NEUTRALITY AND NON NEUTRALITY UNDER THE LOUPE: WHICH ONE IS BETTER?

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Abstract

I propose a characterization of non-neutral Renewable Portfolio Standard policies, credit multipliers and carve-outs quotas, and compare them with the technology neutral approach in terms of their capability to reach their green energy generation objectives, electric tariffs, additional rents, and social welfare. After adjusting the green generation goal for the credit multipliers approach, I found that the three policies studied reach the same generation goal, but the distribution of the generation shares between green producers are different. The neutral policy leads to lower energy tariffs, but also gives more additional rents to green firms, thus cheaper green generators benefit the most from this policy. Finally, in terms of social welfare, I conclude that both non-neutral policies allow reaching a more ambitious green generation goal than the one for the neutral policy, and consequently, less contaminant emissions.

1 Introduction

The Renewable Portfolio Standard (RPS) is known to be a technology-neutral policy. This means that all the green generation technologies (solar, wind, geothermal, bioenergy, etc.) are treated the same; this conveys they receive the same quantity of Tradable Green Certificates (TGC). As a consequence of this undifferentiated support, low cost types of renewable generation sources take most of the profits of this policy, because the certificates'

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price is greater than their marginal generation costs; while it gives no incentive to invest in high cost types of clean energy sources since the price is not enough to cover their marginal costs (Buckman, 2011).

To address this weakness of RPS policy, governments have opted to use another mechanism to support high-cost types of renewable energy resources, like a Feed-in Tariff (FIT) or budget financed subsidies. In other cases, governments redesign their RPS policy so they can provide a differentiated level of support to each technology according to their investment costs (Wang et al., 2024). These policies are known as non-neutral technology, which usually are credit multipliers or banding and carve-out quotas or set-asides.

Credit multipliers policy is a price mechanism that instead of giving one certificate per MWh produced, it grants certificates according to the production costs of the green technologies. Thus, the most expensive ones receive more certificates to trade in the market. While carve-out quotas are a quantity mechanism that sets from the beginning the share of green energy produced with different technologies such that the sum of these quotas is equal to the green energy goal. Each energy producer with the same technology receives one certificate per MWh produced, and they are sold at different prices in submarkets created for each technology.

Why should governments or energy regulators care about these types of non-neutral policies ? Bringing new green energy sources into the electric system is expensive, depends on each country's geography and the stage of adoption of generation technologies. Even if there is enough infrastructure to transport the energy from the generation centers to the final consumer, it is still costly to invest in green generators that can best take advantage of the countries' geographical characteristics or their abundance of resources.

In a setting where the RPS is the policy to attract new green generation and reduce the contaminant emissions, this is relevant for two reasons. The first is that the neutral approach could not be able to promote diversity of generation resources. This makes the electric system vulnerable because the energy mix is not so diverse and, usually, the investment in generation goes towards cheap technologies that may not be efficient to produce energy compared to the expensive ones.

A diverse energy mix is healthy for the electric grid since the energy demand does not depend on a few generation technologies; in case of failure, other generators can be dispatched and serve the demand. From the point of view of reliability, incorporating new green technologies into the energy mix allows the System Operator (SO) to fight the green generation intermittency to meet energy demand. For example, it could be possible to have solar generation during the day and wind at night.

The second reason refers to the energy tariffs that the consumers pay and the additional rents the energy producers receive. In the words of Bergek and Jacobsson (2010), the TGC are a rent generation machine. However, it is important to mention that having a non-neutral scheme does not eliminate these additional rents, but it does reduce them.

In this paper I investigate how the neutral RPS policy compares to the non-neutral ones in terms of their capability to reach their green energy generation objectives, lower electric tariffs, and greater social welfare.

The main objectives of this paper are described as follows. The first is to provide a characterization of the non-neutral policies: credit multipliers and carve-outs. To the best of my knowledge, there are theoretical approaches to analyze the RPS as a neutral policy, but there is no such study for the non-neutral ones.

The second is to qualify some empirical facts about these approaches found in the literature. In particular, I tackle the problem raised in the analysis of Gürkan and Langestraat (2014) and Fischlein and Smith (2013) about credit multipliers policy not being able to reach the green generation goal by proposing a green generation goal adjusted that allows to produce the desired green energy. After using an adjusted goal, I found that the three policies meet the target. Additionally, I compare the energy tariff paid by consumers under the three different approaches to determine which one is more costly for consumers, considering that for carve-outs there are markets for each generation technology, and for credit multipliers, apart from granting different amount of certificates, the adjusted green goal could increase the cost for the consumers. I calculate the additional rent the green technologies receive from the certificates' market according to the described in Kwon (2015a), Bergek and Jacobsson (2010), Haas et al. (2011), Toke (2007) and Buckman (2011). In line with the literature, my findings suggest that carve-outs policy offers the smallest additional income from the certificates market compared to the other two policies.

Finally, I solve the social planner problem to identify the approach that leads to the greatest welfare and green energy generation. I found that in the optimum, both carve-outs and multipliers lead to the same outcomes, even the green generation shares. Also, I conclude that under the RPS policy it is better to give a different treatment to the generation technologies rather than a homogeneous one.

The rest of the paper is organized as follows. Section 1.1 discuss some of the relevant literature regarding neutral and non-neutral RPS. Section 2 provides the equilibrium for the carve-outs and credit multipliers, it also derives the neutral policy as a particular case of the latter. Section 3 compares green generation, energy tariffs and additional rents from the certificate market for the three approaches. Finally, section 4 compares the outcomes under welfare maximization and identifies the optimum policy variables.

1.1 About neutral and non-neutral policies

Empirical evidence shows that policy neutrality often ends up financing the cheapest and most established generation technologies, and displaces or impedes the entrance of new, more expensive green technologies, like offshore wind or concentrated solar power. A good example is Flanders, Belgium, where an RPS policy was established to reduce electricity production using carbon as fuel. As a result, some carbon generators changed to biofuel, a cheap technology, to get the incentive, but there was no new investment in other generation resources, as it was initially intended (Carton, 2016).

Why is this important? In principle, giving the same treatment to the firms should encourage competition. However, this neutrality fails to promote the diversification of the green generation mix, as less mature technologies are less favored due to its higher costs (Wang et al., 2024).

Kwon (2015a) and Bergek and Jacobsson (2010) explain that under a neutral RPS, the generation firms get a significant amount of producer surplus due to the cost difference between different technologies. This is due to the fact that technologies with lower marginal costs benefit from the certificate's price because it represents an income additional to the energy price they receive in the electricity market. While the more expensive ones need higher certificate's price to be profitable. As a consequence, mature technologies with low costs receive rents, whereas immature technologies are forced out of the market even if they have the potential to reduce production costs in the long run, this is known in the literature as rent-seeking.

Multipliers are a device in which different multiples of tradable certificates are issued for each unit of generation depending on the type of renewable energy source (Buckman, 2011). This mechanism has been implemented in the UK and some states in the US and Korea. Under this framework, the green certificate granting not only depends on the energy production but on a multiplier factor that escalates the number of certificates each green generator receives, according to their generation costs. So that the most expensive technology gets more certificates.

Among the advantages of multipliers are flexibility to change the multipliers value according to technological change. There is a unique market to sell certificates, which means more liquidity. One of the weaknesses is that there is no methodology to set the multipliers value, so it is determined by the regulator. The main flaw is that if the target of the RPS is expressed as a number of certificates, then the certificate's multipliers can reduce the actual target reached. To avoid this problem, the UK government sets a higher goal than the one it pretends to reach to account for the goal reduction caused by credit multipliers.

