Taxing Dirty Asset: a Proposal for a Carbon Wealth Tax.

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Abstract

Although economists widely advocate carbon pricing as an effective solution to curb carbon emissions, so far, this mechanism has produced limited effects. This paper proposes a new type of tax to help finance (and accelerate) the green transition. Its main particularity is to be levied on carbon-intensive (brown) capital instead of products. We analyze the impacts of such a scheme by setting up a model of asset pricing and dynamic portfolio decisions. We find that such a tax and subsidy scheme is a feasible and powerful instrument in helping to speed up the transition to a greener economy, particularly in a protracted period of contraction. Our approach also allows to bring in a new perspective into the discussion on wealth inequality.

Keywords: Climate Change; Taxation; Wealth.

1 Introduction

There is an increasing consensus on the urgency of tackling climate change. Limiting the temperature increase to 1.5C implies a CO2 reduction greater than what has been achieved during the whole 2010s. For the 2C threshold, world carbon emissions must fall 25 % from 2010 levels by 2030m and reach zero net emissions by 2070 (Masson-Delmotte et al. 2018). Most likely, that additional reduction has to come from fossil fuels, as they are the main contributor to global warmth in radical mitigation pathways. (Masson-Delmotte et al. 2018; Luderer et al. 2018)

Carbon pricing has been the most popular economic policy for climate mitigation until now, both in the literature and in practice. During the 2010's, governments at the national and state level introduced climate-oriented policies at a record pace. The latest data compiled by the World Bank shows that 46 national jurisdictions implemented at least one form of carbon pricing, covering just over 22 % of global GHG (Greenhouse Gas) emissions (World Bank 2021).

Their popularity, however, contrasts with what those policies achieved so far. Although econometric estimates suggest a significant impact on CO2 emissions, carbon pricing has so far failed to reduce global emissions to the required levels. A large portion of emissions are still not priced, and when they are, the carbon tax is significantly below what would be required to lower emissions to the sustainable path (Stiglitz et al. 2017).

While mitigation efforts have gained pace, meeting the climate challenge will require not only intensifying current solutions, but also new, innovative ones[1]. Even if all the national plans for CO2 reductions submitted to the Paris Agreement (Intended Nationally Determined Contributions (INDC)) are fully implemented, there would be an additional 14 GtCO2 reduction required to meet the least-cost path goal (Masson-Delmotte et al. 2018; Fawcett et al. 2015; Rogelj et al. 2016).

To fill this gap, we propose a Carbon Wealth Tax (CWT), whose objective is to complement current carbon pricing efforts and to accelerate the green transition. It does so by explicitly tackling a production factor that has so far been left aside from climate policy-making, namely, capital income and carbon based wealth. It also echoes a growing public (and academic) concern with low levels of corporate taxation.

The fundamental *rationale* for a CWT is derived from the public finance literature. The proportionality principle in taxation, revived by the work of Richard Musgrave (Musgrave 1973), sustains that those who enjoy a higher proportion of public goods need to pay higher taxes. Viewed in reverse, this means that those who create a higher proportion of "public bads" (Beckerman and Markandya 1974), meaning negative externalities, need to pay also a higher tax. Brown capital stock locks the economy in an unsustainable path from which no individual can exclude theirself. In other words, it implies nonexcludability and, in that sense,it can be thought of as a public bad.

The CWT has the potential to accelerate green transition because it tackles directly

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[1] The literature usually considers alternatives such as energy efficiency standards and subsidies to carbon-free technologies. These practices are better seen as complements of, and not substitutes to, carbon taxation, generally because of their lower (W. Nordhaus 2013). Also, the Stiglitz-Stern report 2017 indicates that "involving other instruments is found to halve the requisite explicit carbon price (Stiglitz et al. 2017). Arguments backing this allegation often include the complexity of government regulation, the discretionary aspect of it, the potential harm of ill-designed policies, and the political interference that can be exerted by vested interests.

the polluting asset, whereas the classic carbon tax targets the flow of emissions associated with the consumption or production of carbon-intensive goods, hence basically an excise tax. In this respect, recent work has shed light into the relevancy of brown capital – carbon intensive industries and firms, power plants, transportation infra-structure etc. – to carbon emission dynamics. First, the emerging economies that are still building up their capital stock are likely to contribute to higher emissions in the near future (Semieniuk et al. 2021). Secondly, those industries with a long life cycle lock the economy into a carbon intensive path: investments in brown capital today imply emissions for a long time in the future. (Luderer et al. 2018; Pfeiffer et al. 2016). Some authors, thus, refer to the Commited Cumulative Emission (CCE), a type of carbon budget associated with energy and transport investment projects. (Pfeiffer et al. 2016). In some calculations, these locked-in emissions already fill up most of the carbon budget (Davis and Caldeira 2010). In this context, policies incentivizing disinvestment and rapid depreciation in installed capacity in dirty sectors can be pivotal for the green transition.

