Response to rapporteur 1

I thank the rapporteur for the relevance of his remarks, which allowed me to improve the paper. below, I answer his remarks one by one.

1. Summary of the paper

This paper looks at the impact of introducing an environmental tax on a brown industry on investments in a green industry. Looking at the electricity production setting where both industries are producing the same output, a model is provided to challenge the conventional idea according to which an environmental tax would positively impact investments in renewable energy sources, as prices would play their role and send the right signals to investors. The author argues that this relationship is more complex than usually thought due to the intermittency of renewable energy sources.

Answer 1:

I liked the summary you gave for the paper and i was inspired by it for my abstract.

2. Overall evaluation

* This paper attracts a much-deserved attention to a very important issue. While this literature is mainly empirical, it provides an interesting insight to this question by the means of a simple but elegant model.

My main issues relate with the way the paper is written and how the model is presented. There are several important results in the paper but the key factor explaining them tends to be unclear. The fact that derivations are all left to the appendix tends to make it a difficult task to the reader. The paper would benefit by being organized around lemma 's and theorems, leaving the less important derivations in the appendix. This way the main forces behind the results could be made more obvious by highlighting the trade-off at work.

Answer 2:

You were right when drawing my attention to this topic. I applied your advice and tried to organize the paper around lemma's and theorems to highlight the important results. As you can see in the paper, I highlighted the derivations and the important equations at the heart of the text. Moreover, I have put in place three proposals which present the most important results, in order to facilitate the comprehension of the paper for the reader.

You will find in the paper:

Proposition 1: page 10.

*Proposition 2:*page 11.

proposition 3: page 14.

This allowed me to better explain the economic intuition of the results and make the paper much more fluid and easier to read.

*** Your proposal:**

For example, according to the introduction, two key assumptions are at the roots of the results: increasing marginal cost of the brown technology and increasing environmental marginal damage. From looking at the model it is not clear how these two assumptions are needed as they are not anymore discussed afterwards. Are they jointly needed? What happens if only one of them is made? Looking at each of them separately could help show the mechanism behind the result.

Answer 3:

Below, I discuss different possibilities concerning the two assumptions: increasing marginal cost of the brown technology and increasing environmental marginal damage. I analyze what happens if only of them is made or if we completely remove them from analysis:

1. Case one: constant environmental marginal damage and production marginal costs:

This means that the marginal production costs and the environmental marginal damage would be equal to:

$C'\left(q\left(\omega\right)\right)=c$

$d'\left(Z\left(\omega\right)\right)=z$

1.1. Optimal policy

$\int_{\omega_0}^{\omega_1}\left[S(D)-C\left(q\left(\omega\right)\right)-F\left(k\right)-d(Z(\omega))\right]dG(\omega)$

subject to:

$D=q\left(\omega\right)+\omega k$ and $Z(\omega)=q(\omega)$ for all ω.

Intergrating the second constraint, the Lagrangian of this problem writes:

$L=\int_{\omega_0}^{\omega_1}\left[\begin{array}{c} S(D)-C\left(q\left(\omega\right)\right)-F\left(k\right)-d(q\left(\omega\right)) \\ -\lambda\left(\omega\right)\left(D-q\left(\omega\right)-\omega k\right)\end{array}\right]dG(\omega)$

let $D^0, q^0\left(\omega\right)$ and k^0 be the solution. It satisfies the first order conditions:

$\lambda\left(\omega\right)=C'\left(q^0\left(\ \omega\right)\right)+d'(q^0\left(\ \omega\right))$, for all ω.

$P(D^0)=\int_{\omega_0}^{\omega_1}\lambda\left(\omega\right)dG(\omega)$

$F'\left(k^0\right)=\int_{\omega_0}^{\omega_1}\lambda\left(\omega\right)\omega dG(\omega)$

Using the linear quadratic specification of our mode, we can write:

$P(D^0)=\int_{\omega_0}^{\omega_1}\left(c+z\right)dG(\omega)=c+z$

$F'\left(k^0\right)=\int_{\omega_0}^{\omega_1}\left(c+z\right)\omega dG(\omega)=c+z$

Using the linear quadratic specification of the model we get:

$$P(D^0)=c+z \tag{1}$$

$$F'\left(k^0\right) = c + z \tag{2}$$

1.2. Competitive equilibrium with emissions tax:

**** Spot market***

For all ω, let $p(\omega)$ represent the equilibrium spot price of electricity in the state ω. The intermittent generators supply ωk.

