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Pasche, Markus

Friedrich Schiller University

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Markus Pasche[1]

Friedrich Schiller University Jena
School of Economics and Business Administration
Carl-Zeiss-Straße 3, D-07743 Jena

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Abstract

The Hotelling rule is applied to the case of a fixed CO2 budget restriction which has to be met in order to reach the global warming goal according to the Paris Agreement. While the theoretical result is well-known and simple, the practical implementation under technological uncertainty suggests that tradable emission certificates are superior to CO2 taxes. The practical implementaion has also to consider that production chains are globalized, and that decarbonization strategies will be pointless if the Global South is not part of it.

Keywords: climate change; CO2 reduction, Hotelling rule, CO2 taxes, emission trading system, globalization

JEL Classification: Q54, Q58, Q30, Q37, Q38, O30

1 Introduction

The Paris Agreement is a broad consensus that global warming should not exceed 1.5 (maximum: 2) degree Celsius. As the global temperature is a function of the total stock of emitted greenhouse gases, this goal implies that the remaining amount of CO2 (and equivalents) which is allowed to being emitted, is restricted: so-called "CO2 budget". As we can interpret the absorbing capacity of the biosphere as a resource input for production, we can use the Hotelling result how to maintain infinite production with a non-renewable resource (Hotelling 1931). It is a normative approach of the intertemporally efficient use of a finite resource. The main difference is that the non-renewable resource is a private good with a price, while emissions are an externality. Moreover, the Hotelling rule is based on the fact that the technology and preferences are given and do not change through time. Thus, the result is not directly applicable to real-world. Nevertheless, the Hotelling path where permanently increasing resource prices induce a permanent substitution by factors which could be accumulated is a sort of blueprint for implementing decarbonization policies under more realistic conditions which are addressed in this paper.

[1] markus.pasche@uni-jena.de

2 Hotelling and the decarbonization path

The discussion starts with the interpretation of the aggregated production function. Such a function is a (very debatable) representation of the entire production apparatus of the economy, consisting of many different technologies in various sectors. Leaving the important and fruitful Cambridge-Cambridge controversy aside (Pasinetti/Scazzieri 1987), we concentrate on two issues: (a) in some sectors we have already backstop technologies which do not depend on fossil inputs, such like renewable energies for producing electricity. (b) In some sectors a substitution with non-fossil technologies is difficult or even impossible at the current state. We assume that this could be represented by a partial substitutability of fossil technologies with non-fossil ones. Substitution does not necessarily mean that we produce exactly the same physical bundle of goods with different inputs, but to obtain the same GDP with different technologies which might imply structural change (de-linking output from environmental input). Non-fossil ("clean") technologies require investments into a capital stock K, while the existing fossil technologies require the use of nature as a sink for CO2 emissions, E. Investments into fossil technologies as well as labor are neglected for sake of simplicity.

Thus, we assume $Y = F(K, E)$ with the usual properties of positive but declining marginal returns, partial substitutability, and constant returns to scale. A decarbonization strategy means that more and more fossil technologies are replaced by "clean" ones, which implies a permanent substitution of E by K.The CO2 budget is given by B. Utility comes from consumption only[2], $u = u(C)$. The optimization problem is (see Bergstrom 2016)

$$\max_{\{C,E\}} \int_0^\infty \beta^t u(C(t))dt$$

with $\beta \in (0, 1)$ as the discount factor, subject to

$$\dot{K}(t) = F(K(t), E(t)) - C(t)$$
$$\dot{B}(t) = -E(t)$$

and $B(t) \geq 0$ and $K(t) > 0$ for all t. Regarding the global warming goal, the compliance with the CO2 budget, here: $B(t) \geq 0 \; \forall t$, is the crucial condition. From the FOC we obtain the Hotelling rule

$$\frac{\dot{F}_E}{F_E} = F_K$$

F_K is the real return of "clean" capital, or in case of competitive markets: it's real interest rate. However, it is not clear whether a price of emissions, i.e. a price according to the marginal productivity F_E, exists. Emissions are an *externality*, unlike the resources in the original Hotelling model which are traded on markets.