The recent debate on wealth taxation (Saez and Zucman 2019; Guvenen et al. 2019) suggests that such a tax can have meaningful consequences in this respect. Wealth tax has gained public notoriety in recent years. In economic theory, it has been show how finite-lived agents (Golosov et al. 2006), heterogeneity of asset's returns (Guvenen et al. 2019) and the introduction of a wealth motive in the utility function (Saez and Stantcheva 2018) undermined the classic "no capital taxation" results from the 1970s (Atkinson and Stiglitz 1976) and 1980s (Chamley 1986; Judd 1985). Empirically, Piketty (2013) showed that wealth is extremely concentrated, much more than income, and follow-up works have associated the recent trend in inequality with the decrease in corporate taxation.

In this paper, we propose a simple dynamic portfolio model to evaluate possible impacts on asset allocation of introducing a tax on dirty capital. The model allow us to understand investment and consumption patterns in different tax regimes. We expect that such tax, if implemented, will decelerate the accumulation of carbon-intensive assets in favor of green ones, contributing thus to the green transition. Moreover, we also investigate the case where the revenues raised with the proposed tax can be further recycled into subsidies to green capital. In bringing together recent contributions on carbon and wealth taxation, we discuss the implementation and incidence of a CWT by combining insights from both types of literature.

Following this introduction, Section 2 is concerned with the literature on carbon emissions, in particular with the carbon taxation that has been discussed and implemented so far, and on the debate on wealth taxation. We aim to highlight how insights from the latter can be used in the former. In Section 3, we introduce our theoretical model, with which we aim to investigate the dynamics of such proposal. Section 4 discusses estimation and results, and finally section 5 concludes.

2 Literature Review

This article brings together two strands of the literature that have flourished in recent years but that have not yet had a significant interconnection. The first one is the prolific literature on carbon pricing and its impact on GHG. The second is the debate on the optimum level of capital (and wealth) taxation, brought about by recent theoretical challenges as well as the empirical relationship between downward corporate taxation and increasing wealth inequality.

2.1 *Carbon Pricing Mechanisms*

Pricing mechanisms to curb carbon emissions has considered mainly two policies: carbon taxation and cap-and-trade systems (Metcalf and Stock 2020; Stiglitz et al. 2017). They diverge in that while carbon taxes are levied on the use of fossil fuels, cap-and-trade sets a limit on emissions and allow producers to trade their “right to pollute”. In other words, carbon tax set a price target and let the quantity float, whereas the cap-and-trade system does the opposite (Stavins 2019).

Preference for one scheme over the other vary in the literature. Prominent names advocating for carbon taxes include W. D. Nordhaus (2008). The arguments range from the simplicity of the tax system (Stavins 2019) to avoiding the potential price volatility associated with a quantity constraint that may further deter the investment process. It has also been pointed that a price-setting policy works better in a scenario with non-linear climate damages caused by carbon emissions and linear mitigation benefits.

The contrary vision (Stavins 2019) argues that quantitative goals such as emission abatements are better tackled by cap-and-trade, due to their reliance on quantitative emission allowances.

However, from the distributional and cost viewpoints, both devices produce equivalent outcomes (Stavins 2019).

Empirical work has found that carbon pricing has a significant, albeit limited, impact on emissions. Among the broad, multi-country studies, Best, Burke, and Jotzo (2020), using a panel data on carbon emissions for 142 countries, found a 2 % decrease in emissions after the adoption of carbon pricing. On the other hand, Haites et al. (2018) investigates all the 55 jurisdictions that had at least one form of carbon policies in 2015. He found that carbon tax has reduced emissions compared to Business-as-usual scenarios, but not in absolute terms. ETS schemes have fared better, reducing more CO2 while costing less. Metcalf and Stock (2020), estimating CO2 reduction using a SVAR model for 31 European countries , found that an imprecise impact of carbon taxing on emissions. It ranges between 3.8 and 6.5 depending on the model specifications.

