Discussion Paper No. 13-066

Ups and Downs. How Economic Growth Affects Policy Interactions.

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Non-technical summary

Emissions trading is key to climate policy in an increasing number of countries. Besides the emission trading system of the European Union (EU ETS), several similar systems in China, California, Australia, and South Korea are planned or are already operating. In reality, emission trading is often supplemented with an additional quota for renewables in energy production. The European Union is one example of such a combined policy regime aiming for a 20% reduction in greenhouse gas emissions and a 20% share of renewables in energy production by 2020. This policy regime has to operate currently under an ex-ante unforeseen economic crisis. An obvious consequence was the collapse of the carbon price. However, this price collapse may have been amplified by the interaction of the emission cap and the renewables quota. The static interaction between climate and renewable policies has been discussed extensively. This paper extends this debate by analysing the interactions between an emissions trading scheme and a renewable quota subject to differeces in economic growth rates.

Making use of a simple partial equilibrium model, we ask how differences in medium to long-run growth rates affect the efficiency and effectiveness of such a policy portfolio. We model a power sector that has two abatement options. One is a relatively cheap fuel switch from coal to gas. The other, which is more expensive, is a replacement of carbon emitting power generation capacities with non-emitting renewables. If economic growth is low, then emissions are low, and the fuel switch is sufficient to stay below the cap of the ETS. However, if the ETS is combined with a minimum renewable share target, abatement efforts are forced towards the more expensive use of renewables. Put differently, the minimum renewable share target becomes particularly binding if economic growth is low. Furthermore, prices for emission allowances become more sensitive to changes in electricity demand if the ETS is combined with a quota for renewables. Reversely, if economic growth is high, then electricity demand is also high, and the minimum renewable share target becomes less binding, as energy production by renewables becomes more and more necessary to stay below the emissions cap. If economic growth is very high the renewable share target may also become completely ineffective, as the emissions cap is sufficient to force the necessary switch to renewables.

Two main lessons can be derived from this analysis: First, prices for emission allowances become more sensitive to changes in electricity demand if the ETS is combined with an instrument that aims for a minimum renewable share. If policy makers value a clear and stable carbon price signal as crucial for encouraging investments in low-carbon technologies the combination of the two policy targets may have unintended negative consequences. Second and following from our first lesson, we show that while the carbon price is always lower if an ETS is combined with a renewable quota, this gap is particularly pronounced if economic growth is low. This leads to additional excess costs during situations when funds are particularly scarce and opportunity costs of climate policies are particularly high.

Das Wichtigste in Kürze

Der Handel von Emissionsrechten ist ein Schlüsselinstrument der Klimapolitik in einer zunehmenden Zahl von Ländern. Neben dem Emissionshandelssystem der Europäischen Union (EU EHS) sind ähnliche Systeme in China, Kalifornien, Australien und Südkorea in Betrieb oder im Aufbau. Oftmals werden zudem neben Emissionsobergrenzen zusätzlich Quoten für den Anteil erneuerbarer Energie in der Energieproduktion gesetzt, so wie es auch in der Europäischen Union der Fall ist. Dieses beiden Politiken müßen auch unter nicht vorhergesehenen Umständen wie der gegenwärtigen Wirtschaftskrise in Europa funktionieren. Der aktuelle Preiszerfall im Europäischen Emissionshandelssystem ist nicht nur eine Folge dieser Krise. Auch Überlagerungseffekte mit anderen Politikzielen wie der Quote für erneuerbare Energien spielen eine Rolle.

Der vorliegende Beitrag untersucht diese Interaktion: Mit Hilfe eines partiellen Gleichgewichtmodells werden die Wechselwirkungen zwischen Emissionshandel und Erneuerbarenquote hinsichtlich ihrer Sensitivität gegenüber unterschiedlichen Wirtschaftswachstumsraten untersucht. Das Modell bildet einen Elektrizitätssektor ab, dem zwei Optionen zur CO_2-Vermeidung offen stehen. Zum einen können die Versorgungsunternehmen einen relativ günstigen Brennstoffwechsel von Kohle zu Gas durchführen. Zum anderen können sie von CO_2 ausstoßenden Kraftwerken auf kostenintensive - jedoch emissionsfreie - erneuerbare Energien umsteigen. Falls das Wachstum und somit der CO_2-Ausstoß hinreichend niedrig ist, ist der Brennstoffwechsel ausreichend um die Emissionsobergrenzen einzuhalten. Wird der Emissionshandel jedoch mit einer Mindestquote für Erneuerbare kombiniert, so werden die Unternehmen gezwungen die teurere Vermeidungsoption nutzen. Anders ausgedrückt entfalten die Überlagerungseffekte ihre Wirksamkeit besonders in Phasen niedrigen Wirtschaftswachstums. Des Weiteren führt der Überlagerungseffekt zu einer erhöhten Sensitivität des CO_2-Preises gegenüber Elektrizitätsnachfrageveränderungen. Falls das Wirtschaftswachstum und somit der CO_2-Ausstoß hinreichend groß ist, wird die Quote für die Nutzung von erneuerbarer Energie redundant, da die Emissionsobergrenze ohnehin nur mit Hilfe eines Wechsels hin zu erneuerbaren Energien eingehalten werden kann.

Zwei wesentliche Lektionen lassen sich aus dieser Analyse ableiten: Zum einen führt die Kombination von Emissionsobergrenze und Erneuerbarenquote zu einem gegenüber wirtschaftlichen Schwankungen sensibleren CO_2-Preis. Falls Entscheidungsträger einen stabilen Preis für CO_2-Zertifikate favorisieren, um z.B. Investitionen in kohlenstoffarme Technologien anzuregen, kann eine Kombination aus den beiden Politikzielen unbeabsichtigte negative Konsequenzen mit sich bringen. Zum anderen zeigt sich, dass eine Kombination aus Emissionsobergrenze und Erneuerbarenquote vor allem dann zu einem niedrigen CO_2-Preis führt, wenn das Wirtschaftswachstum niedrig ist. Das führt zu Zusatzkosten insbesondere dann, wenn finanzielle Mittel knapp und die Opportunitätskosten von Klimapolitik hoch sind.

