welfare under both competition scenarios, and highlight impacts of the optimal refunding on consumers and producers under imperfect competition. Furthermore, section 4 studies the effects of refunding on electricity prices, prices of emission allowances, cost degression of wind as the dominant renewable energy technology, and on investment shares in the sector. Section 5 gives a conclusion.

2 The Model

We consider an electricity market consisting of companies denoted i that are linked to a specific country r, members of the set of companies in a country I^r, and maximize revenues net of costs[2]. Firms face a periodic country specific inverse demand written as $P^{r,t}(X^{r,t})$, where $X^{r,t}$ denotes the according demand.

Production takes place in existing units and in newly installed capacities of technology n. In case of existing capacities, the production of a firm, $q^{i,t}$, causes direct costs of production in each period denoted $C^{i,t}(q^{i,t})$, and costs that are related to emissions, $E^{i,t}(q^{i,t})$, and emission prices, σ^t, which are induced by the emission market. Production in new investments of technology $n \in N$, $q^{i,t,n}$, causes investment costs which are included in the levelized costs of production

[2]For a summary of indices consider the notation at the end of this section.

in new capacities $Cn^{i,t,n}(q^{i,t,n})$. Their corresponding emissions are denoted $En^{i,t,n}(q^{i,t,n})$. Production of firms in old capacities is restricted by production limits, $\overline{q}^{i,t}$, giving rise to shadow prices $\kappa^{i,t}$. Similarly, investments are restricted by available plant sites or renewable energy potentials which induce shadow prices of the resource restrictions, $\phi^{i,t,n}$, if the respective resource potentials are exhausted.

The supply $X^{i,t}$ of a firm is the sum of its regional supplies $x^{i,r,t}$ over all regions and has to be completely covered by its production in each period. The according production balance is expressed by the following equality: $q^{i,t} + \sum_{n \in N} q^{i,t,n} = X^{i,t}$. Furthermore, regional supplies directed to countries other than the home country of the producing firm, denoted $x^{i,r^*,t}$, are restricted by the export limit $\overline{x}^{r,r^*}$, where $\tau^{r,r^*,t}$ denotes the shadow price of transmission capacity in period t.

The emission market is represented by the balance between the emission cap, $\overline{E}^t$, and the sum of emissions of the electricity market, $E^t(\sigma^t)$, and of the emissions of the non-electricity emission trading sectors, $E^t_{nel}(\sigma^t)$, in each period which writes $\overline{E}^t = E^t_{el}(\sigma^t) + E^t_{nel}(\sigma^t)$.

Finally, a share d_g of the emission allowance proceeds from the electricity market, $\sigma^t E^t_{el}$, is equally distributed according to new investments in green technologies denoted $g \in G$, where $G \subset N$. Now we can write the restricted optimization problem of the firm for each period t as the following Lagrangian of the Kuhn-Tucker type:

$$
\begin{aligned}
\max_{q^{i,t},q^{i,t,n}} L^{i,t} \quad = \quad & \sum_{r \in R} P^{r,t}(X^{r,t}) x^{i,r,t} - C^{i,t}(q^{i,t}) - \sum_{n \in N} Cn^{i,t,n}(q^{i,t,n}) \\
& - \sigma^t (E^{i,t}(q^{i,t}) + \sum_{n \in N} En^{i,t,n}(q^{i,t,n})) + d_g \sigma^t E^t_{el} \frac{\sum_{g \in G} q^{i,t,g}}{\sum_{i \in I} \sum_{g \in G} q^{i,t,g}} \\
& - \kappa^{i,t}(\overline{q}^{i,t} - q^{i,t}) - \sum_{n \in N} \phi^{i,t,n}(\overline{q}^{i,t,n} - q^{i,t,n}) \\
& - \sum_{r^* \neq r} \tau^{r,r^*,t}(\overline{x}^{r,r^*} - \sum_{i \in I^r} x^{i,r^*,t}). \qquad (1)
\end{aligned}
$$