So the result of the Hotelling rule implies – given that we have a market economy instead of a central planner – that emissions have to be priced according to their

[2]In addition, it might also be negatively affected by the emissions E, see Xepapadeas 2015.

marginal (social) cost which means that we have to *internalize the external cost*, which prompts for governmental action. Without such a price, emissions will maintain or even increase which will induce immense losses of wealth in the future once when the 1.5 degree goal isn't accomplished. In order to induce a *permanent substitution* of fossil technologies with clean ones, the emission price has to *permanently rise* with the rate F_K according to the Hotelling rule. Technically, this works with a substitution elasticity of at least one. For the next years or even decades this should be not very problematic as we have backstop technologies in many (but not all) CO2 emitting industries which allow for complete substitution.

We should keep in mind that this is a normative model which depends on quite harsh simplifying assumptions. In particular, we have one well-defined function F with properties which do not change in time. This is unrealistic. The underlying production apparatus is permanently changing due to technical progress and technical adjustments. Moreover, we neither have perfectly competitive markets which guarantees that factors are priced according to marginal productivity, nor do we have a perfect internalization strategy for pricing E. But the overall message, that emissions have to decline and being substituted by clean technologies such that $B(t) \geq 0$ for all t holds true, and that therefore the emission price must somehow rise, is still highly plausible. This take-home message from the Hotelling model is an important advice.

3 Practical implementation: CO2 taxes or ETS?

A carbon tax per ton CO2 and year is an instrument which is used by several countries (e.g. Sweden, UK, Switzerland, South Africa, see World Bank/Ecofys 2016). It is relatively easy to implement on a national level. Although it is easy to design a scheme with permanently rising prices (as done in most of the countries), the absolute level is also considering the negative effects on the price-competitiveness of fossil-intensive domestic industries, and are thus an outcome of political bargaining. A policy maker could observe whether the development of past CO2 emissions declined such that it is consistent with the Paris Agreement, or in other words: that it is likely not to exceed the budget constraint $B(t) \geq 0$. If the substitution process is too slow, CO2 taxes have to rise stronger. The problem is that the policy maker neither has the full picture of the production apparatus behind $F(K, E)$, i.e. the substitution elasticities, nor about the innovative change of the technologies and practices. That means that the price path is politically determined but the emission path is an endogenous and uncertain outcome. This is problematic as $B(t) \geq 0 \forall t$ is absolutely mandatory. Another problem regarding internalization of external cost is that in case of a small country the *marginal* effect on global warming is close to zero, even in case of total decarbonization[3]. We do not have an idea about the "correct" national price of CO2 emission if not all countries are strictly committed to the Paris Agreements and implement policies accordingly.

[3]Germany contributes 2.4% to global CO2 emissions. In case of a sudden stop of German carbon emissions (100% reduction), this would be globally statistically insignificant as China, India and US have still growing emissions.

Another internalization strategy which is used for several branches e.g. in the European Union or in the United States is the Emission Trading System (ETS). Purchasing a license for CO2 emissions per year is costly. This requires that the initial offering of the certificates by the governmental authorities is costly, too, e.g. by using an auctioning mechanism[4]. The license can be traded such that in case of competitive markets the substitution of fossil with clean technologies takes place at lowest cost. Only firms with high cost of avoiding emissions will hold certificates. The absolute amount of tradable certificates is fixed and declines each period. Henceforth it is possible to choose a path similar to the Hotelling path and to achieve $B(t) \geq 0$ for all t for sure. Whether this path is optimal (according to the Hotelling rule) is unclear for the same reasons mentioned above: the price for certificates might fluctuate, and the price-quantity path is unlikely to meet the optimality conditions all the time. However, the absolute boundary of the CO2 budget is respected for sure. The policy maker could learn from past price movements whether at the current state a substitution became easier or not. E.g. in case of price stagnation or declines we obviously have reached a technological level which makes substitution easier. Henceforth, in the next period the policy maker could cut the certificate amount even more.