In the carve-outs or set asides setting, the regulator still pursues a green generation objective, but this is divided into different small goals to reach by generating specific quotas of energy from diverse technologies. In simple words, they are RPS submarkets (Buckman, 2011), but each technology in the same group is given one certificate per MWh generated. This policy is widely implemented in some states of the US.

Regarding which non-neutral policy is more effective, the literature is not conclusive. With respect to the credit multipliers, Gürkan and Langestraat (2014) warn that the UK banding policy cannot guarantee that the original obligation target is met, hence potentially resulting in more pollution. In an empirical analysis with data from the US, Fischlein and Smith (2013) suggest that banding allows energy utilities to take advantage to produce energy with the technologies that earn additional certificates and that not necessarily translates into more green energy.

In one of the first quantitative analysis for the UK, Wang et al. (2024) examines the impact of this policy on the development of renewable technologies, focusing on onshore wind, offshore wind, and solar. They suggest that banding was crucial to help the UK to achieve its targets on electricity generation from renewable sources. Xin-gang et al. (2022) show that the introduction of credit multipliers promote TGC transactions, improve the social welfare and optimize the power source structure.

Kim and Tang (2020) show that solar carve-outs increase the diversity of generation technologies such as solar, wind, biomass and geothermal, but it does not happen the same way with credit multipliers. In a quantitative analysis for the US, Sarzynski et al. (2012) found that the presence of state RPS and specific solar carve-out provisions heavily influenced the market deployment of solar technology.

2 The model

In this Section, I propose a set-up to model the credit multipliers and carve-out policies based on the characteristics discussed above. I solve for the equilibrium and then compare them in terms of output, energy tariff and rent-seeking behavior.

Consider an electric market with two goods: electricity and green certificates. Electricity is a homogeneous good produced by three firms in a Cournot oligopoly market: conventional (pollutant), c, and two green technologies (zero emissions), v_1 and v_2. The energy output of all three firms, q_c, q_{v_1}, q_{v_2}, is necessary to satisfy the energy demand q, so in equilibrium, the total generation is $q = q_c + q_{v_1} + q_{v_2}$. Generation costs are $C_i(q_i) = c_i q_i^2$, for $i = c, v_1, v_2$ and $c_{v_1} > c_{v_2} > c_c$.

In this economy, there is an ongoing TGC policy to increase green generation. The regulator sets a green goal α that represents the share of green energy with respect to the total energy production. The environmental regulator can choose between three approaches to grant the certificates (j): neutral, credit multipliers and carve outs, n, m and co, respectively. As I stated before, the difference between these granting mechanisms is the way they treat the different green technologies according to their generation costs. The neutral scheme allocates both green generators 1 certificate per unit of energy generated, regardless of their production costs. The multipliers and carve-outs allow for a differentiated treatment of each green technology to acknowledge this heterogeneity. While multipliers use a price mechanism, the carve-outs use quantity one.

In this setting, all the firms maximize benefits by choosing their energy production, q_i, that is sold at a price P_e. While the green firms 1 and 2 also offer all their certificates stock and this is sold in a competitive market at a price P_c. Notice that the green firms do not choose their certificate supply, this is determined by their generation. Additionally, the market structure is characterized as follows under the three policies: neutral, credit multipliers and carve-outs, $j = n, m, co$, respectively:

(A1) the inverse energy demand function is linear, $P_e^j(q^j) = a - bq^j$, where $a > 0$ and $b > 0$ for $j = n, m, co$;

(A2) the certificates' market clearing conditions are

a. Neutral: $\alpha q^n = q_{v_1}^n + q_{v_2}^n$, where $0 < \alpha < 1$;

b. Credit multipliers: $\alpha q^m = \gamma_1 q^m_{v_1} + \gamma_2 q^m_{v_2}$, where $\gamma_1 > 0$ and $\gamma_2 > 0$;

c. Carve-outs: $\beta_1 q^{co} = q^{co}_{v_1}$ and $(\alpha - \beta_1) q^{co} = q^{co}_{v_2}$, where $0 < \beta_1 < \alpha$;

(A3) the damage function is given by $D(q^j_c) = \frac{d {q^j_c}^2}{2}$, with $d > 0$, for $j = n, m, co$;

The core of the model lies on the Assumption A2, that represent how the regulator treats the green technologies under every approach. Assumption A2.a shows that both firms receive one certificate per MWh produced. Thus, in the neutral case, the green goal α is equivalent to the supply of green certificates. Assumption A2.b breaks this equivalence. Here, the multipliers γ_1 and γ_2 indicates how many certificates receive each technology, this means that A2.b is equivalent to a certificate requirement, not a green energy one. This issue is studied in detail in Section 2.1. Finally, regarding the carve-outs approach, Assumption A2.c shows the market clearing conditions for technologies 1 and 2. In this case, the green generation goal is divided between both technologies by assigning an energy quota to each of them, β_1 and $\alpha - \beta_1$, creating a market for each technology.

In the next Sections, I solve the market equilibrium for the neutral and credit multipliers (Section 2.1) and carve-outs (Section 2.2).

2.1 Credit multipliers

Under this scheme, the regulator allocates an amount of γ_i, $i = 1, 2$, certificates per unit of energy generated (MWh) to each green technology, where the most expensive technology gets more certificates, $\gamma_1 > \gamma_2 > 0$. The certificates are sold at the price P^m_c.

All firms maximize their benefits that consist of their income from the energy and certificate sales, which in the case of the conventional firm this last one is zero, minus their generation costs. The optimization problems for each generator are given by

$$\max_{q_c^m} \quad q_c^m[a - b(q_c^m + q_{v_1}^m + q_{v_2}^m)] - c_c(q_c^m)^2 \tag{1}$$

$$\max_{q_{v_1}^m} \quad q_{v_1}^m[a - b(q_c^m + q_{v_1}^m + q_{v_2}^m)] + \gamma_1 P_c^m q_{v_1}^m - c_{v_1}(q_{v_1}^m)^2, \tag{2}$$

$$\max_{q_{v_2}^m} \quad q_{v_2}^m[a - b(q_c^m + q_{v_1}^m + q_{v_2}^m)] + \gamma_2 P_c^m q_{v_2}^m - c_{v_2}(q_{v_2}^m)^2. \tag{3}$$

The first-order conditions from Equations (1), (2) and (3) along with Assumption (A2.b) should define the equilibrium under the credit multipliers approach. Considering that the ultimate goal of the TGC policy is to reach a green generation target, α, this equilibrium will lead to a result where the green goal is not achieved.

Does this imply that the credit multiplier policy is not effective to reach the green goal? The answer goes beyond a yes or no. To understand why this policy does not reach the expected generation, it is important to look at the clearing certificate market condition in Assumption (A2.b) compared to the one in (A2.a). In the neutral policy, this condition indicates that the supply of certificates is equal to the supply of green energy from both firms because the firms receive 1 certificate per unit of electricity produced, $\gamma_1 = \gamma_2 = 1$. However, under the credit multipliers policy this is not true because the amount of certificates each generator receives depends on their technology γ multiplier. As a result, the amount of certificates in the market does not reflect the amount of green energy produced.

The market clearing condition in Assumption (A2.b) for $\gamma_1, \gamma_2 \neq 1$ puts the green goal α in terms of certificates, but this α is different from the green generation share actually achieved under this credit multipliers scheme, $\frac{\gamma_1 q_{v_1}^m + \gamma_2 q_{v_2}^m}{q_{v_1}^m + q_{v_2}^m + q_c^m} = \alpha_{goal} \neq \frac{q_{v_1}^m + q_{v_2}^m}{q_{v_1}^m + q_{v_2}^m + q_c^m} = \alpha_{real}$. This happens because the multipliers affect the energy production decisions.