Taking the derivative of (1) with respect to production of the firms in existing units yields the according first order optimality conditions. These depend on the assumed competitive behavior. If a firm does not recognize its impact on prices and, hence, acts as a price taker, the first order condition can be expressed as:

$$
\begin{aligned}
P^{r,t}(X^{r,t}) \quad \leq \quad & C^{i,t}_q(q^{i,t}) + \sigma^t E^{i,t}_q(q^{i,t}) + \kappa^{i,t} + \tau^{r,r^*,t}, \\
& \forall i \in I, \forall r \in R, \forall t \in T. \qquad (2)
\end{aligned}
$$

Dominant firms consider their supply effect on prices implied by the price elasticity of residual demand, $\epsilon^{r,t}$, and behave á la Cournot, giving rise to a situation of imperfect competition. If we denote the market share of firm i in region r with $\vartheta^{i,r,t}$, the first order optimality condition in a Nash-equilibrium of oligopolistic suppliers can be expressed as:

$$P^{r,t}(X^{r,t})(1-\frac{\vartheta^{i,r,t}}{\epsilon^{r,t}}) \leq C_q^{i,t}(q^{i,t})+\sigma^t E_q^{i,t}(q^{i,t})+\kappa^{i,t}+\tau^{r,r^*,t}, \quad \forall i \in I, \forall r \in R, \forall t \in T. \tag{3}$$

Comparing (3) and (2) shows that the only difference is the mark-up, $\frac{\vartheta^{i,r,t}}{\epsilon^{r,t}}$, on the left hand side of the equations, which under oligopolistic competition induces prices above the costs which are summarized on the right hand side of the equations.

Since we model a period length of 20 years, - which is roughly the financial recovery period of investments in power plants - , firms do not consider the revenues from newly built capacities in the next model period. Hence, our framework simulates myopic investment behavior. Consequently, the firms do not distinguish between investments and production, since they do not have any incentive to produce less than the investment facilitates. The first order conditions with regard to investment in new capacities for a price taking firm takes the refunding into account and writes:

$$P^{r,t}(X^{r,t})+d_g\frac{\sigma^t E_{el}^t}{\sum\limits_{i\in I}\sum\limits_{g\in G}q^{i,t,g}} \leq Cn_q^{i,t,n}(q^{i,t,n})+\sigma^t En_q^{i,t,n}(q^{i,t,n})+\phi^{i,t,n} +\tau^{r,r^*,t}, \quad \forall i \in I, \forall r \in R, \forall t \in T, \forall n \in N, \tag{4}$$

where d_g is zero for conventional technologies. Since firms do not achieve significant market shares in new investments[3], the first order condition with regard to investment of oligopolists in the Nash-equilibrium differs compared to decision (4) only by the mark-up and writes:

$$P^{r,t}(X^{r,t})(1-\frac{\vartheta^{i,r,t}}{\epsilon^{r,t}})+d_g\frac{\sigma^t E_{el}^t}{\sum\limits_{i\in I}\sum\limits_{g\in G}q^{i,t,g}} \leq Cn_q^{i,t,n}(q^{i,t,n})+\sigma^t En_q^{i,t,n}(q^{i,t,n}) +\phi^{i,t,n}+\tau^{r,r^*,t}, \quad \forall i \in I, \forall r \in R, \forall t \in T, \forall n \in N. \tag{5}$$

[3]Note that significant market shares are apparent only on the national electricity market level, whereas on the European scale a comparable share in terms of new investment is very unlikely. The analysis had to be augmented by market power effects on refunding if e.g. the proceeds of emission allowance sales were collected and redistributed on the national level.

Notation

T	Set of periods
I	Set of companies
I^r	Set of companies in region r
R	Set of regions
N	Set of investment technologies
G	Set of renewable energy investment technologies, subset of N
$P^{r,t}$	Electricity price in region r and period t
δ	social discount factor
σ^t	Price of carbon emissions in period t
$X^{r,t}$	Total electricity supply in region r and period t
E_{el}^t	Total emissions of the electricity sector in period t
E_{nel}^t	Total emissions of the non-electricity ETS sector in period t
$x^{r,r^*,t}$	Export from region r to r^*
$q^{i,r,t}$	Electricity production of firm i in region r and period t in installed power plants
$q^{i,r,t,n}$	Electricity production of firm i in region r and period t in newly installed power plants of type n
$C(q^{i,t})$	Variable costs of electricity production of firm i in period t in installed power plants
$Cn(q^{i,t,n})$	Total costs of electricity production of firm i in period t for newly installed power plants of type n
$E(q^{i,t})$	Emissions of electricity production of firm i in period t in installed power plants
$E(q^{i,t,n})$	Emissions of electricity production of firm i in period t in newly installed power plants of type n
$\overline{q}^{i,t}$	Capacity restriction of installed power plants of firm i in period t
$\overline{q}^{i,t,n}$	Capacity expansion restriction of firm i in period t and technology n
$\overline{x}^{r,r^*}$	Transmission restriction from region r to r^*
$\kappa^{i,r,t}$	Shadow price of capacity restriction of installed power plants of firm i in region r and period t
$\phi^{i,t,n}$	Shadow price of capacity expansion restriction of firm i in period t and technology n
$\tau^{r,r^*,t}$	Shadow price of transmission capacity from region r to r^* in period t
$\epsilon^{r,t}$	price elasticity of demand in region r in period t
d	share of refunded emission trading proceeds