Ups and Downs. How Economic Growth Affects Policy Interactions.

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Abstract

Current climate and energy policy has to operate under an ex-ante unforeseen economic crisis. An obvious consequence is the collapse of prices for carbon emission allowances as, for example, seen in the European Union. However, this price collapse may be amplified by the interaction of a carbon emission cap and supplementary policy targets such as the minimum shares for renewables in the power sector. The static interaction between climate and renewable policies has been discussed extensively. This paper extends this debate by analysing how uncertain differences in medium to long-run growth rates affect the efficiency and effectiveness of a policy portfolio containing an emission trading scheme and a target for a minimum renewable share. Making use of a simple partial equilibrium model we identify an asymmetric interaction of emissions trading and renewable quotas with respect to different growth rates of an economy. The results imply that unintended consequences of the policy interaction may be particularly severe and costly when economic growth is low and that carbon prices are more sensitive to changes in economic growth if they are applied in combination with renewable energy targets. Our main example for the policy interaction is the EU, yet our research also relates particularly well to the uncertainty of economic growth in fast growing emerging economies like China.

Keywords: EU climate policy; Growth uncertainty; Overlapping regulation

JEL-Classification Q43; Q48; Q58

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1 Introduction

Emissions trading is key to climate policy in an increasing number of countries. The primary example is the European Union's Emission Trading System (EU ETS). Launched in 2005, it was the first large carbon emission trading scheme in the world. Thus, it is also an unprecedented grand scale policy experiment that provides lessons to learn for the design of subsequent emission trading systems in other countries and regions as well as about the policy environment they have to operate in. A first major assessment and adjustment of EU's climate policy targets for 2020 - based on the three main pillars of a 20% reduction in greenhouse gas (GHG) emissions, a 20% share of renewables in EU energy production, and a 20% reduction in energy consumption - has been initiated by the European Commission (2013) with the publication of the Green Paper on the EU 2030 climate and energy policy. Herein the Commission asks which targets for 2030 would be most effective and whether there have been "inconsistencies in the current 2020 targets" but also states that the 2030 framework shall reflect "the consequences of the on-going economic crisis" (p. 2).

Both issues have been discussed in the literature. Several studies show that economic growth and CO_2 emissions are procyclical, i.e., there is a positive relationship between economic growth and the level of emissions (cf. Narayan et al., 2011, Heutel, 2012, Doda 2012). Hence, climate policy instruments, which constrain emissions in different ways, respond differently to fluctuations in economic growth. On the one hand, Fischer and Springborn (2011) as well as Heutel (2012) show how emissions intensity targets and emissions trading allow for more flexibility in meeting climate policy goals over the business cycle compared to a tax and help to stabilise the economy. But on the other hand, the low carbon prices during an economic downturn may reduce low carbon investments and the dynamic efficiency of the ETS. Regardless of the drawn conclusion, it is clear that the sensitivity to changes in economic growth on the performance of climate policy instruments cannot be ignored in a comprehensive policy assessment.

The question on the interaction of climate and renewable policy targets has also been discussed by economists before. Böhringer and Rosendahl (2010) show that adding a target for a minimum renewable share to an existing ETS in the power sector unintentionally promotes production by the dirtiest technology. The additional renewables reduce the abatement pressure on the carbon-emitting technologies and cause a reduction in the price of emission allowances. This benefits in particular the most emission-intensive producers.

So far, the two issues have been discussed in isolation of each other. It is the aim of this paper to combine the insights from the literature on the interaction of climate and renewable policy targets with those from the literature on the sensitivity of single climate policy instruments to economic growth. Regarding the latter we focus on uncertain differences in economic growth over the medium to long term instead of short-run fluctuations over the business cycle. This choice reflects the general policy question of how to set caps for emissions trading and targets for renewables for commitment periods that reach out far in the future like todays discussion about the EU's 2030 climate policy targets.

We ask how differences in medium to long-run growth rates affect the efficiency and effectiveness of a simple climate and energy policy portfolio. We focus on the interaction of a cap and trade scheme with a target for a minimum renewable share as implemented in the EU. Our research is guided by the intuition that climate policy instruments may interact asymmetrically depending realised growth rate of an economy and the respective demand for electricity.

We model a power sector that has two abatement options. One is a relatively cheap fuel switch from coal to gas. The other, which is more expensive, is a replacement of carbon emitting power generation capacities with non-emitting renewables. For the European case, this assumption is quite reasonable, as it is in line with projections for future electricity generation costs calculated by the European Commission (European Commission, 2009b).[1] If economic growth is low, then emissions are low, and fuel switch is sufficient to stay below the cap of the ETS. However, if the ETS is combined with a minimum renewable share target, abatement efforts are forced towards the more expensive use of renewables. Put differently, the minimum renewable share target becomes particularly binding if economic growth is low. As a side effect, comparatively more energy will be produced with the dirtiest technology when emissions trading and a renewable share target coexist, compared to a single emissions trading scheme.

Reversely, if economic growth is high, then electricity demand is also high, and the minimum renewable share target becomes less binding, as energy production by renewables becomes more and more necessary to stay below the emissions cap. If economic growth is very high the renewable share target may also become completely ineffective, as the emissions cap is sufficient to force the switch to renewables.

This asymmetric interaction of emissions trading and minimum renewable share targets bears important policy lessons. Most prominently, it implies that the unintended consequences of the policy mix, i.e., more renewables energy production foster also more energy production by the dirtiest policy, may be particularly strong and thus costly if economic growth is low.