The spot market clearing condition is: $D = q(\omega) + \omega k$

Conventional generators supply $q^*(\omega)$ such that:

$p^*(\omega) = C'\left(q^*(\omega)\right) + T$

Using the linear quadratic specification of the model we get:

$$p^*(\omega) = c + T \tag{3}$$

**** Forward market:***

Consider the market of contracts. Each consumer demands D such that $P(D) = \overline{p}$. Retailers supply $\overline{q}$ at price $\overline{p}$. They anticipate that they will buy their electricity at the spot price $p(\omega)$, for all ω. Thus, in equilibrium, the price of contracts $\overline{p}$ must be equal to the expected price of the electricity on the spot markets $\overline{p} = E\left[p(\omega)\right]$, with $p(\omega) = C'(q(\omega)) + T$. Thus competition among retailers drives $\overline{p}$ to be equal to the average of the wholesale price. The forward clearing condition is $D = \overline{q}$.

The equilibrium forward market checks:

$P(D^*) = \int_{\omega_0}^{\omega_1} C'\left(q^*(\omega)\right) dG(\omega) + T$

Using the linear quadratic specification of the model we get:

$$P(D^*) = c + T \tag{4}$$

**** Intermittent capacity :***

The intermittent generators anticipate the equilibrium prices $p(\omega)$, for all ω and correspondingly choose k to maximize: $\pi = \int_{\omega_0}^{\omega_1} (p(\omega)\,\omega k) dG(\omega) - F(k)$.

Under the assumption of perfect competition, the equilibrium capacity will satisfy:

$F'(k^*) = \int_{\omega_0}^{\omega_1} C'\left(q^*(\omega)\right) \omega dG(\omega) + T = c \int_{\omega_0}^{\omega_1} \omega dG(\omega) + T$

Using the linear quadratic specification of the model and $E[\omega] = 1$,we get:

$$F'(k^*) = c + T \tag{5}$$

**** Efficiency of the taxation at the expected environmental marginal damage:***

Let $\overline{T}$ denote the optimal tax rate:

$\overline{T} = \int_{\omega_0}^{\omega_1} d'\left(Z^o\left(\omega\right)\right) dG(\omega) = z.$

The efficiency of this tax rate depends on its ability to recover the same conditions as the optimal state through the conditions of market equilibrium. Thus, we will replace: T by $\overline{T}$, q^* by q^o and D^* by D^o in conditions (4) and (5) and verify if we can find conditions (1) and (2).

By replacing the equilibrium quantities by the optimal quantities, we find the same conditions as those of the optimal state:

$$P(D^o) = c + z \tag{6}$$

$$F'\left(k^o\right) = c + z \tag{7}$$

As we can see, equations (6) and (7) correspond to the conditions of the optimal state (equations 1 and 2). Thus, when the marginal production costs and the environmental marginal damage are constant, the Pigouvian tax rate is effective in decentralizing optimal quantities.

This proposal is consistent with Ambec and Cramps (2015) who suggest that ”The Pigou tax rate is easy to compute under our assumption of constant marginal damage due to pollution. It would be more complex under alternative assumptions on environmental damage such as increasing marginal damage. The Pigou tax rate would then vary with the state of nature (whether there is wind or not) or with pollution concentration”.