As for scheme-specific evaluations, there is evidence that the European Union ETS has decreased CO2 emissions in between 2 % and 6.3 % during the program's first 2 phases (Narassimhan et al. 2017), although accounting for the economic crisis may reduce this number substantially (Bel and Joseph 2015). Pretis (2019), using a Difference-in-Difference model for British Columbia, has found that in spite of a 5 % reduction in transportation emission, carbon taxation has failed to impact aggregate pollution. Martin, De Preux, and Wagner (2014) investigates the England's Climate Change Levy, and find that it lowered CO2 emission by 8.4 % and 22.6 % in firms subject to the levy, when compared to other firms. Lin and Li (2011), analyzing northern European countries, found that in 4 out of 5 of them, reductions remained between 0.5 % and 1.7 %.

As it is clear from the above, the point estimates vary considerably, but they all fall short of the required emission reductions to mitigate climate change. The literature has thus also analyzed additional benefits coming from the potential uses of carbon taxation revenues [2] . The so-called "second dividend" or "revenue recycling" literature stresses that this a key feature in securing efficiency in the policy choice. (Goulder, Parry, and Burtraw 1996; Bovenberg and Goulder 1996). Two forms of recycling are often considered: reducing other kinds of taxation (together with efficiency loss of the overall taxation system) or subsidizing green investments (W. Nordhaus 2013).

Provided that the second dividend is strong enough, carbon tax could be adopted with zero net cost for the economy, and also would avoid the precise calculation of the environment benefits of the carbon tax. (Bovenberg and Goulder 2002). Bovenberg and Goulder (2002) find that such scenario depends crucially on initial levels of pollution taxes and the substitution elasticity between clean and dirty commodities, conditions that are very unlikely to appear in real economies.

Given that in reality economies typically rely on several types of tax, some of them potentially inefficient, the second dividend may also come from lowering taxation elsewhere (Bovenberg and Goulder 1996). In this respect, the current taxation mix is crucial and a carbon tax can improve efficiency provided that it shifts the tax burden from inefficient, high marginal excess burdens to low marginal excess burdens [3].

So far, the majority of studies have suggested the use of carbon revenue to cut capital taxation (Bovenberg and Goulder 2002). Parry and Williams III (2012) find that the efficiency gain can be higher of the recycling scheme produces a shift of taxation from capital to labor. Some authors have gone still further to claim that the benefits of recycling only happen if this shift away from capital taxation takes place (Bovenberg and Goulder 1996). Alternatively, Metcalf (2007) proposes to use carbon tax revenue to decrease income tax, by issuing tax credits equal to payroll taxes. This is sufficient to improve the tax's progressiveness. One main finding is that a regressive carbon taxation can be rendered progressive by shifting the policy design.

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[2] Indeed, revenues associated with carbon pricing are significant and increasingly so. In 2013, it totaled USD 27 billion, in 2017, USD 32 billion (Haites et al. 2018). For 2013, 70 % of ETS revenue was used for green subsidies, while 9 % was used to lower other taxation. For the carbon tax revenue, these figures were 15 % and 44 %, respectively (Haites et al. 2018).

[3] Specifically, that happens if the environmental burden falls on the factor will low marginal excess burden, or if the revenues are used to reduce taxes on the high marginal-efficiency cost factor.

2.2 *Wealth Taxation*

The literature has considered the use of carbon revenue to decrease capital taxation partly because of the long established result of economic theory that optimality conditions include a zero rate for capital tax. However, there have been recent challenges to this result, which raises the question of using carbon pricing not to lower capital taxation, but to raise it.

The classical taxation models proposed that capital revenue should be exempted. Atkinson and Stiglitz (1976) used a life-cycle model to show that taxing only labor is always more efficient than taxing a mix of labor and capital. Moreover, the canonical models of Chamley (1986) and Judd (1985) showed that the steady-state optimal capital taxation is zero when the long-run capital supply is infinitely elastic.