Our main example for the policy interaction is the EU, yet our research also relates particularly well to the uncertainty of economic growth in fast growing emerging economies like China. Divergences from projected growth rates are likely to be particularly strong in fast growing countries. Hence, the interactions of emissions trading with a minimum renewable share targets should also be considered very carefully in fast growing countries like China.

In the following, we first discuss the existing literature on interactions of climate

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[1] The options for abatement in the electricity sector and the related costs are discussed in detail in the literature on marginal abatement cost curves (cf. Delarue et al. 2010): Abatement costs are multi dimensional functions that depend on several factors, such as fuel price ratios, installed capacities, load, and specific investment costs. For the sake of simplicity we refer to a scenario with two abatement options that differ in the associated costs.

policy instruments and climate policy instrument behaviour. Second, we set up a simple partial equilibrium model for analysing the interaction of emissions trading and a minimum renewable share targets in more detail. Third, we calibrate our model to the EU in 2030. Thereby we illustrate the economic consequences of the interaction between emissions trading and renewable share targets for the reference, low and high economic growth projections of the EU's Roadmap for moving to a competitive low carbon economy in 2050 (European Commission, 2011) and aim to contribute to the assessment of the EUs 2030 climate policy targets. Fourth, we discuss the interaction of emissions trading and renewable share targets more broadly. We focus on both, results of the model and calibration that are expected to generalise, and additional aspects, which policy makers should take into account when deciding on a climate and energy policy mix. We conclude with the main policy lessons and a short outlook to future research.

2 Lessons from the Literature

In practice, the goal to mitigate climate change is one of many policy goals. Governments want to reduce air pollution, take energy security issues into consideration, want to create jobs and secure international competitiveness. Going back to Tinbergen (1952), we know that several policy targets need a similar number of instruments. Manifold goal-setting, as it is the case in the EU's climate and energy policy, necessitates therefore the implementation of several regulatory instruments.

Apart from additional policy goals, the occurrence of market failures additional to the climate externality justifies the implementation of multiple climate and energy policy instruments (Bennear and Stavins, 2007). For example, market failures - caused by a lack of credible information or myopic behaviour - may distort incentives to invest sufficiently into energy efficiency measures. Other market failures may arise due to the non-consideration of spillovers from accumulated knowledge and learning by doing on the benefits from new innovations in the energy sector. All this reasons may justify additional policy instruments.

Following this argument, a considerable amount of literature evolved, that is engaged with the optimal choice and composition of climate and R&D policy portfolios.[2] Recent studies indicate that a combination of policies to cut emissions and research and development subsidies is necessary in order to mitigate climate change at least cost. Fischer and Newell (2008), Otto et al. (2008) and Acemoglu et al. (2012) show how technology externalities and path dependencies in technology choice justify this combination of subsidies and carbon emission regulation.

In contrast, Böhringer and Rosendahl (2010), Böhringer et al. (2008), Böhringer et al. (2009), Fankhauser et al. (2010) and Boeters and Koorneef (2011) show that overlapping regulation may have adverse effects on efficiency and effectiveness of policy portfolios. Böhringer and Rosendahl (2010) investigate the interference between

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[2] For a comprehensive overview see Goulder and Parry (2008) and Goulder (2013).

emission and renewable quotas. They demonstrate that overlapping regulation leads to distortions since renewable quotas lower the price for emissions in a cap and trade system and thus promote dirty production technologies. These distortions can cause significant costs: Boeters and Koorneef (2011) show that the renewable share target creates excess costs of up to 33% depending on the availability of low cost technologies and the stringency of the renewable share target. Using a computable general equilibrium model to analyze EU climate policy framework for 2020 Böhringer et al. (2009) demonstrates that implementing several instruments for reaching the emissions goal leads to higher costs. Only in the presence of market distortions, caused, for example, by market power or inefficient taxation, overlapping regulation can be justifiable if it reduces the respective distortions.

Fankhauser et al. (2010) support this finding, by reviewing theoretical implications for the carbon price due to combinations of emissions trading with other policy instruments. Additional policies promoting renewables undermine the carbon price and are likely increase costs without reducing emissions. Also unilateral initiatives to cut emissions in countries that are under regulation of a superior international emissions trading scheme have detrimental consequences. Based on theoretical and numerical analysis Böhringer et al. (2008) show for the case of the EU ETS that additional national carbon taxation is environmentally ineffective and increases overall costs associated with emission reduction.

A second, very recent, strand of literature is concerned with the policy choice to mitigate climate change when economic shocks or business cycle fluctuations occur. Fischer and Springborn (2011) and Heutel (2012) employ dynamic stochastic general equilibrium models to shed light on the mutual relationship between climate policy and business cycles.

Fischer and Springborn (2011) analyse the cost-effectiveness a carbon tax, emissions trading, and an intensity target when unexpected shocks to productivity occur. The intensity target performs best in terms of cost-effectiveness while the emissions trading scheme leads to the lowest volatility in output. A carbon tax increases volatility.

In contrast to Fischer and Springborn (2011) Heutel (2012) does not consider the effects of static policies subject to economic shocks. Instead he analyses the optimal dynamic, i.e. endogenous, climate policy. By way of preliminary empirical analysis he shows that carbon dioxide emissions evolve pro-cyclically. According to the results of his theoretical model, optimal endogenous climate policy accounts for this characteristic by allowing emissions to increase when economic conditions prosper and decrease when recessions occur. Yet, optimal design of climate policy dampens the pro-cyclicality of emissions in comparison to the scenario without policy intervention.