2. Case two: constant environmental marginal damage and increasing marginal production costs:

This means that the marginal production costs and the environmental marginal damage would be equal to:

$C'\left(q\left(\omega\right)\right) = cq\left(\omega\right)$

$d'\left(Z\left(\omega\right)\right) = z$

2.1 Optimal policy

$\int_{\omega_0}^{\omega_1} \left[S(D) - C\left(q\left(\omega\right)\right) - F\left(k\right) - d(Z(\omega))\right] dG(\omega)$

subject to :

$D = q\left(\omega\right) + \omega k$ and $Z(\omega) = q(\omega)$

for all ω

Intergrating the second constraint, the Lagrangian of this problem writes:

$L = \int_{\omega_0}^{\omega_1} \left[\begin{array}{c} S(D) - C\left(q\left(\omega\right)\right) - F\left(k\right) - d(q\left(\omega\right)) \\ -\lambda\left(\omega\right)\left(D - q\left(\omega\right) - \omega k\right) \end{array} \right] dG(\omega)$

let $D^0, q^0\left(\omega\right)$ and k^0 be the solution. It satisfies the first order conditions:

$\lambda\left(\omega\right) = C'\left(q\left(\ \omega\right)\right) + d'(q\left(\ \omega\right))$, for all ω.

$P(D) = \int_{\omega_0}^{\omega_1} \lambda\left(\omega\right) dG(\omega)$

$F'\left(k\right) = \int_{\omega_0}^{\omega_1} \lambda\left(\omega\right) \omega dG(\omega)$

Using the linear quadratic specification of the model we get:

$$P(D^o) = c\int_{\omega_0}^{\omega_1} q^o\left(\omega\right)dG(\omega) + z \tag{8}$$

$$F'\left(k^o\right) = c\int_{\omega_0}^{\omega_1} q^o\left(\omega\right)\omega dG(\omega) + z \tag{9}$$

2.2. Competetive equilibrium with emissions tax:

**** Spot market:***

For all ω, let $p(\omega)$ represent the equilibrium spot price of electricity in the state ω. The intermittent generators supply ωk.

The spot market clearing condition is: $D = q(\omega) + \omega k$

Conventional generators supply $q^*(\omega)$ such that:

$$p^*(\omega) = C^{'}\left(q^*(\omega)\right) + T = cq^*\left(\omega\right) + T \tag{10}$$

**** Forward market:***

Consider the market of contracts. Each consumer demands D such that $P(D) = \overline{p}$. Retailers supply $\overline{q}$ at price $\overline{p}$. They anticipate that they will buy their electricity at the spot price $p\left(\omega\right)$, for all ω. Thus, in equilibrium, the price of contracts $\overline{p}$ must be equal to the expected price of the electricity on the spot markets $\overline{p} = E\left[p\left(\omega\right)\right]$, with $p(\omega) = C'(q\left(\omega\right)) + T$. Thus competition among retailers drives $\overline{p}$ to be equal to the average of the wholesale price. The forward clearing condition is $D = \overline{q}$.

The equilibrium forward market checks:

$$P(D^*) = \int_{\omega_0}^{\omega_1} C^{'}\left(q^*(\omega)\right)dG(\omega) + T = c\int_{\omega_0}^{\omega_1} q^*\left(\omega\right)dG(\omega) + T \tag{11}$$

**** Intermittent capacity***

The intermittent generators anticipate the equilibrium prices $p(\omega)$, for allω and correspondingly choose k to maximize:

$\pi = \int_{\omega_0}^{\omega_1}\left(p(\omega)\right)\omega k dG(\omega) - F\left(k\right)$

Under the assumption of perfect competition, the equilibrium capacity will satisfy:

$$F'\left(k^*\right) = \int_{\omega_0}^{\omega_1} C^{'}\left(q^*(\omega)\right)\omega dG(\omega) + T = c\int_{\omega_0}^{\omega_1} q^*(\omega)\omega dG(\omega) + T \tag{12}$$

**** Efficiency of the taxation at the expected environmental marginal damage:***

Let $\overline{T}$ denote the optimal tax rate:

$\overline{T} = \int_{\omega_0}^{\omega_1} d'\left(Z^o\left(\omega\right)\right) dG(\omega) = z.$

The efficiency of this tax rate depends on its ability to recover the same conditions as the optimal state through the conditions of market equilibrium. Thus, we will replace: T by $\overline{T}$, q^* by q^o and D^* by D^o in conditions (11) and (12) and verify if we can find conditions (8) and (9).

By replacing the equilibrium quantities by the optimal quantities, we find the same conditions as those of the optimal state.