For example, assume the green goal is $\bar{\alpha}$ with $\gamma_1 > \gamma_2 > 1$, this means that less energy is necessary to reach the target since green generation is worth more in terms of certificates, so the green generation would be less than the one under the neutral scheme. In contrast, the opposite occurs when $\gamma_1 < 1$ and $\gamma_2 < 1$ because green energy is less valuable in terms of certificates, and more energy is needed to get to $\bar{\alpha}$. In both cases, the policy results into not reaching the green goal α, and the green energy ratio is either above or below α.

There are two lessons from the last paragraphs. The first is that under the credit multipliers scheme, the green energy is not equal to the quantity of certificates supply. And the second is that the multiplier size matters, especially when it is greater than one because it leads to a lower green energy production. These issues could mislead the unaware policymakers to assess the TGC policy as successful when it is not. Especially, in the second case, where firms receive income from the certificate market, but the energy market is not producing the green energy expected.

This issue has been identified in Fischlein and Smith (2013). They explain that credit multipliers have a negative impact on the share of renewable energy because utilities produce the type of energy that earn more certificates, and it lowers the quantity of renewable power to achieve the goal. To deal with this concern, the UK government considers the additional certificates to be created before adding on its headroom adjustment (Buckman, 2011 and Department for Energy Security & Net Zero, 2023).

Currently, the UK considers a headroom of 10%; however, the Guidance to calculate the Renewables Obligation for 2024 to 2025 does not specify how this headroom is obtained. As a part of my analysis, I calculate an adjusted green goal $\tilde{\alpha} = \tilde{\alpha}(\alpha)$ to account for the amount of certificates to be emitted and to achieve the green goal. This result is shown in Proposition 1 and the calculations are detailed in Section 6.

Proposition 1 *In the credit multipliers setting (A1), (A2.b) and the first-order conditions from problems (1), (2) and (3), there is a green requirement* $\tilde{\alpha}(\alpha) = \frac{\alpha(\gamma_1^2(b+2c_{v_2})+\gamma_2^2(b+2c_{v_1}))-(1-\alpha)(\gamma_1-\gamma_2)^2(b+2c_c)}{\gamma_1(b+2c_{v_2})+\gamma_2(b+2c_{v_1})}$ *that allows to reach the green goal* α *when the regulator grants certificates from a credit multipliers perspective, this is* $\alpha = \frac{q^m_{v_1}(\tilde{\alpha})+q^m_{v_2}(\tilde{\alpha})}{q^m_{v_1}(\tilde{\alpha})+q^m_{v_2}(\tilde{\alpha})+q^m_c(\tilde{\alpha})}$.

The adjusted green goal in Proposition 1 can be read as the difference between the "marginal cost"[1] of the green generation (first term) and the "marginal cost" of the conventional one,

[1] This term is between quotation marks because it is not exactly the marginal cost, but it is close. Note that

weighted by the certificates' multipliers and the green generation cost. As expected, an increase in the desired green goal α, as well as conventional and green technology 2, result into a bigger adjusted goal. However, the effect of an increase in the green technology and both multipliers is not clear and depends on the size of α.

Proposition 1 shows how much the regulator will need to adjust up or down its certificate requirement in order to reach its green goal α. This means that the consumer needs to get more or less certificates, depending on the size of the multipliers. Considering that the new requirement will be different from the one required by the other two approaches, it is reasonable questioning if this policy is more or less expensive for the consumers than the neutral or carve out ones. To answer this question, first, it is necessary to determine the generation equilibrium under the credit multipliers perspective. To this purpose, it is important to update the Assumption (A2.b) as follows.

(A2.b') the certificate market clearing condition for the credit multipliers case is $\tilde{\alpha}(\alpha)q^m = \gamma_1 q^m_{v_1} + \gamma_2 q^m_{v_2}$, where $\gamma_1 > 0$ and $\gamma_2 > 0$;

The equilibrium under the credit multipliers mechanism can be characterized in the following way:

Proposition 2 *In the credit multipliers setting under Assumption (A2.b') a Cournot equilibrium exists with outcomes*

$$q^m_c = \frac{a(1-\alpha)}{b+(1-\alpha)(b+2c_c)},\ q^m_{v_1} = \frac{a[\alpha\gamma_1(b+2c_{v_2})-(1-\alpha)(\gamma_1-\gamma_2)(b+2c_c)]}{(b+(1-\alpha)(b+2c_c))(\gamma_1(b+2c_{v_2})+\gamma_2(b+2c_{v_1}))},\ q^m_{v_2} = \frac{a[\alpha\gamma_2(b+2c_{v_1})+(1-\alpha)(\gamma_1-\gamma_2)(b+2c_c)]}{(b+(1-\alpha)(b+2c_c))(\gamma_1(b+2c_{v_2})+\gamma_2(b+2c_{v_1}))},$$

$$\text{and } P^m_c = \begin{cases} 0,\ if\ 0 < \alpha \leq \alpha_1,\ \alpha_1 = \frac{2(b+2c_c)(b+c_{v_1}+c_{v_2})}{3b^2+4c_{v_1}c_{v_2}+4c_c(c_{v_1}+c_{v_2})+4b(c_c+c_{v_1}+c_{v_2})} \\ \frac{a[\alpha(b+2c_{v_1})(b+2c_{v_2})-(1-\alpha)((b+2c_c)(b+c_{v_1}+c_{v_2})-b^2)]}{(b+(1-\alpha)(b+2c_c))(\gamma_1(b+2c_{v_2})+\gamma_2(b+2c_{v_1}))},\ if\ \alpha_1 < \alpha < 1. \end{cases}$$

Notice that the amount of conventional production is determined by $1-\alpha$. Also, considering that, under this approach, the most expensive technology receives more certificates $\gamma_1 > \gamma_2$, the second term in q_{v_1} shows how the generation of firm 1 adjusts to this incentive,

the green generation marginal cost is $2q_{v_1}c_{v_1}+2q_{v_2}c_{v_2}$, but instead I got $\frac{q_{v_1}+q_{v_2}}{q_{v_1}+q_{v_2}+q_C}(\gamma_1^2(b+2c_{v_2})+\gamma_2^2(b+2c_{v_1}))$.

so it produces less energy. On the contrary, firm 2 receives fewer certificates, so the second term of q_{v_2} is positive, thus, firm 2 produces produces more energy.

It is important to point out that the certificates' price, P_c^m, is not always positive. When the requirement α is lower than α_1, $P_c^m < 0$. This happens because without a certificates' market, there is an amount of green energy production traded in the oligopolistic energy market. Once a RPS policy is adopted and the regulator sets a green goal, it could happen that this goal is lower than the green energy production without the RPS policy, so there would be an excess of certificates' supply and the price would be zero. However, when the goal is greater than α_1, then the RPS policy induces a larger green energy production compared to the case without it.

To conclude the characterization of the outcomes under the credit multipliers approach, I derive the energy production and certificates price of equilibrium from the neutral policy as a particular case of the credit multipliers specification.

If $\gamma_1 = \gamma_2 = 1$, the regulator grants one certificate per unit of energy produced. This assignment rule corresponds to the one used under the neutral approach. When $\gamma_1 = \gamma_2 = 1$, Equations (1), (2) and (3) along with (A2.b') define the equilibrium in the neutral scheme. This is characterized in the following Proposition.