Summing up the above discussion of the literature three lessons emerge. First, given multiple market failures the optimal policy portfolio contains policies that separately address each market failure. Second, if more than one policy instrument is used to achieve climate and energy policy goals there is a danger that policy instruments overlap, i.e., policies try, at least partly, to achieve the same goal. This overlap makes some individual policies ineffective and the overall portfolio less efficient. Third, climate policy instruments are responsive to fluctuations in economic activity. This relationship just recently caught attention by economists and surely deserves more study.

So far, to our best knowledge, there is no literature that investigates the response of climate and energy policy portfolios to fluctuations in economic activity. We shed first light onto this relationship focusing on differences in medium to long-run growth rates rather than on short term fluctuations. In the following we present a model guiding the readers enlightenment.

3 A Model of Climate and Energy Policy Interaction

The model describes in a highly stylized fashion the European electricity sector. Electricity generation is the single largest CO_2 emitting sector and responsible for more than a third of Europe's CO_2 emissions. Our aim is to analyse the interaction of an ETS with a target for a minimum renewable share regarding uncertain economic growth rates. The model focuses on the interaction of policies if the future state of the economy differs from the expected baseline case.

In our analysis we neglect the rationales behind the policies. In the long run renewable policies may spur innovation, cause additional cost reductions through learning effects or might help overcoming technological lock-in effects. Turning the argument on its head says that the economic costs of those market failures has to be at least as large as the excess cost from an additional renewable energy portfolio standard overlapping with an emission trading scheme in order to justify such a regime.

3.1 Model Characteristics

The model distinguishes between three different technologies that generate electricity. The produced electricity from each source is a homogeneous good and we assume perfect competition and market clearance in the electricity market. We call the three different technologies coal, natural gas, and renewables. They are denoted c, g, and r and differ in their production costs as well as carbon emission intensity.

It is assumed that aggregated production costs per technology are quadratic in output $C_i(q_i) = c_{i1}q_i + c_{i2}q_i^2/2$ for $i \in \{c, g, r\}$ and hence marginal costs are linearly increasing in output. q_i denotes the quantities produced with the respective technology and the cost parameter c_{1i} and c_{2i} differ by technology. Since we neglect specific fixed costs our marginal costs represent rather levelized costs, the average costs at which electricity is generated from a specific source over the lifetime of the project. For a specific technology the low cost locations are occupied first and an increase in generation capacity is accompanied with production at higher cost locations. In general, a reasonable assumption is then that $c_{2c} < c_{2g} < c_{2r}$. Apart from costs, electricity generation technologies also differ in their carbon emission intensity μ_i with $\mu_c > \mu_g > \mu_r = 0$. To simplify notation,

Q denotes total electricity generation $Q = \sum_i q_i$.

Electricity demand is assumed to be linear around the examined area. Inverse demand is described by $p(a) = a - Q$, where $p(a)$ is the price of electricity. We assume that a higher GDP, caused by higher economic growth rates in the past, is related to a higher demand for electricity at a certain price. This is reflected in an outward shift of the demand curve. Thus, the higher electricity demand caused by higher economic activity, the greater a. Therefore, total demand and supply in equilibrium depends on a, so we write $Q(a)$.

Hereafter, we examine three different policy regimes: (i, Single Emissions Cap) a regime where carbon emissions are capped and abatement efforts are guided by an emissions trading scheme, (ii, Single Renewable Share) a regime in which a requirement is set that a specific percentage of electricity generation be from renewable sources, and (iii, Joint Emissions Cap and Renewable Share) a regime where both policies are implemented jointly. The analysis is conducted in two steps: First, we derive analytically the necessary first order conditions that describe an equilibrium solution and discuss their characteristics. Second, we calibrate the model to a projection of the European electricity market in 2030. This enables us to roughly quantify the order of magnitudes of the examined effects from overlapping policies.

Baseline: No Policy. Our point of departure is the case without any policy target. This marks our baseline and reference point for the subsequent policy analysis. The model is based on the principle of profit maximisation in the electricity sector. Profits in the electricity sector in the absence of any policy intervention are described by

$$\Pi = p(a)Q(a) - \sum_i C_i(q_i(a)). \tag{1}$$

The representative price-taking firm maximises profits with respect to output from each technology yielding the following first order conditions:

$$p(a) = c_{1i} + c_{2i} q_i(a), \qquad \forall i \in \{c, g, r\}, \tag{2}$$

i.e. each technology is supplied until its increasing marginal costs are equal to the market price. Since $c_c < c_g < c_r$, in the baseline equilibrium $q_c > q_g > q_r$. It is straight forward to show that equilibrium quantities $q_i(a)$ depend linearly on the value of a, the parameter that proxies the overall level of economic activity.

Single Emissions Cap. Now, let us assume that the regulator limits the total amount of CO_2 the electricity sector is allowed to emit to $\bar{E}$. We allow for emissions trading. The cap puts a price tag on carbon emissions generated by fossil fuel technologies and the only CO_2 abatement opportunities depend on fuel switching. We abstract from intra-technology abatement measures such as an increasing efficiency of the respective technology. Thus, each unit generated with gas and coal emits CO_2 in relation to its fixed emission intensity μ_i. Hence, the following policy condition has to hold:

$\bar{E} \geq \mu_c q_c(a) + \mu_g q_g(a)$. Let us assume that the policy is binding in equilibrium and emission prices are positive. The market equilibrium can then be characterized by

$$\max_{q_i} \Pi = p(a)Q(a) - \sum_i C_i(q_i(a)) + \lambda_1(\bar{E} - \mu_C q_C(a) - \mu_g q_g(a)), \tag{3}$$

where λ_1, the shadow price of the emission reduction condition, can be interpreted as the price of one unit of carbon regulated in an emission market such as the EU ETS. An interior market equilibrium has to fulfil the following first order conditions:

$$\begin{aligned} p(a) &= c_{1i} + c_{2j} q_j(a) + \lambda_1 \mu_j && \forall j \in \{c, g\}, && (4) \\ p(a) &= c_{1r} + c_{2r} q_r(a), && && (5) \\ \bar{E} &= \mu_c q_c(a) + \mu_g q_g(a), && && (6) \end{aligned}$$

where j refers to the set of non-renewable technologies. The binding cap $\bar{E}$ on CO_2 emissions increases the costs of gas- and coal-fired technologies and reduces generated quantities for a given electricity price relative to the baseline. Coal-fired generation, which has the largest CO_2 intensity, is confronted with the largest additional costs per unit of production causing the largest reduction in output. In contrast, renewables become relatively cheaper and increase their share in the total electricity mix. However, the stringency of the policy depends crucially on the economic activity. If $\bar{E}$ is close to the emissions realised under a low a, the emission constraint is less stringent. This is reflected in a low shadow price for CO_2 that causes only limited changes in the composition of the electricity sector. However, if a is large, the fixed emission constraint gets particularly stringent. The high CO_2 price then leads to a higher reduction of coal and less enlargement of renewable equilibrium quantities.

Single Renewable Share. Next, we turn our attention to the case where the regulator sets only a minimum share $\bar{R}$ of renewables in the total quantity of generated electricity. Such targets related to minimum percentages can be achieved with renewable portfolio standards or “green certificate” schemes. $q_r = \bar{R}Q$ denotes the restriction on the technology use. Accordingly, the market equilibrium can be described by the following optimisation problem:

$$\max_{q_i} \Pi = p(a)Q(a) - \sum_i C_i(q_i(a)) + \lambda_2(q_r(a) - \bar{R}Q(a)). \tag{7}$$

λ_2 describes the shadow price for the use of non-renewables and can also be interpreted as price for green certificates that are traded in the framework of renewable portfolio standards. The first order conditions of the problem are

$$
\begin{aligned}
p(a) &= c_j q_j(a) + \lambda_2 \bar{R} && \forall j \in \{c, g\}, && (8)\\
p(a) &= c_r q_r(a) - \lambda_2 (1 - \bar{R}), && && (9)\\
q_r(a) &= \bar{R} Q(a), && && (10)
\end{aligned}
$$

where j refers to the set of non-renewable technologies. Since both non-renewable technologies have to cope with the same additional costs, their share decreases by the same amount on the extent of the fostered renewables.

Joint Emissions Cap and Renewable Share Last, we derive the equilibrium describing the situation, in which both policies are implemented simultaneously. Here we impose both restrictions on the use of renewables and the discharged emissions as defined above. Note that now the overlap of policies may cause cases where one of the two policies is not binding. Thus, we characterize the market equilibrium as a Karush-Kuhn-Tucker problem:

$$\max_{q_i} \Pi = p(a)Q(a) - \sum_i C_i(q_i(a)) + \lambda_1(\bar{E} - \mu_c q_c(a) - \mu_g q_g(a)) + \lambda_2(q_r(a) - \bar{R}Q(a)). \quad (11)$$

First order conditions and complementary slackness are described by

$$
\begin{aligned}
p(a) &= c_j q_j(a) + \lambda_1 \mu_j + \lambda_2 \bar{R} && \forall j \in \{c, g\}, && (12)\\
p(a) &= c_r q_r(a) - \lambda_2 (1 - \bar{R}), && && (13)\\
0 &= \lambda_1(\bar{E} - \mu_c q_c(a) - \mu_g q_g(a)), && && (14)\\
0 &= \lambda_2(q_r(a) - \bar{R}Q(a)). && && (15)
\end{aligned}
$$

Note that the corner solutions, where one policy makes the other obsolete, are equivalent to the cases presented above. For situations, when the demand for electricity is sufficiently high, the renewable quota is obsolete: The emissions cap can only be achieved with a share of renewables higher than the renewable quota. For situations, when the demand for electricity is sufficiently low, the emissions cap is not binding, but the renewable quota definitely is.

3.2 Calibration to the European electricity sector

We aim to make use of the insights generated by our model and shed light onto the efficiency and effectiveness of the proposed EU's climate and energy strategy for post-2020. Thus, we apply the theoretical model discussed above to a stylised calibrated representation of the electricity sector in the EU and analyse the interaction of a policy portfolio that combines an emission reduction target with a minimum renewable share target under different states of economic activity.

Since we aim to discuss the consequences of political decisions on targets done today on future states of the European electricity market when growth paths are uncertain, we

P_0	Price of electricity (EUR/MWh)	95	EC (2009)
c_{2c}	Slope supply curve coal (EUR/MWh^2)	5.024×10^{-9}	EC (2009)
c_{2g}	Slope supply curve gas (EUR/MWh^2)	7.370×10^{-9}	EC (2009)
c_{2r}	Slope supply curve renewables (EUR/MWh^2)	8.840×10^{-9}	EC (2009)
μ_c	CO_2 intensity coal-fired (tCO_2/MWh)	0.915	IEA (2012)
μ_g	CO_2 intensity gas-fired (tCO_2/MWh)	0.391	IEA (2012)

The values are either calibrated to the Reference scenario values of 2030 in “EU energy trends to 2030” (European Commission, 2009b) or taken from “CO_2 Emissions from Fuel Combustion Statistics” (IEA, 2012).

Table 1: Parameter values used for calibration.

calibrate our model to the year 2030. Reasonable policy targets are derived from EU’s long-term aspirational targets outlined in the “Roadmap for Moving to a Competitive Low Carbon Economy in 2050” (European Commission, 2011). To be roughly consistent with the pathway outlined in this Roadmap, we assume an emission reduction of 40 per cent and an envisaged share of Renewables in the electricity sector of 40 per cent.