Thus, when marginal production costs are increasing and the environmental marginal damage is constant, the Pigouvian tax rate is effective in decentralizing optimal quantities. bnn b The taxation at the environmental marginal damage allows to internalize the environmental damage. However, the assumption of increasing environmental marginal damage is important in our paper. Indeed, this hypothesis makes it possible to account for the additional difficulties involved in introducing renewable energy into the energy mix.

3. Case three: constant marginal production costs and increasing environmental marginal damage:

$C'\left(q\left(\omega\right)\right) = c$

$d'\left(Z\left(\omega\right)\right) = z\left(q\left(\omega\right)\right)$

3.1. Optimal policy

$\int_{\omega_0}^{\omega_1} \left[S(D) - C\left(q\left(\omega\right)\right) - F\left(k\right) - d(Z(\omega))\right] dG(\omega)$

subject to :

$D = q\left(\omega\right) + \omega k$ and $Z(\omega) = q(\omega)$

for all ω

Intergrating the second constraint, the Lagrangian of this problem writes:

$L = \int_{\omega_0}^{\omega_1} \left[\begin{array}{c} S(D) - C\left(q\left(\omega\right)\right) - F\left(k\right) - d(q\left(\omega\right)) \\ -\lambda\left(\omega\right)\left(D - q\left(\omega\right) - \omega k\right) \end{array} \right] dG(\omega)$

let $D^0, q^0\left(\omega\right)$ and k^0 be the solution. It satisfies the first order conditions:

$\lambda\left(\omega\right) = C'\left(\ q\left(\omega\right)\ \right) + d'(q\left(\omega\right)$ for all ω.

$P(D) = \int_{\omega_0}^{\omega_1} \lambda\left(\omega\right) dG(\omega)$

$F'\left(k\right) = \int_{\omega_0}^{\omega_1} \lambda\left(\omega\right) \omega dG(\omega)$

using the quadratic specification of the model we get:

$$P(D^o) = c + z\int_{\omega_0}^{\omega_1} q^o\left(\omega\right) dG(\omega) \tag{13}$$

$$F'\left(k^o\right) = c + z\int_{\omega_0}^{\omega_1} q^o\left(\omega\right) \omega dG(\omega) \tag{14}$$

3.2. Competitive equilibrium with emissions tax:

Spot market:

For all ω, let $p(\omega)$ represent the equilibrium spot price of electricity in the state ω. The intermittent generators supply ωk.

The spot market clearing condition is: $D = q(\omega) + \omega k$

Conventional generators supply $q^*(\omega)$ such that:

$p^*(\omega) = \ C^{'}\left(q^*(\omega)\right) + T = c + T$

**** Forward market:***

Consider the market of contracts. Each consumer demands D such that $P(D) = \overline{p}$. Retailers supply $\overline{q}$ at price $\overline{p}$. They anticipate that they will buy their electricity at the spot price $p\left(\omega\right)$, for all ω. Thus, in equilibrium, the price of contracts $\overline{p}$ must be equal to the expected price of the electricity on the spot markets $\overline{p} = E\left[p\left(\omega\right)\right]$, with $p(\omega) = C'(q\left(\omega\right)) + T$. Thus competition among retailers drives $\overline{p}$ to be equal to the average of the wholesale price. The forward clearing condition is $D = \overline{q}$.

The equilibrium forward market checks:

$$P(D^*) = \int_{\omega_0}^{\omega_1} C^{'}\left(q^*(\omega)\right) dG(\omega) + T = \int_{\omega_0}^{\omega_1} c dG(\omega) + T = c + T \qquad (15)$$

**** Intermittent capacity***

The intermittent generators anticipate the equilibrium prices $p(\omega)$, for all ω and correspondingly choose k to maximize:

$\pi = \int_{\omega_0}^{\omega_1} \left(p(\omega) + T\right) \omega k dG(\omega) - F\left(k\right)$

Under the assumption of perfect competition, the equilibrium capacity will satisfy:

$$F'\left(k^*\right) = \int_{\omega_0}^{\omega_1} C^{'}\left(q^*(\omega)\right) \omega dG(\omega) + T == c + T \qquad (16)$$

**** Efficiency of the taxation at the expected environmental marginal damage:***

Let $\overline{T}$ denote the optimal tax rate:

$\overline{T} = \int_{\omega_0}^{\omega_1} d'\left(Z^o\left(\omega\right)\right) dG(\omega) = z.$

The efficiency of this tax rate depends on its ability to recover the same conditions as the optimal state through the conditions of market equilibrium. Thus, we will replace: T by $\overline{T}$, q^* by q^o and D^* by D^o in conditions (15) and (16) and verify if we can find conditions (13) and (14).