Proposition 3 *In the credit multipliers setting with $\gamma_1 = \gamma_2 = 1$, along with the first-order conditions from problems (1), (2) and (3), and Assumption (A2.a), a Cournot equilibrium exists with outcomes*

$$q_c^n = \frac{a(1-\alpha)}{b+(1-\alpha)(b+2c_c)},\ q_{v_1}^n = \frac{\alpha a(b+2c_{v_2})}{2(b+c_{v_1}+c_{v_2})(b+(1-\alpha)(b+2c_c))},\ q_{v_2}^n = \frac{\alpha a(b+2c_{v_1})}{2(b+c_{v_1}+c_{v_2})(b+(1-\alpha)(b+2c_c))},\ and$$

$$P_c^n = \begin{cases} 0,\ if\ 0 < \alpha \leq \alpha_1, \\ \frac{a(\alpha(b+2c_{v_1})(b+2c_{v_2})-2(1-\alpha)(b+2c_c)(b+c_{v_1}+c_{v_2}))}{2(b+c_{v_1}+c_{v_2})(b+(1-\alpha)(b+2c_c))},\ if\ \alpha_1 < \alpha < 1. \end{cases}$$

In this case, the certificate clearing market condition and the green energy production share are the same, so it is not necessary to use the adjusted green goal. Even more, when $\gamma_1 = \gamma_2 = 1$, the adjusted objective is $\tilde{\alpha}(\alpha) = \alpha$. Contrary to the credit multipliers policy, here there is no need to modify energy production since both green generators receive the same amount of certificates, so the productions only depend on their costs.

2.2 Carve - outs quotas

Now, I analyze the carve-outs scheme. Under this setting, the regulator gives both generators one certificate per MWh of energy generated, as in the neutral policy. However, it sets a quota β_1 and β_2 that has to be covered by the consumer with certificates of each green technology. Under this setting, the total certificates' requirement is equal to the sum of both requirements, so that $\beta_2 = \alpha - \beta_1$. Notice that different from the credit multipliers and the neutral cases, there is a certificate market for each technology, the certificates are sold at prices $P_{c_1}^{co}$ and $P_{c_2}^{co}$.

The conventional firm optimization problem is equal to the one in Equation (1), but choosing q_c^{co}. The corresponding problems to the green firms are

$$\max_{q_{v_1}^{co}} \quad q_{v_1}^{co}[a - b(q_c^{co} + q_{v_1}^{co} + q_{v_2}^{co})] + P_{c_1}^{co} q_{v_1}^{co} - c_{v_1}(q_{v_1}^{co})^2, \tag{4}$$

$$\max_{q_{v_2}^{co}} \quad q_{v_2}^{co}[a - b(q_c^{co} + q_{v_1}^{co} + q_{v_2}^{co})] + P_{c_2}^{co} q_{v_2}^{co} - c_{v_2}(q_{v_2}^{co})^2. \tag{5}$$

The second term in Equations (4) and (5) shows that each technology will get a different amount of certificate market income depending on the quota β_1 and the equilibrium price for each one. Another important feature of this specification is that unlike the credit multipliers case, here there are no additional green certificates created, so it is not necessary to adjust the green energy share objective to effectively reaching it.

The equilibrium under the Carve-Out quotas can be characterized in the following way:

Proposition 4 *In the Carve-Out quotas setting (A1), (A2.c) and the first-order conditions from problems (1), (4) and (5), a Cournot equilibrium exists with outcomes*

$q_c^{co} = \frac{a(1-\alpha)}{b+(1-\alpha)(b+2c_c)}$, $q_{v_1}^{co} = \frac{a\beta_1}{b+(1-\alpha)(b+2c_c)}$, $q_{v_2}^{co} = \frac{a(\alpha-\beta_1)}{b+(1-\alpha)(b+2c_c)}$,

$$P_{c_1} = \begin{cases} \frac{a[\beta_1(b+2c_{v_1})-(1-\alpha)(b+2c_c)]}{b+(1-\alpha)(b+2c_c)}, \; if \; \alpha_1 < \alpha < 1, \; \frac{(1-\alpha)(b+2c_c)}{b+2c_{v_1}} < \beta_1 < \frac{\alpha(b+2c_{v_2})-(1-\alpha)(b+2c_c)}{b+2c_{v_2}} \\ 0, \; if \; 0 < \alpha \leq \alpha_1, \end{cases} \text{, and}$$

$$P_{c_2} = \begin{cases} \frac{a[(\alpha-\beta_1)(b+2c_{v_2})-(1-\alpha)(b+2c_c)]}{b+(1-\alpha)(b+2c_c)}, \; if \; \alpha_1 < \alpha < 1, \; \frac{(1-\alpha)(b+2c_c)}{b+2c_{v_1}} < \beta_1 < \frac{\alpha(b+2c_{v_2})-(1-\alpha)(b+2c_c)}{b+2c_{v_2}} \\ 0, \; if \; 0 < \alpha \leq \alpha_1. \end{cases}$$

Under this approach, the amount of green energy produced by each technology is automatically fixed when the regulator sets the quotas β_1 and α. Unlike the neutral and multipliers policy, productions for each technology do not depend on green technology costs, but only the conventional ones. This means that an increase in c_c, results into a reduction not only of conventional production but green. This may seem counterintuitive, however it is because of the design of the carve-outs scheme. A reduction in conventional production caused by an increase in c_c means that there is room to expand green energy production. However, since the quotas of each technology are fixed, the firms cannot respond accordingly. In this case, it seems useful the design used in some states of the US; they set quotas for specific technologies, but the green goal is bigger than the sum of the quotas, so it allows the energy production to respond to these kinds of external changes.

Now that I have calculated the equilibria in each case, I am ready to compare them to identify which one leads to more energy production, higher tariffs and identifying the additional rent the green generators receive under all the schemes.

3 Comparing equilibria and rent-seeking behavior

3.1 Energy production

As expected, the share of green energy produced is identical among the three certificate granting approaches and equal to α, but not the generation of each green technology. The objective of non-neutral policies is to increase the generation of expensive technologies by giving them an incentive through certificate prices or quotas. Proposition 5 shows the results of comparing the production of technology 1 among the three schemes.

Proposition 5 *Let* $q^i_{v_1}$, $i = n, m, co$ *the generation of equilibrium under the three approaches,* $0 < \beta_1 < \alpha$, *and* $\gamma_1 > \gamma_2 = 1$, *then*

1. *When the green goal is small,* $0 < \alpha < \alpha_1$, *(high,* $\alpha_1 \leq \alpha < 1$*), the production of the green technology 1 is greater (lower) under the neutral scheme than the credit multipliers one.*

2. *When the quota* β_1 *is small,* $0 < \beta_1 < \frac{\alpha(b+2c_{v_2})}{2(b+c_{v_1}+c_{v_2})}$, *(high,* $\frac{\alpha(b+2c_{v_2})}{2(b+c_{v_1}+c_{v_2})} \leq \beta_1$*) the production of the green technology 1 is greater (lower) under the neutral scheme than the carve outs one.*

3a. *For* $\beta_1 < \alpha$ *and a small green goal* α, $0 < \alpha \leq \alpha_2 = \frac{(\gamma_1-1)(b+2c_c)}{b(2\gamma_1-1)+2(\gamma_1-1)c_c+2\gamma_1 c_{v_2}}$, *the production of the green technology 1 is greater under the carve-outs approach than the credit multipliers one.*

3b. *When the quota* β_1 *is small (high) and the green goal is high,* $0 < \beta_1 \leq \frac{\alpha\gamma_1(b+c_{v_2})-(1-\alpha)(\gamma_1-1)(b+2c_c)}{\gamma_1(b+2c_{v_2})+b+2c_{v_1}}$ *(*$\frac{\alpha\gamma_1(b+c_{v_2})-(1-\alpha)(\gamma_1-1)(b+2c_c)}{\gamma_1(b+2c_{v_2})+b+2c_{v_1}} < \beta_1 < \alpha$*) and* $\alpha_2 < \alpha < 1$, *the production of the green technology 1 is greater (lower) under the multipliers scheme than the carve-outs.*

Even though the comparison is not conclusive on which of the three granting mechanisms incentives more energy production with the technology 1, this exercise allows having a clearer idea on the conditions that make one approach to perform better than another. The neutral scheme performs better when the green goal is low, this means that when the TGC policy is in its early stages it is more convenient to implement a neutral policy since it will lead to more energy produced with technology 1. However, when the policy is mature and the regulator aims to reach a bigger green goal, it is a good choice to execute a non-neutral policy.