In our partial framework, welfare is defined as:

$$W(d) = \sum_{r \in R} \sum_{t \in T} \int_0^{X^{r,t}} \delta^{t-1} [P^{r,t}(X^{r,t}) dx - \sum_{i \in I} C^{i,t}(q^{i,t}) - \sum_{i \in I} \sum_{n \in N} Cn^{i,t,n}(q^{i,t,n})], \tag{6}$$

where δ denotes the social discount factor. (2) will be used for the calculation of the welfare effects of different levels of refunding shares.

In the next section we introduce the data for the numerical simulation of the model, i.e the demand projection, the costs and restrictions of the simulated technologies, and two possible emission allowance reduction pathways envisaged by the European Union's ETS.

3 Model Data and Calibration

The inverse demand function is assumed to have a linear form and writes

$$P^{r,t} = a^{r,t} - b^{r,t} X^{r,t}. \tag{7}$$

The model is calibrated via the elasticity of demand ϵ^t of the first period 2010 at the reference points $P_0^{r,t}, X_0^{r,t}$ of the regions. Their respective values are historical values of the year 2008, mainly based on EUROSTAT[4] information and own calculations. The calibration yields an elasticity of 0.5. The expected demand growth until 2030 and 2050, the second and the third model period, are represented by an increase of reference demand of ten percent per period. These values are similar to projections found in comparable assessments (Bulteel and Capros (2007)). Furthermore, the social discount rate for the intertemporal aggregation of welfare is two percent.

The dynamic supply side of the model uses existing capacities for the first model period and fuel prices as documented in Traber and Kemfert (2009) and applies a decomissioning according to life expectancy or, in case of German nuclear power plants, in line with the scheduled nuclear phase out by 2022. Furthermore, new investment is added to the capital stock of the next period if its expected lifetime significantly exceeds twenty years, i.e. in case of fossil fuelled power plants and small scale hydro power. Large existing hydro power units are assumed to be maintained throughout the model's time horizon.

In each time step, existing capacities give rise to linearly increasing marginal cost and marginal emission functions calculated with a small auxiliary program

[4] Statistical information service of the European Union.

that minimizes supply costs including emission costs subject to plant capacities and plant availabilities. For this purpose, emission allowance prices from a preliminary run of the core model are used, and marginal cost and marginal emission functions are fed back to the core model until convergence of emission allowance prices is achieved.

As mentioned earlier, the costs of production in new capacities include the investment costs levelized to kilowatt hours and are, in case of fossil fueled units based on MIT (2007), Rubin et al. (2007) and our own calculations. Table 1 shows an overview of our projection for the year 2030 and a rather optimistic technology development, which constitutes the lower cost level in the model. More pessimistic forecasts yield about twenty percent higher levelized costs that are taken as the upper cost boundary.

Table 1: Fossil fuel-fired technologies by 2030: optimistic technology scenario.