However, recent developments have cast doubts on such results. Saez and Stantcheva (2018) show how incorporating wealth into the utility function produces heterogeneity in wealth (unrelated to heterogeneity in labor earnings), invalidating the zero capital tax result of Atkinson and Stiglitz (1976). Builidng on the same assumptions of the canonical models, Straub and Werning (2020) proved that intertemporal elasticity below one is already sufficient to produce positive capital taxation. Guvenen et al. (2019), in turn, studied an economy in which agents, because of their idiosyncratic abilities, are able to extract different returns from the assets. This heterogeneity is enough to yield a rationale for a wealth taxation, since it penalizes idleness of the asset holder.

Empirically, it is a well documented fact that the developed countries have lowered extensively the corporate taxation in the last decades. On average, statutory corporate income tax rates was around 33 % in 2000, dropping to less than 25 % in 2020 (OECD 2021). This downward trend was mirrored by an upward trend in wealth concentration. For US, China, UK and France, Alvaredo et al. (2017) found that since 1990 there is a clear upward trend of the share of wealth of the 1 % bracket.

Thus, the historically low levels of corporate tax, together with the recent theoretical developments, supports our consideration that the increase in carbon pricing required by climate change may assume the form of additional taxation of asset gains.

2.3 *Tax implementation and incidence.*

Usually, a wealth tax's base is the net worth of individuals or companies. This is the case in Saez and Zucman (2019) and Jakobsen et al. (2020), whose tax base is the household's net wealth, there included all financial and nonfinancial assets net of liabilities. Thre is also the proposal of Guvenen et al. (2019), where the base consists of all assets in the economy(ignoring, thus, the liabilities).

In the present work, we consider wealth taxation as an additional rate on (brown) capital gains. Although different in form, in actual fact the two specifications are equivalent. This is so because a sufficiently high capital tax amount to the same thing as a small tax on the entire wealth. To see why, consider the following after-tax wealth formulas from Guvenen et al. (2019), where w_i is the individual's wealth, r is the return on wealth, τ_k is a capital revenue tax, and τ_w is a wealth tax. It is possible to write the following:

$$w^{after-tax} = w_i + (1 - \tau_k).r.w_i \tag{1}$$

$$w^{after-tax} = (1 - \tau_w).w_i + (1 - \tau_w).r.w_i \tag{2}$$

Combining Eq. 1 and Eq. 2 gives us a mapping from the capital income tax into wealth tax:

$$\tau_w = \frac{\tau_k.r}{1 + r} \tag{3}$$

Therefore, there is always a (high) level of capital income taxation that corresponds to tax levied directly on wealth (Auerbach 2008).

There are important reasons that justify our option. First, the implementation is straightforward, since capital taxation is already adopted in the majority of countries, whereas net worth taxation in much less so. Secondly, it overcomes opacity issues. As pointed out by Kopczuk (2020), net worth taxation is not based on observable arm's-length transactions, which would hinder government's oversight and give incentive to under-reporting [4].

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[4] This is, by the way, one of the reasons why the sole form of wealth taxation that continue to be commonly adopted by governments is the estate taxation: inheritance of property is the one occasion where

Next, we discuss the crucial issue of tax incidence. The classic model of Harberger (1962) showed that, in a two-sector general equilibrium model, the sector in which the tax is levied is not necessarily the one which ends paying for it. In fact, the result was that the capital taxation would be borne by the two forms of capital in proportion to their relative size (Auerbach 2006). In the case of CWT, the problem is less stringent. First, brown sectors are evidently the greater part of the economy, so the incidence would still fall on the targeted sector. Secondly, the low substitutability between brown and green capital hinders tax shifting. Morevoer, to the extent that substitutabiliy actually happens, with brown capital moving to the green untaxed sector, that is actually what is intendeded in a green transition context.

A potential shortcoming in our proposal is related to the tax's efficiency. All wealth tax schemes are subject to prompt capital flight to foreign countries, thus increasing tax evasion problems. To the extent that the CWT is adopted by only one or few countries, it would be subject to the same criticism. However, capital flight depends crucially on the elasticity of capital supply. In this respect, there is at least some evidence that the elasticity is not high (Saez and Stantcheva 2018).

2.4 *Identification of green and brown assets.*

Finally, the CWT relies fundamentally on the discrimination between green and brown assets. Accordingly, our proposal has to take into account a way to differentiate the assets. Fortunately, in recent years there has been much effort, from the academic community, private NGOs and the public sector, in this direction. The identification strategies fall on two distinct approaches: a sector-level and firm-level identification.