Which one should the regulator choose? The second point in Proposition 5, shows that if the regulator chooses a quota β_1 greater than technology 2 weighted cost, $\frac{\alpha(b+2c_{v_2})}{2(b+c_{v_1}+c_{v_2})}$, the energy production with technology 1 is greater than the one under the neutral approach, no matter the size of the green goal. This is an advantage with respect to the credit multipliers policy. However, it is not clear how big the quota β_1 should be. This issue is analyzed in Section 4.

Regarding the total energy produced, notice that it is the same in all the cases, $q = \frac{a}{(2-\alpha)b+2(1-\alpha)c_c}$. In particular, conventional generation is equal in all the specifications. This is due to the clearing certificate market condition that sets the share of conventional generation as $(1-\alpha)$. As a consequence, the energy price is the same in every case. Thus, the difference in the electric tariff the consumer pays lies on the expenditure in certificates. In the next section, I identify which granting approach leads to a greater energy tariff.

3.2 Which approach makes the consumer to pay more for certificates?

This section compares the consumers' expenditure on energy for the three certificates' schemes, by comparing the electric tariff they would pay. This is important because even though the consumers do not demand green certificates, this obligation is indirectly transferred to them by the retailer through the energy tariff, that is the sum of the energy and certificates prices. For the neutral and carve-outs approaches, the consumer tariffs are $T^n = P_e + \alpha P_c^n$ and $T^{co} = P_e + \beta_1 P_{c_1} + (\alpha - \beta_1) P_{c_2}$, respectively. The tariff for the credit multipliers case is $T^m = P_e + \tilde{\alpha} P_c^m$. In this case, I consider that the regulator ask for $\tilde{\alpha}$ certificates per MWh of energy consumed instead of α as in the previous cases. The reason behind this is in Proposition 1, that says that in order to reach a green goal α, the regulator has to adjust this requirement to $\tilde{\alpha}$. Proposition 6 shows the results of this comparison.

Proposition 6 *Let* $\gamma_1 > \gamma_2 > 0$ *and* $0 < \beta_1 < \alpha < 1$. *Then,*

a) $P_e + \alpha P_c^n < P_e + \tilde{\alpha} P_c^m$;

b) $P_e + \alpha P_c^n < P_e + \beta_1 P_{c_1} + (\alpha - \beta_1) P_{c_2}$

Surprisingly, non-neutral policies do not result into cheaper energy tariffs for consumers. In the case of the credit multipliers approach, this is due to the use of the adjusted green goal, which means that regulators asks the consumers to pay a larger quota of certificates. When comparing the cost of getting an amount α of certificates under both policies, it results that $\alpha P_c^n > \alpha P_c^m$ when $\frac{2(b+2c_c)}{3b+4c_c+2c_{v_2}} < \alpha < 1$. so for a high green goal, it is cheaper opting for the credit multipliers scheme. In the carve-outs' scenario, the source of this elevated electric tariff is the fact that this policy creates one market for each technology, which reduces the certificates' supply according to the established quota and sets a higher certificates' price for both technologies.

This result is according to the literature that argues that green certificates' policy are an onerous burden for consumers who end up paying high electric bills to support established green generation technologies. Does this mean that non-neutral policies do not work? To answer this question, it is necessary to focus not only in consumer tariffs but in the social welfare that results of applying these policies. This issue is studied in Section 4, but before going there, in Section 3.2 I analyze in detail the certificates' prices in terms of marginal costs and identify the additional rents that each scheme provides to the generators.

3.3 Rent seeking behavior

3.3.1 Some preliminaries about rent seeking

One of the main critics of the neutral TGC policy is that it does not promote the technological change nor investment in immature technologies because the price offered is not enough to incentivize the expensive technologies, but it is high enough to attract mature and established technologies so they can benefit from the price differential; this behavior is known in the literature as rent seeking. The idea behind this is that investors in new renewable energy sources should be compensated fairly but by no means of exaggerated profits (Haas et al., 2011).

Bergek and Jacobsson (2010) distinguish between two types of rents. The first is generated by already profitable plants without the additional payment. The second one is related to the fact that the overall marginal cost curve for renewables consists of several different curves. At each point, the certificate price corresponds to the most expensive technology for each level of requirement α (marginal technology) and all technologies with lower costs will receive an extra profit. As more expensive technologies are required to fill the quota, the rents to submarginal technologies will increase.

Before banding were introduced in the UK, the critics argued that due to RPS policy arrangements, it was more profitable for onshore wind developments compared to offshore wind farms, even though the latter has greater energy production potential, but it is more expensive (Toke, 2007). To reduce the amount of additional rents, some countries implemented credit multipliers and carve-out quotas.

Following Kwon (2015a) credit multipliers can reduce RPS rents, but this reduction depends on the size of the multipliers (γ). The author claims that the ratio of multipliers must be proportional to the generation cost of each technology less the average electricity price. However, it would be difficult to find the right γ due to information asymmetry between green energy producers and the regulator. In the UK, this estimation is not done by the regulator but by consultant firms based on short and medium term green technologies generating costs (Buckman, 2011). Considering the difficulties to estimate the multipliers, carve-outs is a more effective policy design because it creates a market for each technology.

3.3.2 Identifying additional rents in the certificates price

In the remainder of this section, I will determine the additional rent the green generation firms receive under the three RPS approaches and weight up each of them to identify which one generates the minimum extra income for green energy producers.

The certificate prices P_c in Propositions 2, 3 and 4 can be written as

$$\begin{aligned}
neutral: \quad & P_c^n = \frac{\omega_2(MC_1 - P_e) + \omega_1(MC_2 - P_e) + b(q_{v_1}\omega_2 + q_{v_2}\omega_1)}{\omega_1 + \omega_2}, \\
credit\ multipliers: \quad & P_c^m = \frac{\omega_2(MC_1 - P_e) + \omega_1(MC_2 - P_e) + b(q_{v_1}\omega_2 + q_{v_2}\omega_1)}{\gamma_2\omega_1 + \gamma_1\omega_2}, \\
carve-outs: \quad & P_{c_1} = MC_1 - P_e + bq_{v_1} \quad and \quad P_{c_2} = MC_2 - P_e + bq_{v_2}, \\
& with\ \omega_i = b + 2c_{v_i},\ i = 1, 2\ and\ MC_1,\ MC_2\ are\ the\ marginal \\
& costs\ of\ technologies\ 1\ and\ 2,\ respectively.
\end{aligned}$$

Now, I proceed to compare the certificates price for the three approaches with the ideal price that reduce the additional rents that the green producers receive, i.e., $P_c = MC_1 - P_e$, to identify which one transfers more extra income to the green firms.