Fuel		Gas	Hard Coal		Lignite	Gas	Hard Coal		Lignite
Technology		CC	IGCC	PC	PC	CC CCS	IGCC CCS	PC CCS	PC CCS
Efficiency	%	59	50	45	43	51	43	37	35
Investment	Euro/kW	480	1250	1100	1200	880	1650	1650	1750
Capital Cost*	cent/kWh	0.76	1.97	1.74	1.89	1.39	2.60	2.60	2.76
Fuel Cost**	cent/kWh	5.4	1.8	2.0	1.0	6.2	2.1	2.4	1.3
O&M Cost	cent/kWh	0.1	0.2	0.2	0.3	0.2	0.3	0.4	0.5
Full Cost	cent/kWh	6.3	4.0	3.9	3.2	7.8	5.0	5.4	4.5
CO_2	g/kWh	336	684	760	929	78	159	185	228

*capacity factor 0.85; depreciation 20 years; interest rate 10%; overnight construction.

**fuel prices for the year 2030: natural gas 3.2 cent/kWh,
hard coal 1 cent/kWh, lignite 0.5 cent/kWh, own assumptions.

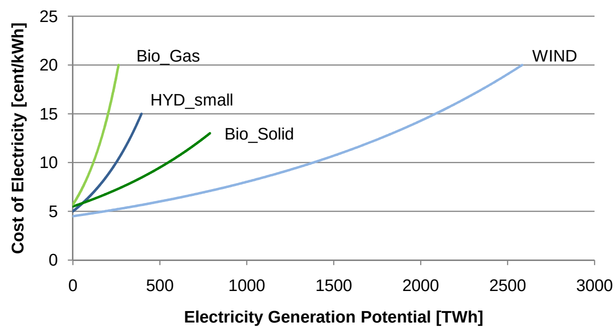
Sources: MIT (2007); Rubin et al. (2007); own calculations.

With regard to renewable energy technologies, the model utilizes data from the Green-x project[5] which reports cost estimates and national resource potentials for the twenty seven countries of the EU (Ragwitz et al. (2007)), and from the ADAM[6] project (ISI (2007)). The respective model inputs are summarized in Figure 1, which shows the wide ranges of cost estimates for the different renewable energy technologies against their aggregated European resource potentials. In addition, we apply a twenty percent market entry penalty on top

[5]http://www.green-x.at/
[6]Adaptation and Mitigation Strategies: Supporting European Climate Policy

of the estimated production cost, since market barriers are likely to prevent the entry of these locally dispersed technologies to a significant extent.

Figure 1: Long run marginal cost of renewable energies and aggregated EU potentials.



The range of marginal costs is integrated through the resource limits of the technologies: the more a resource is used the closer the costs approach the upper cost estimate. Here we differentiate between fossil fueled units and renewable resources. In case of fossil fueled units, the currently existing capacities of each fuel carrier determine the investment opportunities for each firm. In the first period firms may increase their capacities by fifty percent, and in the following periods by one hundred percent. This assumption is justified by the scarcity of sites suitable for large scale power plant projects and the expected decommissioning in the coming decades which makes way for replacement. By contrast, the potential of electricity production from renewable energy is based on regional resource potentials, and is assumed to be solely available for investment of price taking firms. The logic behind this assumption is that when companies compete for scarce renewable energy resources, oligopolistic companies have a smaller propensity to invest since they expect a mark-up on returns.

Moreover, costs of new technologies are assumed to decrease according to an experience curve as follows:

$$cn^{n,t} = cn_0^{n,t}(\sum_{t \in T} q^{n,t} + q_0^n)^{j(n)}, \tag{8}$$

where $cn_0^{n,t}$ denotes the base period costs of the first unit, and $j(n)$ the experience index which is calculated from the progress ratios PR according to the following function

$$j(n) = \log_2(PR). \tag{9}$$

We apply a PR of 0.9 which is a modest assumption when compared with estimates found in the literature (McDonald and Schrattenholzer (2002), Uyterlinde et al. (2007)).

Furthermore, we set up the market for emission allowances. On the one hand, demand for emission allowances has been broken down into two parts, i.e. the endogenuously calculated demand of the electricity sector, and the demand of the non-electricity emission trading sectors which is documented in Traber and Kemfert 2009) and assumed to be constant over the whole time horizon. On the other hand, the supply side for emissions which is determined by the European ETS policy. Currently, the cap on emissions imposed by the European ETS is at a level of 2085 MT CO_2 and will decrease linearly by 1,74 percent annually, - even if no satisfactory worldwide emission reduction policy is agreed upon according to the EU-directives 2003/87/EC and 2009/29/EC. This policy will lead to a reduction of the ETS cap of 70 percent by 2050 compared to the current level.