By replacing the equilibrium quantities by the optimal quantities, we get:

$$P(D^o) \neq c + z \int_{\omega_0}^{\omega_1} q^o(\omega) dG(\omega)$$

$$F'\left(k^{o}\right) \neq c + z \int_{\omega_0}^{\omega_1} q^{o}(\omega) dG(\omega)$$

These conditions are different from the conditions of the optimal state (conditions 13 and 14). Thus, when marginal production costs are constant and the environmental marginal damage is increasing, the Pigouvian tax rate is not effective in decentralizing the optimal quantities. This result is intuitive since our goal is to internalize environmental damage with a tax on emissions. Thus, when the environmental damage is constant, the Pigouvian tax is effective to decentralize the optimal state. However, when environmental damage is increasing, the intermittency of renewable energies prevents the Pigouvian tax from decentralizing the optimal state (as demonstrated in the paper).

Concerning the adoption of the hypothesis of increasing production costs, it is appropriate to represent the initial situation where the incumbent firms own many generating units, using a large variety of conventional technologies (hydro, nuclear, coal, gas, oil), with different marginal costs of generating electricity, and where the overall capacity of this set of generating units is sufficient to match the demand and to prevent black-out. This picture fits quite well the actual situation of several countries in Europe, where there exists an overcapacity of conventional units remaining in operation till the end of their programmed lifetime.

With regard to the assumption of increasing environmental damage, it is important to highlight the additional challenges imposed to the regulators induced by the existence of renewable energy sources in the energy mix.

This is why, these two assumptions are needed jointly, to better reflect the actual situation of the electricity sector.

*** Your proposal:**

It is also unclear to me what happens when there is an electricity shortage. You state that the ≪ load-shedding involves voluntarily stopping the supply of one or more consumers to quickly restore the balance ≫. How does this translate to the consumers and the regulator in your model. How is the utility of electricity users modeled in this case? Has someone to pay for the disutility created? The retailer? As this issue is clearly related with intermittency, the driver of the main result of the paper, this should be clarified at the very least.

Answer 4

According to the assumptions adopted in this model(all consumers are on traditional meters, fossil sector has no capacity constraints), this sentence should not have been there because our model does not deal with the issue of load shedding. If the model does not deal with this question it is because the current situation of the electricity sector excludes this kind of situation because of the over-capacity of electricity production in Europe.[1]

This sentences was introduced in our paper as part of the possibility of considering the situation of having a price cap in our model. I think she has nothing to do in our context and I chose to remove it from the paper. This question may be a subject for future research but with more appropriate hypotheses. For indication, I can put this part in appendix if you think that it is important. If not I removed this part of the paper to avoid misleading the reader.

3. Other issues

[1] https://www.lesechos.fr/30/12/2014/lesechos.fr/0204046299664-tarif-de-l-electricite—le-paradoxe-europeen.htm

The paper could benefit from being more explicitly linked to the literature on directed technical change in this environmental context such as in Aghion et al. (2016). Several papers in this literature have looked empirically at questions really close to the one of the paper (mostly focusing on RandD instead of investments) like Nesta et al. (2014) or Noailly and Smeets (2015) in the context of renewable energy sources.

Answer 5:

Following your recommendations, I read and analyzed the papers you suggested to me. Indeed, it's a very rich literature. It is true that these papers have looked empirically at questions close to the one of the paper, but as you have mentioned, they are focusing on RandD while we suppose that technologies are given. I think that even if we do not treat the question in the same way, this literature is very interesting and gives another interesting approach to deal with the efficiency of the optimal taxation. Thus, I positioned the paper in relation to this literature in the introduction.(page 3, paragraph 2)

*** Your proposal:**

The paper could benefit of a better explanation of where the setting assumed in the model (as defined by the assumptions made related to the cost structure and the assumption of an infinite capacity of brown technology) fits the best. For example, I doubt that it works well to understand the situation in under-developed countries or countries with many brown producers retiring soon.