Under ideal conditions, i.e. well-known function F and competitive markets, both solutions could be designed such that they are equivalent. However, given the lack of knowledge about the production apparatus and the permanent technological change, the ETS solution is more favorable in terms of precisely targeting the ecological goals. Regarding the implementation, both strategies have their caveats if we consider an open economy which is embedded in global value chains and trade patterns.

Both strategies will lead to an additional governmental income, either in form of CO2 taxes or revenues from initially selling certificates. Decarbonization is a megatrend which will massively change the way of producing goods and services, and all that has to be managed in quite short time. Therefore, both pricing strategies will lead to tremendous additional expenditures of households which many of them will not be able to afford. As the purpose of both policies is to change the *relative* prices in order to spur the substitution process towards decarbonization, these additional governmental income should be given back to the households directly and immediately, preferably in a *lump-sum transfer* so that it does not distort allocation. So we should see only the substitution effect due to relative price changes, but not negative income effects. The disposable aggregated household income should be unchanged. As poor and rich households have different consumption patterns, economists expect also positive redistributive effects from such an appropriate pricing-transfer scheme (see Edenhofer/Schmidt 2018).

Some countries implement both systems (World Bank/Ecofys 2016), that is they participate in an ETS for particular industries and branches plus having a carbon tax. This might be suitable if the necessary extension of an ETS to all sectors is difficult because it requires supranational adjustments, while the domestic decarbonization should be spurred also in the short-run. One problem is, that due to the

[4]The so-called "grandfathering" of allocating certificates is one of the most criticized inconsistencies of the European ETS, see Clò 2010.

existence of parallel systems there is no unique price for CO2 in the economy, and eventually some branches might pay a double price. All that create inefficiencies. However, it could be the second-best if the alternative is to do nothing.

4 International issues

Each environmental policy measure or decarbonization strategy on a national level necessarily changes the relative prices, i.e. makes fossil-intensive activities relatively more expensive. If these domestic industries lose price-competitiveness, and the country loses comparative advantages for producing this good or task, the global production chains will re-arrange, and the fossil-intensive production moves to other countries ("Carbon Leakage"). The effect on reducing *global* CO2 emissions might thus be zero or even negative. This underlines that a global externality (or making policies in favor of a global commons) is a public good and results in inefficient Nash equilibria. The Paris Agreement should provide a solution, however, it is not reinforcable and thus imposes weak incentives. Any decarbonization strategy should keep in mind that the vast share of future CO2 emission comes from developing and emerging countries which are growing rapidly (Busch 2015; note that the vast majority of past accumulated emissions stem from Europe and the US). A purely national decarbonization strategy is pointless if it is not considering this fact. On the other hand, higher CO2 prices in developed countries might also spur technological innovations towards greener production as there is an incentive to save expensive inputs. Henceforth, an economy might eventually benefit from a technologically leading position, at least if other countries also adopt decarbonization policies (see Porter/van der Linde 1995).

A first answer to this problem is to impose *Border Carbon Adjustment* taxes (BCA) in order to establish a playing level field. The correction of relative prices (due to internalization) should not harm the domestic industry or create benefits for countries with a lax climate policy. Also the BCA revenues should be immediately returned to the households in order to avoid negative income effects. In case of CO2 taxes, the BCA should be at the same level – minus carbon related taxes or emission licence fees the exporting firm might have paid in foreign countries (avoiding double taxation). It is essential to note that BCA are *not* tariffs, and they are *not* distorting competition but establishing fair competition. Thus, they are conform with WTO rules (Mehling et al. 2017).