The price in the neutral case corresponds to the weighted sum of the differences between the marginal cost of each technology and the energy price, plus the weighted sum of the energy production of green firms. As found empirically in the literature, under the neutral case, there is extra rent going to both generators, $P_c^n > P_c$. In particular, I found that the green firm 1 receives $rent_1^n = \frac{b(q_{v_1}\omega_2 + q_{v_2}\omega_1) - \omega_1(MC_1 - MC_2)}{\omega_1 + \omega_2} > 0$, while the green firm 2 gets $rent_2^n = \frac{b(q_{v_1}\omega_2 + q_{v_2}\omega_1) + \omega_2(MC_1 - MC_2)}{\omega_1 + \omega_2} > 0$. Since the firm 1 has greater marginal costs, then the rent received by the firm 2 is bigger than the one that firm 1 gets. As the green generation goal increases, the certificate price goes up, so the additional rent is bigger too.

The certificate price in the credit multipliers case is almost the same as in the neutral one, with the denominator also multiplied by the number of certificates granted to each technology, γ. Notice that the price in the neutral case is equivalent to the one for credit multipliers when $\gamma_1 = \gamma_2 = 1$.

As Kwon (2015b) suggests, credit multipliers may reduce the additional rent, but it depends on the size of the γ's. It all comes down to solve $P_c^m - P_c = 0$ to find γ_1 that makes zero the extra profit for firm 1. However, in this case, since there is only one equation it is not possible to determine the value of γ_2, so I will assume $\gamma_2 = 1$. When $\gamma_1 = \tilde{\gamma}_1 =$

$\frac{b(q_{v_1}\omega_2+q_{v_2}\omega_1)-\omega_1(MC_1-MC_2)+\omega_2(MC_1-P_e)}{\omega_2(MC_1-P_e)}$, so that $P_c^m = MC_1 - P_e$, and the additional rent for firm 2 is the difference between the marginal costs of both generators, $rent_2^m = MC_1 - MC_2$, and $rent_2^n > rent_2^m$. However, if the regulator chooses $1 < \gamma_1 < \tilde{\gamma}_1$, there is an extra profit for the green firm 1, but it is smaller than the one under the neutral scheme. Also, when $\gamma_1 > \tilde{\gamma}_1$, $P_c^m < MC_1 - P_e$, this means that the certificate price is not enough to cover the costs of the most expensive technology. This is relevant because the regulator may think that the more certificates green expensive technologies receive, the better. However, this is not necessarily true, since more certificates in the market would decrease the price and send the wrong signal of plenty of green energy production in the economy when there is only abundance of certificates.

The case of carve-outs is a different scenario. Here, since there is one market for each technology, both prices are near to their own marginal cost. However, this does not mean the extra rent is zero but close. Both generators get an income of $rent_i^{co} = bq_{v_i}$ for $i = 1, 2$.

4 Social welfare

In this section, I endogenize the public policy variables (α, β_1 and γ_1, I assume $\gamma_2 = 1$) to allow the regulator to choose the ones that maximize the social welfare to identify which approach leads to a greater welfare, but also allows reaching a bigger green generation goal.

For this task, I assume the regulator wants to cut CO_2 emissions from conventional generation by increasing the green generation. The environmental harm caused by conventional production is represented through the damage function from (A5). From (A1) and (A5), the social welfare function for this electric market under the three scenarios is $SW^i = U(q^i) - c_c q_c^i - c_{v_1} q_{v_1}^i - c_{v_2} q_{v_2}^i - \frac{d {q_c^i}^2}{2}$, for $i = n, m, co$.

Since the three approaches drive to the same output, the term that make welfare functions distinct is $-c_{v_1} q_{v_1}^i - c_{v_2} q_{v_2}^i$. This means that the difference in the optimal policy variables will depend on how the generation shares are distributed between the two green technologies under the neutral, credit multipliers and carve-outs policies.

Proposition 7 shows the results to the following problems:

$$\text{neutral:} \quad \max_{\alpha} SW^n; \tag{6}$$

$$\text{multipliers:} \quad \max_{\alpha,\gamma_1} SW^m; \tag{7}$$

$$\text{carve outs:} \quad \max_{\alpha,\beta_1} SW^{co}. \tag{8}$$

Proposition 7 *Under assumptions (A1), (A5), and Propositions 2, 3 and 4,*

a) the optimal green goal α is the same under the multipliers and carve outs, $\alpha^m = \alpha^{co} = \frac{(c_{v_1}+c_{v_2})(b^2+4c_c^2+b(6c_c+d))}{b^2(c_{v_1}+c_{v_2})+4c_c(c_{v_1}c_{v_2}+c_c(c_{v_1}+c_{v_2}))+b(4c_{v_1}c_{v_2}+(6c_c+d)(c_{v_1}+c_{v_2}))}$;

b) $\alpha^m = \alpha^{co} > \alpha^n$;

c) the generation shares for both green technologies are the same under the multipliers and carve outs, with $\beta_1^{co} = \beta_1^m = \frac{c_{v_2}(b^2+4c_c^2+b(6c_c+d))}{b^2(c_{v_1}+c_{v_2})+4c_c(c_{v_1}c_{v_2}+c_c(c_{v_1}+c_{v_2}))+b(4c_{v_1}c_{v_2}+(6c_c+d)(c_{v_1}+c_{v_2}))}$ and $\gamma_1 = \frac{c_{v_2}(b^2+4c_c^2+2c_{v_1}d+b(6c_c-2c_{v_1}+d))\gamma_2}{c_{v_1}(b^2+4c_c^2+2c_{v_2}d+b(6c_c-2c_{v_2}+d))}, \gamma_2 > 0$;

d) $SW^{co} = SW^m > SW^n$.

Surprisingly, in the optimum, both non-neutral policies reach the same green generation goal, which is greater than the one for the neutral approach. These policies not only promote the production of more green energy for specific technologies, but also, this differentiated treatment incentivizes them to produce a greater green output compared with a neutral policy.

Even though the credit multipliers and carve-outs schemes seem costly in terms of identifying the right multipliers and adjusting the green goal or the administration of certificates market for each green technology, these non-neutral policies can end up in a greater participation of green energy sources as a proportion of the total production. At the same time, they also increase the energy production of both technologies compared to the neutral case. Another peculiarity of the non-neutral policies is that it does not matter if it is a quantity or a price mechanism, in the two cases the energy production for all the green technologies is the same.

Contrary to literature and my initial assumption, the optimum multiplier of technology 1 can be larger or smaller than γ_2, depending on the social cost of emissions, d. If it is low, $0 < d < \frac{2bc_{v_2} - b^2 - 6bc_c - 4c_c^2}{(b+2c_{v_2})}$, then, the technology 1 receives more certificates than technology 2. This may indicate that there is a trade-off between the emission cost and the size of the multiplier for technology 1. Since this is the most expensive generator, the regulator cannot set $\gamma_1 > \gamma_2$ when d is high because the increase in the generation of firm 1 would result into larger generation costs and a welfare loss. On the contrary, when d is low, then the regulator can incentivize more energy production from the firm 1 by giving it more green certificates than firm 2.

This result is relevant because when policymakers decide to boost energy production from expensive technologies, it may seem reasonable to assume they should receive more certificates because they are more costly and need to receive more income from the certificates' market to cover their costs. However, when the social cost of emissions is considered, then keeping this assumption would end in a welfare reduction.

Finally, the result in Proposition 7 may result counterintuitive after Proposition 6. Even though the value of non-neutral policies does not rely on offering cheaper tariffs to consumers compared to the neutral policy, it allows reaching a higher green energy goal. A bigger α reduces energy prices that can compensate the expenditure in certificates. In addition, in the social optimum, there is more production of green energy, compared to the neutral approach, which also reduces the emissions of conventional generation.