The sector-level identification uses Input-Output tables to combine information from the economic activity and the CO2 emission per sector. There are publicly-available databases, such as the World Input-Output Database (WIOD), that provide information spanning over several years and almost 40 countries. It combines energy use data coming from different sources, including International Energy Agency, OECD and Eurostat. Additionally, some countries' statistics bureaus include environmental tables in their national accounts. Notably, Germany has a particularly accurate and detailed table, which has been used, for

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agents have to disclose and evaluate fairly their assets to the government.

instance by Kato et al. (2013), to differentiate between dirty and green sectors. Advantages of this approach include its broader scope, since it (in principle) covers all the firms and companies activities in each economic sector. Moreover, it allows the input-output calculations such as forward and backward economic linkages between the sectors, by measures such as the Hilferding-Hirschman indexes, which permits assessing the emissions along all the productive chains.

The second approach is to directly assess how much carbon emission is associated with the activities of each company. The recent interest in tracking portfolio emissions has boosted such practice. Central Banks, notably the Bank of England and the European Central Bank (ECB), have introduced policies to ensure financial resilience to climate risks and to support the economy's green transition (Bank of England, 2021). They consist of offering lower borrowing costs and support for bond placement for firms that are making a contribution to emission reduction. Enabling such policy requires an environmental assessment of their financial position on sovereign and corporate bonds The European Commission has recently established directives to create a green taxonomy to be applied to financial instruments, in particular green bonds. A special technical group determined, for each economic activity, which actions were required for mitigation and adaptation to climate change. Based on this, it will be required from companies to disclose how much of their turnover and capex/opex are related to these climate actions. Depending on such values, the company will be able to claim that a project has green bond standard.

In a third approach, the private sector has been developing its own assessment of the environmental risks. Financial companies have created indexes tracking environmental compliance, exposure and risks of publicly traded bonds and stocks. One such example is MSCI's ESG Index. Ultimately, both Central Banks and financial indexes rely on private (for-profit and non-for-profit) source of information, such as the GHG Protocol or the Carbon Disclosure Project. Other researches have used company-level emissions. Those include Schoenmaker (2021), who proposes a simple ratio emissions/sale, emissions valued throughout all the full corporate value chain.

In summary, a CWT on capital gains in the brown sectors and firms is feasible and reasonably efficient, in the sense that it is levied on broadly on the targeted factor.

3 The Model

The dynamic portfolio models were first introduced by (Merton 1975, 1973) to investigate wealth trajectories according to different asset allocations. In the model's framework, there are two class of assets available for investor, one risky and the other risk-free. There is no production sector, so investors do not receive wages nor profits. They maximize a expected intertemporal utility derived from consuming a portion of their wealth. Their sole source of income is the asset returns from their portfolio. At each period, the agent faces two choices: how much of their wealth to consume, and how to allocate their portfolio between the available assets.

This class of models asks questions similar to the more popular Capital Asset Pricing Model (CAPM) introduced by Markowitz (1952), although they diverge in crucial assumptions. Most importantly, unlike the CAPM where asset returns are usually static, the dynamic portfolio model features time-varying returns, which in turn are particular useful to capture asset-specific externalities and varying investment horizons (Semmler et al. 2021).

Indeed, the model was recently used in climate economics by Semmler, Lessmann, and Tahri (2020), who investigate the effects to wealth allocation (and green investments) of short-termism in a green transition context. Braga (2021) uses the same framework to investigate the investor's behavior (and investment decisions) in a financial market increasingly affected by environmental issues. His model features green and brown bonds whose yield explicitly depends on climate positive (and negative) externalities.

Similar to these works, our model shares the background that environmental risks will affect investment decisions in important ways. However, we expand the other dynamic portfolio models by introducing an exogenous, asset-specific tax regime. Taxes are levied either on consumption or on a particular asset and may be used to fund subsidies to investment in the other. This framework allow us to address relevant questions to the climate literature, such as the effects of taxation in speeding up the green transition, and its role in funding green investment, at the same time that allow us to track wealth trajectories, as well as the representative investor's portfolio allocation in green and brown assets.

The problem is not trivial since asset taxation faces but also changes substantially the pattern of time-variant returns, hence impacting wealth dynamics. Guvenen et al. (2019) addressed the effects of tax regimes in asset return heterogeneity across households and across periods. Returns are not permanent and do not necessarily replicate past performances. But whereas their focus is on the households - i.e, the ability of, say, gifted entrepreneurs in extracting higher yields from a capital asset, ours is justified by heterogeneity of technologies.