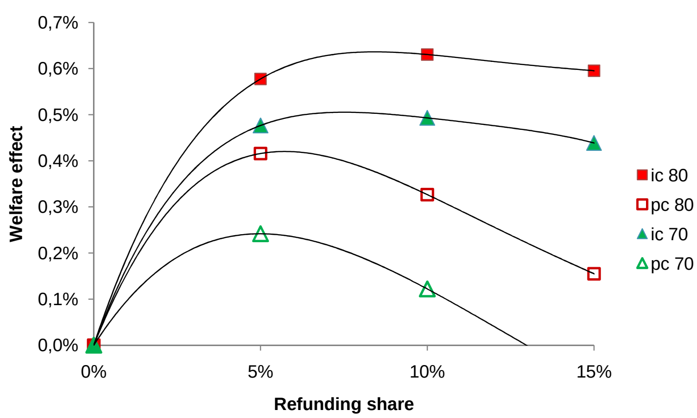
However, the European Union envisages a further tightening of the ETS target so as to establish a reduction of overall emissions of about 30 percent, translating into an ETS reduction of about 33 percent by 2020 for the case of an international agreement. Such policy yields an ETS cap reduction of 80 percent when it is linearly extrapolated into 2050. Thus, we adopt two emission reduction scenarios reaching 70 and 80 percent reductions compared to current ETS levels. However, another important derterminant of the future ETS will be the allowed use of emission reduction units (ERUs) and certified emission reductions (CERs). The new ETS directive aims to ensure that the overall use of CERs and ERUs does not exceed 50 percent of the reductions. Given comparatively low cost compared to ETS allowance prices, we assume that these 50 percent will be fully utilized. It follows that the reduction of the ETS allowances for the modelled sectors is in effect only 35 and 40 percent respectively in the 70 and 80 percent reduction scenarios.

In addition to the two emission reduction scenarios, we apply two behavioral assumptions in regard to the suppliers of electricity. Behavioral assumption pc assumes perfect competition, while assumption ic represents imperfectly competitive behavior of dominant firms and price taking behavior of small firms. Altogether, we calculate for each behavioral assumption two reduction scenarios: pc 70 and pc 80 for perfect competition, and ic 70 and ic 80 for imperfect competition.

4 Results and Discussion

Figure 2 reports the welfare effects induced by shares of refunding from zero to fifteen percent in our four scenarios. It turns out that refunding of up to ten percent of ETS proceeds improves welfare irrespective of the scenario. In particular, in scenario ic 80 a refunding share of ten percent maximizes the welfare effect, increasing welfare by 0.63 percent compared to no refunding. In comparison, under scenario ic 70, we find smaller achievable welfare gains. While the optimal refunding share is not changed by the change of emission target and remains at ten percent, the welfare gain is only 0.50 percent compared to no refunding.

Figure 2: Welfare effect of refunding shares with tight (80) and baseline (70) percent reduction targets by 2050 under perfect (pc) and imperfect competition (ic).



If perfectly competitive markets are assumed, we find lower welfare gains and lower optimal refunding. Under the tight emission target, scenario pc 80, the optimal refund of about five percents yields a maximum welfare gain of 0.42 percent, while a relaxed target induces even smaller maximal welfare gains of only 0.24 percent. Comparing the results of both behavioral assumptions shows the impact of market power on optimal refunding and on potential welfare gains. We find that market power increases both the optimal refunding and the maximal welfare gains of the instrument. Furthermore, a more restrictive emission trading policy does not change the optimal refunding but improves the associated welfare gain.

We can explain the result in regard to market power in the following way.

If no market power is present, the only motivation to spur technological change is the presence of experience effects that are not taken into account by the investors. If instead market power is exercised, the competition enhancing effect of renewable energies leads to extra rewards of technology development in the future. Hence, this finding rests on a pro competitiveness of renewable energies. This might be an innocent assumption if market power is predominantly executed through capacity withholding which might be not an option for dispersed renewable energy production. However, the development of large scale centralized renewable energy projects could make the pro competitiveness assumption questionable.