To some extent it might be possible to "export" the decarbonization strategy by setting incentives to adopt similar policy schemes in other countries. While BCA might be a mild incentive to implement carbon prices in the foreign country, too, in order avoid BCA payments, the instrument of *production standards* can be used as well. Usually (high) standards are seen as protectionist measures. But in most cases the purpose is clearly not to prevent foreign firms to export their goods but reasons of environmental or consumer protection, labor standards etc., which means: reasons rooted in externality or information asymmetry problems of market allocation. In case of climate change, all countries share a common interest to shape the rules of economic activities such that carbon emissions are reduced, although there might be

different national strategies how to implement it. Standards which aim to protect the biosphere, a global commons, instead of the domestic industry should be acceptable. Therefore, standards should facilitate fair and efficient market exchange, national and cross-border, and should thus not be seen as a barrier to (efficient) trade. Defining decarbonization standards in a general manner might be an instrument to promote such policies in other countries. These standards could range from reporting the carbon footprint of the product or service (via the entire production chain), or enforcing that at least 50% of the BCA have to be reduced by foreign carbon prices, guaranteeing low carbon production by using green technologies etc. Such standards could be made more acceptable for poor countries if also an easier access to knowledge and clean technologies is provided at the same time.

Another form of "exporting the decarbonization strategy" is to facilitate global *diffusion of best practice green technologies*. Instead of making most private profit of developing green technologies in the Global North, it is essential to make the highest social profits by promoting the adoption of these technologies in the Global South. Now and in the future, large-scale CO2 reductions could be achieved in emerging countries. This requires massive investments from the Global North.

Finally, the instrument of *Free Trade Agreements* (FTA) should be based on joint decarbonization goals. This means that the Sustainable Development Goals of the UN as well as the Paris Climate Agreement should not just be mentioned in FTAs ("for kind attention") but being the basis of it. Trade easing such like reducing tariffs or harmonizing standards are strictly *conditional* to rigorous and enforced environmental standards and implemented policies in all participating countries in order to reach joint environmental goals. This might include the provision of technological knowledge how to achieve a greener production (see above). It is not a wise strategy to disentangle trade policy and environmental policy because sustainable production and trade necessarily requires that ecological conditions ("planetary boundaries") are met. *Because national environmental policy efforts are threatened by the global free-riding problem, it is essential to address these problems in trade agreements.* Unfortunately, even the recent examples of FTA such like between the EU and the Mercosur countries most agreements follow the traditional route of kindly mentioning environmental and social goals in a general manner (without much enforcement), followed by particular trade alleviations which ignore the conditionality on sustainability goals[5]. This might have something to do with the question who is participating in the trade negotiations. But without a substantial change of the FTA towards the conditionality on ecological goals such like decarbonization, national policies of the Global North will have moderate or low global impact. The atmosphere doesn't mind where, how and why CO2 emissions are reduced as long as the reduction is sufficient to prevent overheating.

[5]Example: Reducing import tariffs on agricultural products from Brazil to zero if and only if the rainforest is protected. In case of substantial grubbing, the tariffs will automatically rise to XX %. A very small step towards this direction was done by pushing Brazil's president Bolsonaro to stay with the Paris Agreement in exchange to participation with the EU-Mercosur-FTA.

5 Conclusion

In order to meet the Paris Agreement it is essential not to exceed the CO2 budget. The safest way is to implement an ETS where all sectors have to participate without any exception. The strategy to cut the yearly amount of available certificates could be triggered by the development of the observed prices. Hence it might come – more or less – close to the optimality conditions of the Hotelling rule. A CO2 tax (or a mixed system) is also a good policy option but seen as second-best. The main problem is the unpredictability of technological changes so that the substitution path cannot be controlled properly. Both decarbonization strategies have in common that they generate income of the fiscal budget which should be directly and immediately returned to the households in order to avoid negative income effects. Another important issue is that national decarbonization strategies are limited by globalization: in order to achieve level playing field and to avoid that dirty industries move to other countries with lax policies, Border Carbon Adjustment taxes (or similar measures) are necessary. But globalization could also be a chance rather than hindrance: defining environmental standards which have to be met across the entire global production chain as an import requirement, and using Free Trade Agreements by making trade alleviations conditional to such policies, could promote decarbonization policies in other countries.

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