The model is calibrated to 2030 in a constructed no policy scenario based on on the Reference scenario of the “EU energy trends for 2030” (European Commission, 2009b). The Reference scenario reflects the current economic downturn. Medium and long term growth projections follow the baseline scenario of the 2009 Aging Report (European Commission, 2009a), which assumes between 2020 and 2030 annual GDP growth rates of 1.7 per cent. The cost function is calibrated such that $c_{1i} = P_0$. The slope of the supply curve c_{2i} is derived by comparing quantities and prices in the Reference scenario with the Baseline 2009 scenario, similar to Fischer and Newell (2008). CO_2 intensity coefficients are taken from IEA (2012). Table 1 summarizes the calibrated parameters. We focus in our numerical analysis on the three technologies specified above. In order to be consistent with total generated and demanded quantities we include nuclear and hydro generation but fix their quantities on the 2030 level in the Reference scenario arguing that those technologies have much longer planning horizons and are rather insensitive to the discussed mid-term policy targets and changes in GDP growth rates.

In the following, we run the above outlined four different scenarios (baseline, single carbon policy, single renewable policy, and a scenario where the two targets are jointly in placed) with our calibrated model.

4 Results

Table 2 shows the prices and generated quantities in 2030 under the different policy regimes if economic growth follows the reference scenario growth assumptions. A single emissions cap (Single Cap) leads to a price of 10 EUR/tCO_2 for a carbon emission allowance and affect coal generation the most where generation reduces by 42 per cent relative to the baseline case without policy. Gas-fired generations is slightly increasing, whereas renewables increase their production by 76 per cent leading to a total share

		Baseline	Single Cap	Single RES	Joint
P^C	Price CO_2 (EUR/tCO_2)		10.0		8.14
P^R	Price RES-E (EUR/MWh)			7.74	2.02
q_c	Coal Generation (MWh)	1.35×10^9	5.77×10^8	9.66×10^8	6.21×10^8
q_g	Gas Generation (MWh)	9.24×10^8	1.11×10^9	6.58×10^8	1.01×10^9
q_r	RES-E Generation (MWh)	7.70×10^8	1.36×10^9	1.42×10^9	1.42×10^9
q_b	Base Generation (MWh)	1.02×10^9	1.02×10^9	1.02×10^9	1.02×10^9

Table 2: Prices and generation levels under the different scenarios.

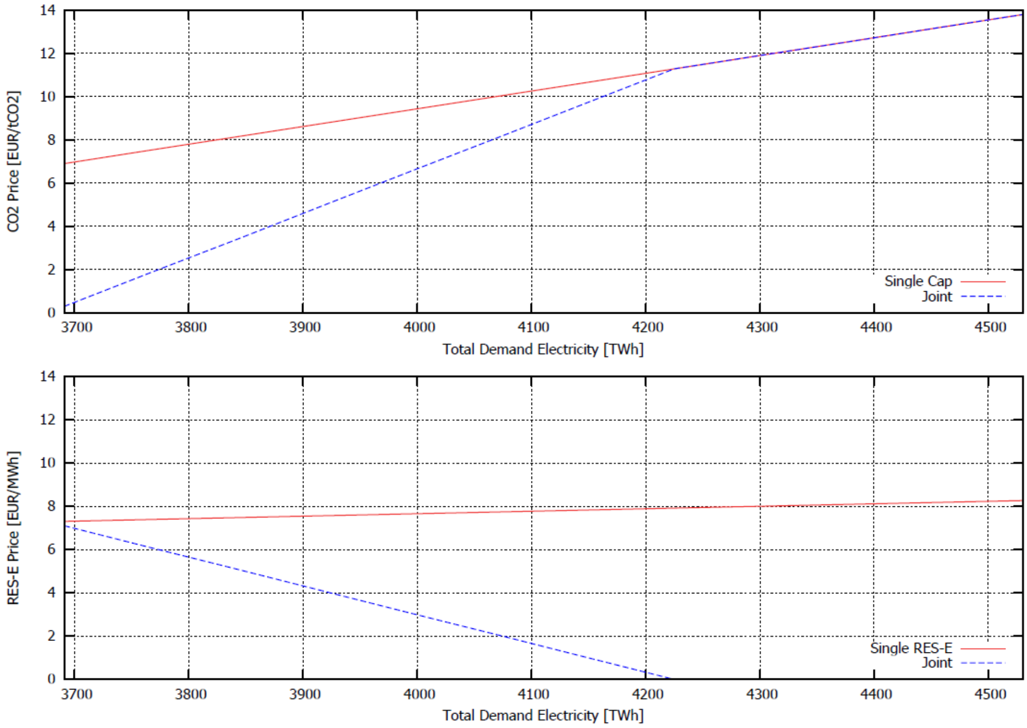
of renewables in the single cap case of 31 per cent. Note that our stylized model, where the only abatement options are fuel switches and renewable energy in the power sector, overestimates the burden of the emissions cap. In reality also other sectors with eventually lower abatement costs are included in the emission reduction efforts.

In the scenario with a single renewable share (Single RES) both coal and gas based technologies reduce their generation proportionally. The price of the respective green certificate (RES-E) is 7.74 EUR/MWh.

The joint emissions cap and renewable share regime (Joint) leads to lower prices for CO_2 and green certificates when compared to the single policy regimes. The reason is that in the joint emissions cap and renewable share regime both policies overlap and substitute each other. The lower CO_2 price promotes in particular the dirtiest technology, coal, and leads to higher coal generation compared to the case with a single emissions cap. Note that the joint emissions cap and renewable share regime makes compliance with the emission target more expensive since the emissions alone could have been mitigated by a less costly fuel switch from coal to gas without generating higher quantities of rather expensive renewables. Those results correspond to the findings of Bhringer and Rosendahl (2010) and others. However, the question remains how the interaction changes if total economic activity and therefore total demand for electricity changes.