The impact of the stringency of the ETS regime on the welfare gains of refunding can be attributed to the increasing value of technological advances in low carbon technologies in an ever more restricted carbon market. This would also suggest an increase of the optimal refunding share which, however, appears to be relatively robust against the change in emission targets. The economic intuition behind this result is that higher emission prices due to tighter emission targets trigger higher diffusion of renewables and larger experience effects even in the absence of refunding. Thus, additional gains from experience are harder to reap.

Moreover, the refunding scheme has pronounced redistribution effects in intertemporal and intersectoral dimension which are featured in Figure 3. To facilitate a more detailed discussion we focus in the following on scenario ic 70, while scenario ic 80 is subsequently used for a brief sensitivity analysis.

Observing the welfare effects shown in table a) of Figure 3, one finds that welfare is reduced by half a percent in the first period, and increased by 1.2 and 0.4 percent in the second and third model period respectively by the optimal ten percent refund of ETS proceeds. Thus, a central characteristic of the instrument is its intertemporal redistribution from the present to future periods. Since the main driver of welfare improvements triggered by the instrument are experience spillovers, which only contribute to future wealth, this result is in line with economic intuition. Discounting to present value with a social discount rate of two percent, leads to the welfare impact of optimal refunding of 0.5 percent mentioned earlier, and can be seen from the last row of table a). Furthermore, the welfare effects are composed of largely differing impacts on consumers, producers and the government.

Tables b), c) and d) of Figure 3 allows us to compare these sectoral redistribution effects. First, we see that welfare gains are predominantly due to large increases in consumer surplus, i.e. 10.4, 5.2 and 3 percent in the periods 2010, 2030, 2050 respectively. Second, the gains on the consumer side are at least partially offset by losses in producer surplus and government proceeds from sales of ETS allowances. While producers lose 12.4, and 2.6 percent in the first and second period respectively, they gain by 0.5 percent from the refunding in 2050. This gain has to be explained by a pronounced emission price reduction effect of

Figure 3: Intertemporal effects of optimal refunding for scenario ic 70 and ic 80.

	ic 70			ic 80		
table a) Welfare						
Bio. €	Baseline	10% refund	rel. Change	Baseline	10% refund	rel. Change
2010	174	173	-0.5%	174	173	-0.5%
2030	158	161	1.2%	156	159	1.2%
2050	168	170	0.4%	163	165	0.7%
Present value	356.7	358.5	0.50%	353.1	355.3	0.63%
table b) Consumer surplus						
Bio. €	Baseline	10% refund	rel. Change	Baseline	10% refund	rel. Change
2010	98	108	10.4%	98	108	10.4%
2030	83	90	5.2%	82	89	5.1%
2050	85	91	3.0%	82	88	3.0%
Present value	192.4	209.4	8.8%	190.5	207.3	8.8%
table c) Producer surplus						
Bio. €	Baseline	10% refund	rel. Change	Baseline	10% refund	rel. Change
2010	43	38	-12.6%	43	38	-12.6%
2030	51	49	-2.6%	51	49	-2.5%
2050	63	64	0.5%	62	61	-0.7%
Present value	106.6	100.1	-6.1%	106.4	99.1	-6.8%
table d) ETS proceeds electricity sector						
Bio. €	Baseline	10% refund	rel. Change	Baseline	10% refund	rel. Change
2010	33	27	-16.7%	33	27	-16.7%
2030	23	22	-4.6%	22	21	-4.2%
2050	20	15	-10.8%	18	16	-5.1%
Present value	57.7	49.0	-15.1%	56.2	48.9	-13.1%
table e) ETS allowance prices						
€/t CO_2	Baseline	10% refund	rel. Change	Baseline	10% refund	rel. Change
2010	25	21	-16.2%	25	21	-16.2%
2030	32	30	-6.5%	33	31	-5.9%
2050	52	40	-21.9%	62	56	-9.9%
table f) Electricity prices						
cent/kWh	Baseline	10% refund	rel. Change	Baseline	10% refund	rel. Change
2010	5.23	4.83	-7.7%	5.23	4.83	-7.7%
2030	6.24	5.96	-4.5%	6.27	6.00	-4.4%
2050	6.48	6.25	-3.5%	6.60	6.37	-3.5%
table g) Costs first unit wind						
cent/kWh	Baseline	10% refund	rel. Change	Baseline	10% refund	rel. Change
2010	5.40	5.40	0.0%	5.40	5.40	0.0%
2030	4.99	4.37	12.5%	4.99	4.37	12.5%
2050	4.00	3.67	8.3%	3.99	3.66	8.2%

almost 22 percent in that period as documented in Table e) of Figure 3. Thirdly, the government budget from emissions trading in the electricity sector is reduced in all three periods since electricity sector emissions and, consequently, emission prices decline in all periods as can also be seen from Table d). Thus, a further property of the refunding scheme is that it redistributes rents from polluting producers and government budgets to consumers of electricity.