Here, Proposition 7 explains that under the optimum policy variables α, β_1 and γ_1, both credit multipliers and carve-outs policies reach the same social welfare, thus they are equivalent. Again, it does not matter if it is a quantity or price approach, the non-neutral policies lead to identical outcomes in the optimum.

5 Conclusions

The neutral RPS policy promotes the competence in the same conditions for all the green generation technologies. However, this may hinder the diversification of generation resources and favor cheap and mature technologies. To face this limitation, some countries have implemented non-neutral policies which give a differentiated treatment to the green technologies depending on their costs.

I characterize the equilibria for the non-neutral policies: credit multipliers and carve-outs. The difference between the neutral approach and my specification lies in the clearing market conditions I proposed. The first one considers the additional certificates for each technology, so it breaks with the duality between certificates market equilibrium and green generation goal.

The literature about credit multipliers warns on not reaching the generation target because of the increase in the available certificates. This issue was also present in my specification; however, I solve it by calculating an adjusted $\tilde{\alpha}$. After using this instead of α, I found that the electric market reached the green generation goal.

This adjustment is similar to what is done in the UK with the headroom adjustment when this country sets its annual green energy goal. This is important because it sets a simple formula to calculate how big $\tilde{\alpha}$ needs to be in order to reach α, with the size of the multipliers and generation costs as inputs.

After comparing the energy outcomes, surprisingly, I noticed that the three policies ended up producing not only the same share of green energy but also the energy production, even though I used $\tilde{\alpha}$ to estimate the credit multipliers equilibrium. The only difference is how the generation distributes between green technologies in all the policies. This result is different from what Gürkan and Langestraat (2014) and Fischlein and Smith (2013) found in the UK and the US.

After calculating the electric tariff for the consumer in each case, I found that the neutral policy results in lower energy expenditure compared to both non-neutral scenarios. I expected them to be more expensive since the obligation for certificates creates a submarket for each technology and the quota sets the price, in the case of carve-outs. While for credit multipliers, the certificates granted to each technology determines the price.

Does this mean that the neutral policy is better than the non-neutral ones? No. I analyzed the rent-seeking behavior of the green firm under both approaches, and I observed that the neutral policy gives the biggest additional income, followed by the credit multipliers. Since each technology is liquidated in a separated market, the carve-outs scheme is the one that gives the least additional income to green firms. This finding is in line to previous descriptive analysis in the literature, where carve-outs are characterized as the best option to finish with the rent-seeking behavior, although in practice having many submarkets incurs in additional administrative costs for the regulator.

Finally, in terms of social welfare, after comparing the three schemes, it turned out that both non-neutral policies lead to the same optimal green energy share, which is greater than the neutral one. On top of that, the production of the two technologies is the same under credit multipliers and carve-outs. I conclude that it does not matter which non-neutral policy the regulator chooses, in the social welfare optimum, they lead to the same outcomes and, even though they entail more administrative costs, the welfare is superior compared to implementing an RPS neutral policy.

6 Proofs

Proof of Proposition 1. The conventional, green 1 and green 2 firms solve their optimization problems in (1), (2) and (3), respectively, that leads to the following first-order conditions (FOC). Since this problem refers to credit multipliers' approach, I will omit the superscript m.

$$q_c: \quad a - b(2q_c + q_{v_1} + q_{v_2}) - 2c_c q_c = 0, \tag{9}$$

$$q_{v_1}: \quad a - b(q_c + 2q_{v_1} + q_{v_2}) - 2c_{v_1} q_{v_1} + P_c\gamma_1 = 0, \tag{10}$$

$$q_{v_2}: \quad a - b(q_c + q_{v_1} + 2q_{v_2}) - 2c_{v_2} q_{v_2} + P_c\gamma_2 = 0 \tag{11}$$

The objective functions are strictly concave, the second-order condition (SOC) is $-2b - c_i$, $i = c, v_1, v_2$. Thus, there is a maximum. Solving the system equation in (9), (10) and (11)

$$q_c = \frac{a(b+2c_{v_1})(b+2c_{v_2}) - bP_c(b(\gamma_1+\gamma_2) + 2(\gamma_2 c_{v_1} + \gamma_2 c_{v_2}))}{4b^3 + 6b^2(c_c + c_{v_1} + c_{v_2}) + 8b(c_c(c_{v_1}+c_{v_2}) + c_{v_1}c_{v_2}) + 8c_c c_{v_1} c_{v_2}}, \tag{12}$$

$$q_{v_1} = \frac{a(b+2c_c)(b+2c_{v_2}) + P_c\left(b^2(3\gamma_1-\gamma_2) + b(4\gamma_1 c_c - 2\gamma_2 c_c + 4\gamma_1 c_{v_2}) + 4\gamma_1 c_c c_{v_2}\right)}{4b^3 + 6b^2(c_c + c_{v_1} + c_{v_2}) + 8b(c_c(c_{v_1}+c_{v_2}) + c_{v_1}c_{v_2}) + 8c_c c_{v_1} c_{v_2}}, \tag{13}$$

$$q_{v_2} = \frac{a(b+2c_c)(b+2c_{v_1}) + P_c\left(-b^2(\gamma_1-3\gamma_2) + b(-2\gamma_1 c_c + 4\gamma_2 c_c + 4\gamma_2 c_{v_1}) + 4\gamma_2 c_c c_{v_1}\right)}{4b^3 + 6b^2(c_c + c_{v_1} + c_{v_2}) + 8b(c_c(c_{v_1}+c_{v_2}) + c_{v_1}c_{v_2}) + 8c_c c_{v_1} c_{v_2}}. \tag{14}$$

Using (A3) to find the certificates' price, $P_c(\alpha, \gamma_1, \gamma_2)$ to obtain the equilibrium outcomes in terms of the policy parameters.

Now, I verify if credit multipliers policy reaches the green generation goal $\frac{q_{v_1}+q_{v_2}}{q_{v_1}+q_{v_2}+q_c} = \alpha$

$$\frac{q_c}{q_{v_1}+q_{v_2}+q_c} = \frac{b\left(-\alpha(\gamma_1+\gamma_2) + \gamma_1^2 + \gamma_2^2\right) + 2\gamma_2 c_{v_1}(\gamma_2-\alpha) + 2\gamma_1 c_{v_2}(\gamma_1-\alpha)}{2\left(b\left(\gamma_1^2 - \gamma_1\gamma_2 + \gamma_2^2\right) + c_c(\gamma_1-\gamma_2)^2 + \gamma_2^2 c_{v_1} + \gamma_1^2 c_{v_2}\right)} \neq (1-\alpha) \tag{15}$$

To find the adjusted green goal, it is necesary to solve for $\tilde{\alpha}$ that refers to the goal the regulator should set to reach its original goal α, this is $\frac{q_{v_1}(\tilde{\alpha})+q_{v_2}\tilde{\alpha}}{q_{v_1}\tilde{\alpha}+q_{v_2}\tilde{\alpha}+q_c\tilde{\alpha}} = \alpha$

$$\frac{b\left(\tilde{\alpha}(\gamma_1+\gamma_2)+(\gamma_1-\gamma_2)^2\right)+2\left(c_c(\gamma_1-\gamma_2)^2+\tilde{\alpha}\gamma_2 c_{v_1}+\tilde{\alpha}\gamma_1 c_{v_2}\right)}{2\left(b\left(\gamma_1^2-\gamma_1\gamma_2+\gamma_2^2\right)+c_c(\gamma_1-\gamma_2)^2+\gamma_2^2 c_{v_1}+\gamma_1^2 c_{v_2}\right)} = \alpha$$

$$\tilde{\alpha} = \frac{(2\alpha-1)b\gamma_1^2-2(\alpha-1)b\gamma_1\gamma_2+(2\alpha-1)b\gamma_2^2+2(\alpha-1)c_c(\gamma_1-\gamma_2)^2+2\alpha\left(\gamma_2^2 c_{v_1}+\gamma_1^2 c_{v_2}\right)}{b(\gamma_1+\gamma_2)+2(\gamma_2 c_{v_1}+\gamma_1 c_{v_2})}$$

Notice that when $\gamma_1 = \gamma_2 = 1$, then $\tilde{\alpha} = \alpha$ because it is the neutral policy case and there is no need of additional adjustment for the green generation goal.