Figure 1 illustrates how the price signals of the regulation changes if total demand for electricity changes. According to the “EU Energy Trends to 2030” (European Commission, 2009b) Reference scenario gross electricity generation is 4073 TWh in 2030. The “Energy Roadmap” also contains a Low GDP Growth Scenario based on the Reference Scenario but with 0.4 percentage points lower GDP growth. This leads to a demand for gross electricity generation of 3848 TWh in 2030. In its High GDP Growth Scenario assuming 0.4 percentage points higher GDP growth, gross electricity demand increases to 4289 TWh in 2030.

The upper schedule shows how the CO_2 price responds to changes in demand. The price for the CO_2 certificate is shown for two cases: First, for a single emissions cap (red continuous line), and second for the joint emissions cap and renewable share regime (blue dashed line). The lower schedule shows the price of the green certificate for a single renewable share (continuous red line), and the joint emissions cap and a renewable share



The upper panel shows the price of CO_2 if implemented as single policy or in combination with a renewable share over a range of electricity demand levels. The lower panel shows the price of a green certificate if implemented as single policy or in combination with a CO_2 emissions cap over a range of electricity demand levels.

Figure 1: Prices of CO_2 and green certificates.

regime (blue dashed line).

In the single emissions target regime, the CO_2 price increases continuously in demand. Yet, below a certain minimum level of demand the CO_2 price is zero. In this case, demand and corresponding emissions are so low that no abatement efforts are necessary to fulfil the target.

In case of a single renewable share the price of the renewable certificate behaves in an analogue fashion. The only difference is that the price of the renewable certificate is positive for any positive demand level since a higher quantity of renewable energy than in baseline needs to be generated, no matter the overall level of demand.

In the combined policy regime, both the behaviour of the CO_2 certificate price and the green certificate price change. Compared to the single emissions emissions cap the CO_2 price stays much longer at zero as demand increases. The intuition is that the renewable share requires energy production by renewables that have zero emissions. This leads to an overall reduction in emissions and keeps the emissions cap non-binding for comparatively higher levels of demand. Without target for a renewable share, a switch from coal to gas would have been necessary to keep emissions below the cap resulting in a positive price for CO_2.

From a level of demand above 3650 TWh we observe a positive CO_2 price also in

	Low GDP	Reference	High GDP
Excess Cost [EUR]	1.1 bn	450 m	0

Table 3: Excess costs evaluated with policy prices in the respective scenarios.

the joint policy regime, which increases in demand. Note that the CO_2 price change is now steeper than with the single emissions cap. This is an important corollary from our analysis. It shows that the CO_2 emission price reacts more sensitive to changes in demand for electricity if combined with an renewable share. Thus, the combination of both targets leads to higher uncertainty about the profitability of low-carbon investments if electricity demand is uncertain.

Even if demand increases, the CO_2 emission limit stays the same. So, either a fuel switch from coal to gas is required, or the more demand increases, an additional switch to renewables is needed. In turn, the price of the renewables certificate drops. The CO_2 certificate is now a substitute for the green certificate. The more emissions are constrained by the fixed cap the more generation by renewables is needed to stay below the cap regardless of the renewable share target. From a total energy demand of about 4280 TWh onward the green certificate reaches a price of zero, the renewable share target is not binding anymore and the outcome corresponds to a case with a single emissions cap.

These results indicate that the additional costs from the overlapping targets vary over the level of economic activity and the respective GDP growth rates. Following Boeters and Koornneef (2011) we calculate excess costs of the overlapping regulations. We define excess costs as the additional costs caused by the renewable share target if combined with a CO_2 emissions cap. Then, we compare the case where the two targets are jointly implemented with the single emissions cap case evaluated at prices of the joint target case. Hence, excess costs are $EXC = p_r^{joint}(q_r(a)^{joint} - q_r(a)^{ets}) - p_C^{joint}(q_g(a)^{joint} - q_g(a)^{ets})$, which are the costs of the additional generation in renewables due to the renewable share minus the costs from saved emission abatement efforts in the cheaper abatement option. Table 3 shows the excess costs for the Low GDP, the Reference Scenario, and the High GDP Scenario as outlined above. Under the Low GDP Scenario, when the renewable share target is particularly binding, those excess costs are 1.1 bn EUR, compared to costs of 450 m EUR in the Reference case. In the High GDP case, the renewable share target is not binding anymore and hence excess costs are zero. All in all, our analysis implies that a costly interaction between an emissions trading scheme co-existing with an renewable share target is particularly costly for low GDP growth rates.

Summing up the above discussion four main lessons emerge from this analysis: First, with the additional renewable share target the CO_2 price is comparatively lower as long as the renewable share target is binding. Second, if combined with a renewable share the CO_2 price responds more sensitive to changes in electricity demand and approaches zero faster for low levels of economic growth. In current debates on the future of the EU ETS, several mechanisms to stabilise prices are discussed. The results of our model imply that removing the additional renewable share would foster price stabilisation and limit the range of CO_2 certificate price fluctuations. Third, for high levels of demand the renewable share target becomes non-binding and thus irrelevant. Fourth, with low and medium GDP growth and corresponding electricity demand levels more energy is produced both by coal and by renewables compared to the single emissions cap. This increases the excess costs of the energy mix, since more cost-efficient abatement options cannot be exploited, and makes CO_2 abatement particularly expensive when GDP growth rates are low.

5 Discussion

Our model presents a very stylized view on the interaction of emissions trading and renewable share targets. It helps to easily identify the mechanisms at work when economic growth turns out to be higher or lower than expected. Yet, the real world is more complex. In the following we discuss in a less rigorous but more realistic way what should be kept in mind when drawing policy lessons from our model.

We see the main simplifications of our model in first, restricting the energy supply to only three technologies. Second, we do not take into account positive externalities that arise from research and development in and deployment of renewable energies. Third, our approach does not allow for taking potential myopia of investors into the energy sector into account. Fourth, while we focus on the interaction between emissions trading and a renewable share target we do not take into account that a lot of countries, also in the European context, have actually introduced feed-in tariffs for renewables instead of an explicit renewable share target. In the following we discuss the implications of our simplifications turn in turn.