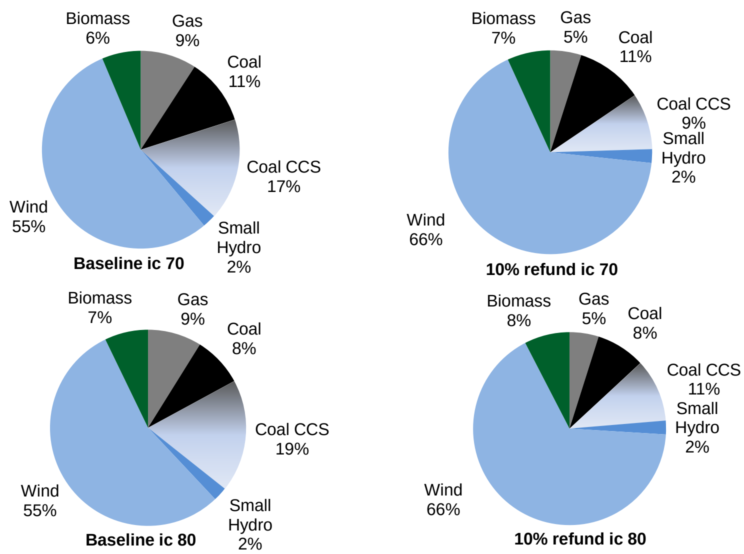
This sectoral redistribution induced by the refunding scheme should be especially important when political concerns of too high energy prices due to climate protection are brought to the fore. In fact, the first phase of the ETS saw a large allocation of free emission allowances to the polluting industry, and, simultaneously, emission price driven electricity price increases which lead to huge windfall profits that heated up the debate. By contrast, refunding of proceeds from auctioning off ETS allowances may mitigate some of the financial burden of emission reduction for the consumers at the expense of electricity suppliers. Therefore, refunding could improve the political acceptability of even deeper emission cuts beyond current targets. If we compare the consumer surplus in the baseline scenario without refunding under the less ambitious climate policy, ic 70, with the ambitious scenario ic 80 and a ten percent refunding, we find that consumers are about 7.7 percent better off in the latter case.

The reported results are mainly driven by dampening effects of the refund on the average European electricity prices, which are summarized in Table f) of Figure 3. In scenario ic 70 we find electricity prices are reduced by refunding by 7.7, 4.5, and 3.5 percent in the first, second, and third period respectively. The price effects of the refund can in turn be attributed to three sources. First, the support triggers an increase in renewable electricity which directly reduces electricity prices. Second, renewable energy partially crowds out emission intensive electricity and reduces emission prices as can be seen from table d) where we observe emission price reductions of 16.2, 6.5, and 21.9 percent in the first, second, and third period respectively. Thirdly, the increased deployment of renewable energy reduces the costs of renewables via experience effects which leads to increased renewable energy even without continuing support.

To see this, consider that the reduction of emission allowance proceeds and the increase of investments in renewable energy lead to a substantial decrease of the refund per output over the time horizon while the absolute price reduction of the instrument is relatively stable. More precisely, in scenario ic 70 the refunding of ten percent of ETS proceeds amounts to an equivalent production subsidy of 1.15, 0.32, 0.14 cent per kilo watt hour in the first second and third period respectively, while the corresponding price reductions amount to 0.40, 0.28, and 0.23 cent per kilo watt hour. This suggests that at least in the third period an important part of price reduction has to be attributed to experience effects and subsequent emission price reductions.