Proof of Proposition 2. To obtain the new outcomes after adjusting with $\tilde{\alpha}$, it is enough with replacing $\tilde{\alpha}$ in $P_c(\tilde{\alpha})$ and then plug it into equations (12), (13) and (14).

$$q_c^m = \frac{a(\alpha-1)}{(\alpha-2)b+2(\alpha-1)c_c}, \tag{16}$$

$$q_{v_1}^m = -\frac{a(b((2\alpha-1)\gamma_1-\alpha\gamma_2+\gamma_2)+2((\alpha-1)c_c(\gamma_1-\gamma_2)+\alpha\gamma_1 c_{v_2}))}{((\alpha-2)b+2(\alpha-1)c_c)(b(\gamma_1+\gamma_2)+2(\gamma_2 c_{v_1}+\gamma_1 c_{v_2}))}, \tag{17}$$

$$q_{v_2}^m = \frac{a(b((\alpha-1)\gamma_1-2\alpha\gamma_2+\gamma_2)+2(\alpha-1)c_c(\gamma_1-\gamma_2)-2\alpha\gamma_2 c_{v_1})}{((\alpha-2)b+2(\alpha-1)c_c)(b(\gamma_1+\gamma_2)+2(\gamma_2 c_{v_1}+\gamma_1 c_{v_2}))}. \tag{18}$$

Proof of Proposition 3. To obtain the outcome under the neutral policy, I assume $\gamma_1 = \gamma_2 = 1$ and replace them in (17), (18) and (19).

$$q_c^n = \frac{a(\alpha-1)}{(\alpha-2)b+2(\alpha-1)c_c},$$

$$q_{v_1}^n = -\frac{a\alpha(b+2c_{v_2})}{2((\alpha-2)b+2(\alpha-1)c_c)(b+c_{v_1}+c_{v_2})},$$

$$q_{v_2}^n = -\frac{a\alpha(b+2c_{v_1})}{2((\alpha-2)b+2(\alpha-1)c_c)(b+c_{v_1}+c_{v_2})}.$$

Proof of Proposition 4. The conventional, green 1 and green 2 firms solve their optimization problems in (1), (4) and 53), that leads to the following FOC. Since this problem refers to carve-outs approach, I will omit the superscript *co*.

$$q_c: \quad a - b(2q_c + q_{v_1} + q_{v_2}) - 2c_c q_c = 0, \tag{19}$$

$$q_{v_1}: \quad a - b(q_c + q_{v_1} + q_{v_2}) - bq_{v_1} - 2c_{v_1} q_{v_1} + P_{c_1} = 0, \tag{20}$$

$$q_{v_2}: \quad a - b(q_c + q_{v_1} + q_{v_2}) - bq_{v_2} - 2c_{v_2} q_{v_2} + P_{c_2} = 0. \tag{21}$$

Solving the system equation gives as result,

$$q_c = \frac{a(b + 2c_{v_1})(b + 2c_{v_2}) - b(b(P_{c_1} + P_{c_2}) + 2(c_{v_1} P_{c_2} + c_{v_2} P_{c_1}))}{4b^3 + 6b^2(c_c + c_{v_1} + c_{v_2}) + 8b(c_c(c_{v_1} + c_{v_2}) + c_{v_1} c_{v_2}) + 8c_c c_{v_1} c_{v_2}}, \tag{22}$$

$$q_{v_1} = \frac{a(b + 2c_c)(b + 2c_{v_2}) + b^2(3P_{c_1} - P_{c_2}) + b(4c_c P_{c_1} - 2c_c P_{c_2} + 4c_{v_2} P_{c_1}) + 4c_c c_{v_2} P_{c_1}}{4b^3 + 6b^2(c_c + c_{v_1} + c_{v_2}) + 8b(c_c(c_{v_1} + c_{v_2}) + c_{v_1} c_{v_2}) + 8c_c c_{v_1} c_{v_2}}, \tag{23}$$

$$q_{v_2} = \frac{a(b + 2c_c)(b + 2c_{v_1}) - (b^2(P_{c_1} - 3P_{c_2})) + b(-2c_c P_{c_1} + 4c_c P_{c_2} + 4c_{v_1} P_{c_2}) + 4c_c c_{v_1} P_{c_2}}{4b^3 + 6b^2(c_c + c_{v_1} + c_{v_2}) + 8b(c_c(c_{v_1} + c_{v_2}) + c_{v_1} c_{v_2}) + 8c_c c_{v_1} c_{v_2}}. \tag{24}$$

Using (A4) to find the prices P_{c_1} and P_{c_2},

$$P_{c_1} = \frac{a[\beta_1(b + 2c_{v_1}) - (1 - \alpha)(b + 2c_c)]}{b(2 - \alpha) + 2c_c(1 - \alpha)}, \tag{25}$$

$$P_{c_2} = \frac{a[(\alpha - \beta_1)(b + 2c_{v_2}) - (1 - \alpha)(b + 2c_c)]}{b(2 - \alpha) + 2c_c(1 - \alpha)}. \tag{26}$$

Substituting P_{c_1} and P_{c_2} in (23), (24) and (25),

$$q_{v_1}^{co} = -\frac{a\beta 1}{(\alpha - 2)b + 2(\alpha - 1)c_c},$$

$$q_{v_2}^{co} = \frac{a(\beta 1 - \alpha)}{(\alpha - 2)b + 2(\alpha - 1)c_c}.$$

Proof of Proposition 7. The regulator solves the following social welfare maximization problems

$$\text{neutral:} \quad \max_{\alpha} SW^n = U(q^n) - c_c q_c^n - c_{v_1} q_{v_1}^n - c_{v_2} q_{v_2}^n - \frac{d(q_c^n)^2}{2}, \tag{27}$$

$$\text{multipliers:} \quad \max_{\alpha,\gamma_1} SW^m = U(q^m) - c_c q_c^m - c_{v_1} q_{v_1}^m - c_{v_2} q_{v_2}^m - \frac{d(q_c^m)^2}{2}, \tag{28}$$

$$\text{carve outs:} \quad \max_{\alpha,\beta_1} SW^{co} = U(q^{co}) - c_c q_c^{co} - c_{v_1} q_{v_1}^{co} - c_{v_2} q_{v_2}^{co} - \frac{d(q_c^{co})^2}{2}. \tag{29}$$

The SW^n function is strictly concave, the SOC $SW^n_{\alpha,\alpha} < 0$, thus, there is a maximum. The SW^{co} is concave with $M_1 \leq 0$ and $M_2 \geq 0$, thus, there is a maximum. The SW^m has two critical points $P_1 = (\alpha', \gamma_1')$, and $P_2 = (\alpha'', \gamma_1'')$. The determinant of the Hessian matrix in P_1 is positive and $SW^m_{\alpha,\alpha} < 1$, thus, P_1 is maximum. Regarding P_2, the determinant is negative, thus, P_2 is a saddle point.

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