Answer 6:

As mentioned in the introduction (page 3, paragraph 3), the context and assumption adopted in the model presented in this paper, corresponds quite well to the current situation of several European countries, such as Germany, where there is an overcapacity of conventional units remaining in operation until the end of their programmed life.

*** Your proposal**

There is an important stochastic ingredient in the model that comes from the uncertain production of electricity from renewable sources. It could be interesting to discuss what happens if you assume that the regulator is risk averse.

Answer 7:

In the current context of the model: the regulator is not risk averse: The total surplus is as follows:

$$W(w) = S(D) - C(q(\omega)) - d(Z(\omega)) - F(k)$$

The utility of the regulator is therefore the following:

$$\int_{\omega_0}^{\omega_1} [U(W(w))] \, dG(\omega) = \int_{\omega_0}^{\omega_1} [S(D) - C\left(q\left(\omega\right)\right) - d(Z(\omega))] \, dG(\omega) - F\left(k\right),$$

The linear form of the utility function proposed in the model facilitates the resolution of the model and provides us readable and understandable equations. As we can see in the previous equation, we could leave $F(k)$ outside the integral because it does not depend on ω.

If we consider that the regulator is risk-averse, its utility function will be concave:

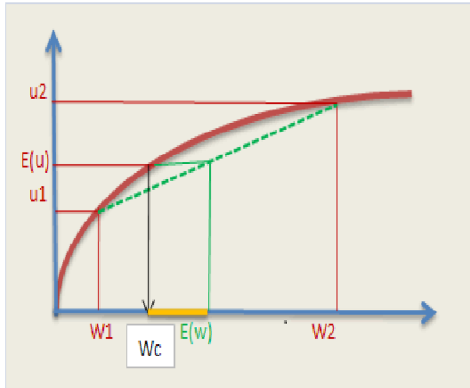

Figure 1: utility function of a risk-averse economic agent

In our context, the Utility function of a risk averse regulator would be equal to:

$$\int_{\omega_0}^{\omega_1} \left[S(D) - C\left(q\left(\omega\right)\right) - d(Z(\omega)) - F\left(k\right)\right] dG(\omega),$$

Thus, the $F(k)$ remains inside the integral. If we want to consider the risk aversion of the regulator we can for example, solve the model with a function of utility in the following form:

$$\int_{\omega_0}^{\omega_1} \sqrt{S(D) - C\left(q\left(\omega\right)\right) - d(Z(\omega)) - F\left(k\right)} dG(\omega),$$

However, this form of modeling is not standard and is quite unusual compared to what is done in the literature with respect to this subject. I think that it's not a good idea to do it for several reasons:

* Since it is unusual, such modeling makes the model not comparable with what is done in the literature.

* It complicates the calculation and we obtain illegible equations, which makes their interpretation more difficult.

Also, I think that the hypothesis of the regulator is risk averse may not be justified because the regulator has the opportunity to diversify his risk and therefore he can insure himself against the risk.

Involvement of concavity of utility functions in general:

* If the second derivative of the utility function is negative, then the function is concave, which means that the higher the level of wealth of an individual, the less risky it is,

* **An infinitely rich agent is therefore risk-neutral.**

* **Your proposal**

According to your graphs (figure 2 and 3), the supply function is linear. Shouldn't it be convex, following your assumption?

Answer 8:

The convexity of the supply function implies that: the function of total costs is convex but the function of marginal costs is increasing.

*** Finally, I correct all the typos below as you have suggested**

Typos:

- Page 2, second paragraph: there is one ≪ the ≫ extra.

- Page 3, third paragraph: focuses instead of focus.

- Page 4, third paragraph: the sign is unknown. It is positive I imagine.

- Page 8, second paragraph: pollution emitted instead of polluting emitted

- Page 11, last paragraph: I don't grasp the phrase ≪ benefit when to them"