The experience effects are exemplified in Table g) of Figure 3 by the cost of the first unit of production of wind power, i.e. the least cost opportunity

Figure 4: Investment shares of technologies with and without refunding in scenarios ic 70 and ic 80 with (pie charts on the right of figure) and without (pie charts on the left of Figure) a ten percent refunding of ETS proceeds.



to produce renewable energy. We find that wind production costs decrease significantly from 5.4 cent per kilo watt hour to five cent per kilo watt hour by 2030 and four cent per kilo watt hour by 2050, even without support of refunding and irrespective of the emission reduction scenario. Refunding brings down the costs of wind power by an additional 12.5 percent by the second, and more than 8 percent by the last model period. Due to less pronounced investment increases, refunding leads to relatively small experience effects in other renewable energy technologies.

Figure 4 above shows the investment shares in installed production potential of new capacities over the time horizon of the model in the scenarios ic 70 and ic 80 with and without a ten percent refunding of ETS proceeds. On the one hand, we find that the investment shares are not dramatically impacted by the choice of the emission reduction scenario when we compare the upper pie charts with the lower pie charts. Only a significant shift of coal investments from conventional to CCS units occurs when we tighten the emission budget. To the contrary, the shares of wind power, the dominant investment option in all scenarios, and natural gas units are not affected by the change of the ETS emission target. On the other hand, introducing a ten percent refund of ETS proceeds to renewable energy yields more significant changes: in both reduction scenarios wind power increases its share in investments from 55 to 66 percent, biomass units gain one percent, and coal fired CCS and natural gas power plants lose eight and four percent respectively.

Hence, it turns out that the analyzed technological indifferent renewable support scheme predominantly favors investments in wind power units. In the scenario ic 80 with ten percent refund, which is most favorable for wind power, the generation share of wind power is almost forty percent by 2050. We therefore have to point out that our results are based on assuming absence of intermittency problems of wind power, i.e. a possibly reduced reliability of electricity services. Weather or not a forty percent wind power share would lead to reliability problems of current grid systems is questionable. If, however, the policy is supplemented by a strengthening of and move towards smarter electricity grids which are able to balance load between supply and demand more efficiently, this caveat might be obsolete.

Finally, we compare our simulations for the scenarios ic 70 and ic 80 is documented in Figure 3 and Figure 4 in regard to the sensitivity of the model. It turns out that the results are qualitatively almost unchanged and quantitatively comparable, in particular if we consider the relative changes induced by refunding. In fact, the relative induced changes of the refund are almost the same for the consumer surplus, electricity prices, and the cost degression of wind power. This shows t relative robustness of the applied model. Only the effect of refunding on producer surplus in the third model period is, opposed to scenario ic 70, negative in scenario ic 80, which can be explained by a less pronounced relative reduction of emission allowance prices, i.e. ten percent emission price reduction by 2050 against twenty two percent in scenario ic 70.

5 Conclusion

Developing the electricity market model EMELIE EUR 25 to a dynamic model with investment, we analyzed welfare effects of refunding ETS proceeds to support the diffusion and development of renewable energies. We find that under fairly modest assumptions in regard to experience effects, refunding might improve welfare. Particularly, under conditions of imperfect competition, potential welfare gains are significant. Under both a 70 and 80 percent reduction of the ETS cap the optimal refund is about ten percent of proceeds from ETS allowance sales, leading to welfare gains of 0.50 and 0.62 percent respectively. Under perfect competition the optimal refunding and its welfare effects are less pronounced. However, when tight targets on the emission market are imposed, refunding can improve welfare by 0.42 percent. Hence, our study shows that investments in the development of renewables may have a particularly high reward if market power is a problem.

Furthermore, we find that the welfare improvements induced by the optimal refunding favor consumers at the expense of producers. While consumers benefit over the whole time horizon, the loss in producer rent and government proceeds from selling allowances is more than compensated by the consumer gain in the first period. At a social discount rate of two percent, however, these welfare losses in the first period are more than offset by future gains.

Our results rest on the assumption that no other policies are in place and that there are no available policies which spur technological learning more cost effectively. An obvious candidate would be, for instance, the promotion of R&D. However, support to R&D is hard to channel to specific areas that are essential for cost reductions in the renewable energy industry. Furthermore, the countries of the European Union already apply policies to support renewable energies. It is therefore a task for future research to analyze wheather existing instruments should be either substituted or improved by a refunding scheme, since it has the important feature of providing support in dependence of the emission targets. Therefore, it reshapes the problematic interaction of instruments.

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