Limiting the technologies for energy production to three options is surely a simplification. In reality there are way more technologies, and there are as well significant differences within each separate group of technologies like coal, gas, and renewables. However, limiting our analyses to the three technologies above is actually not a very harsh assumption. The main implication of our analysis regarding technology is the following: A renewable share crowds out energy production by non-renewable technologies, of which at least some, can provide the same level of abatement at lower costs. The renewable share limits the available abatement options. This implication still holds, even if we increase the options of available technologies. Hence, the limitation to three technologies is merely a model simplification to keep results tractable. The policy implication regarding technology choice of our model is, that the addition of a renewable share to an ETS crowds out energy production by relatively clean fossil sources and increases the amount of more dirty energy production by fossil fuels.

In our model we abstract from positive externalities that result from research and development of renewables as well as from their deployment. We deliberately did not model these benefits to focus on the pure interaction of an emission trading scheme and a renewable share target for varying levels of economic activity. Thereby we could show that the unintended and costly interaction of an ETS with a target for a minimum renewable share is particularly strong when economic growth is low. This result should hold in general independent of the societal benefits that innovation in and adoption of renewable energy sources provide.

Yet, our results in general may be biased against the benefits of a renewable share target. An optimal policy mix in the real world does surely require that inventors and adopters of renewable energy technologies are compensated fully for the societal benefits that they provide. Given our results of the costly interaction between emissions trading and renewable share targets our research thus calls for investigating additional possibilities to reward innovators and renewable energy adopters that interfere less with emissions trading. Such measures could be, for example, direct support for research and development, prizes for developing renewable energy technologies, and/or adopting renewables energy technologies. The costs and benefits of these options are surely worth studying.

Our simple model does not allow for investigating the effects of potential myopia by investors into the energy infrastructure. Given the highly uncertain future of both climate policies and the energy prices investors may indeed focus on fairly short time horizons and not take the full time horizon of their investment decision into account. An important problem that evolves from this myopia is that what pays off today with low carbon prices may not pay off tomorrow with the high carbon prices which are needed to achieve the political agreed goal of a maximum expected warming by two degrees Celsius. Investments may easily be sunk. An argument in favour for renewable share targets is thus that they help avoiding sunk investments in energy generation by fossil fuels. However, one should keep in mind that the speed of how fast the investment costs for renewable energy production decline is also uncertain. Hence, there is also a risk of over- or underinvestment with a renewable share target. Furthermore, our model shows that a renewable share target, which is added to an emissions trading scheme distorts the price of CO_2 certificates by forcing it towards zero. Thus, investors that rely on the price of CO_2 certificates for deciding in which technology to invest may actually underinvest in low carbon technologies due to CO_2 certificate price depression caused by the renewable share target.

Many governments make actually use of feed-in tariffs instead of renewable share targets. Explicitly modelling the interaction of an emissions trading scheme with feed-in tariffs may actually reveal additional insights. In general we would expect the same logic to apply. The feed-in tariffs incentivize renewable energy production no matter the overall demand for energy production while the emissions trading scheme provide more incentives the higher the level of energy demand. In combination with emissions trading, feed in tariffs will hardly be effective when economic growth turns out to be higher than expected while they depress the price of CO_2 certificates even further if growth turns out to be lower than expected.

In addition, feed-in tariffs seem particularly attractive when economic growth is low since their fixed returns then become comparatively more attractive. Thus there is a relative increase in renewable supply if economic growth is low, which leads the price for CO_2 certificates to drop even faster. Regarding policy, the lesson is that no matter whether a renewable share target or an feed-in tariff is applied in addition to an emissions trading scheme the unintended and costly side effects of their interactions are particularly strong when economic growth is low.

Above we discussed how the results of our model relate to reality. No matter which assumption we relax the main result, that unintended and costly interactions between emissions trading and renewable share targets are particularly strong if economic growth is low, still holds. In addition one should consider that the declining marginal utility of income also implies that our model rather touches at the lower cost level of these adverse interaction effects.

6 Conclusion

We examine the interaction between climate and renewable policies if there is uncertainty about future economic growth rates - and as a consequence uncertainty about the demand for electricity. By means of a calibrated stylized model we analyze the effect of exogenous changes in electricity demand on the prices for emission allowances and renewable credits. Two main lessons can be derived from this analysis:

First, prices for emission allowances become more sensitive to changes in electricity demand if the ETS is combined with an instrument that aims for a minimum renewable share. If policy makers value a clear and stable carbon price signal as crucial for encouraging investments in low-carbon technologies the combination of the two policy targets may have unintended negative consequences.

Second and following from our first lesson, we can show that while the carbon price is always lower if an ETS is combined with a renewable quota, this gap is particularly pronounced if economic growth is low. This leads to additional excess costs during situations when funds are particularly scarce and opportunity costs of climate policies are particularly high.

These lessons hold generally, i.e., for improving existing emission trading schemes like the EU ETS as well as for new and emerging ETS like those in China. The second lesson bears particular importance for fast growing emerging economies that plan to implement climate policies but are confronted with a lot of uncertainty regarding future growth rates. If economic growth turns out to be lower than expected the interaction between emissions trading and a target for a minimum renewable share turns out to be particularly costly. These costs should be weighted against the benefits of the deployment of renewables due to knowledge spillovers that justify their support.

We believe that this study opens a fruitful avenue of future research. While we analysed the interaction between climate and renewable policies if there uncertainty about future economic growth rates in the medium to long-term, it would also be worthwhile to gain a better understanding on how climate policy instruments interact in the short-term over explicitly modelled business cycles.

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