In our model, there are three kinds of assets: brown, green and safe asset. Whereas the share of investments in the safe asset is exogenous, the share of portfolio allocated in brown and green assets is optimally determined at each period. In accordance to Merton's original formulation, the investment's return increases wealth from one period to another. Safe assets are assumed to yield a constant rate of return of 3 %, and the proportion of wealth allocated in safe assets in each period is denoted by $(1 - \pi_t^1)$.

On the other hand, both green and brown assets are subject to time-varying returns. π_t^2 is the share of risky investments allocated in green assets, and $(1 - \pi_t^2)$ in brown assets. A representative investor choose to hold any proportion of them bounded by 10 % and 90 %, so that they always diversify a small fraction but are not allowed to incur into short selling.

The investor's problem constitutes of optimally allocating their wealth on each asset at each period in order to maximize utility derived from consumption. In each period, they choose the consumption level c_t together with the portion allocated in green and brown assets π_t^2. The indirect utility function is given by:

$$\max_{c,\pi} E \left\{ \int_t^N e^{-\delta_0 (s-t)} F(c_s W_t) ds \right\} \tag{4}$$

The asset utility of the owner stems from consumption at every period. We specify the utility's function form as a log utility function:

$$F(c_s W_t) = log(c_t W_t)) \tag{5}$$

The state equation represents the dynamic wealth process. In each period, the time-variant asset returns increase the investor's wealth. In practice, the wealth grows by the weighted average of the three types of return: safe, green and brown. On the other hand, wealth is subtracted by the amount the investor chooses to consume, as well as by the transaction costs of transforming assets into money. Transaction costs have been long considered in the portfolio optimization literature (Cadenillas 2000). In our specification, we follow Duffie and Sun (1990) and Liu and Loewenstein (2002) in setting them proportionally to the assets held (and thus to the investor's wealth). The resulting state equation is:

$$\dot{W}(t) = \pi_t^1 \pi_t^2 W_t r_t^g + \pi_t^1 (1-\pi_t^2) W_t r_t^c + (1-\pi_t^1) W_t r_t^f - c_t W_t - X(\Pi_t, W_t) \tag{6}$$

The allocation proportion π_t^2 is the key variable as it determines the share of green investment in the economy. A similar approach was used by Bonen et al. (2016) who also investigate the green transition dynamics through the share of capital allocated to growth or adaptation and mitigation purposes. Hence, in our model the behavior of π_t^2 across time represents the ability of the economy to finance the green transition. We expect that taxation and subsidies to alter the variable's behavior, in particular in early periods where green investment is more crucial to green transition.

The crucial variable determining portfolio allocation is the time-varying return on assets. We model the green and brown returns using harmonic estimation in the same way as Chiarella et al. (2016). The process uses the Fast Fourier Transform to obtain the low frequency oscillations, that later we incorporate into the dynamic portfolio model. The resulting equations follow the form:

$$r_{brown} = \sum_{k=1}^{k} \alpha_{1i} sin(\frac{1}{\omega_i} 2\pi) + \alpha_{2i} cos(\frac{1}{\omega_i} 2\pi) \tag{7}$$

$$r_{green} = \sum_{k=1}^{k} \beta_{1i} sin(\frac{1}{\omega_i} 2\pi) + \beta_{2i} cos(\frac{1}{\omega_i} 2\pi) \tag{8}$$

We expand the previous models by incorporating taxation into the wealth dynamics. Specifically, our goal is to investigate the role that a different tax schemes - excise tax, wealth tax and green subsidies - may have in the transition to a green economy.

Returns are modified by the wealth taxation, understood as a high level of τ_k. Brown returns decrease proportionally to the incidence rate, whereas green returns increase in case the tax revenue is spent as subsidies. The latter has an additional corrector term $\frac{1-\pi^2}{\pi^2}$ that factors in the relative size of the brown assets in the portfolio. It captures the fact that as allocation shifts between brown and green sectors, so does the the CWT tax base.

$$r_{brown}^{after-tax} = r_{brown}.(1 - \tau_k) \tag{9}$$

$$r_{green}^{subsidies} = r_{brown}.(1 + \tau_k).\frac{(1 - \pi_i^2)}{\pi_i^2} \tag{10}$$

We consider two cases for the CWT. First, the additional capital gains taxation τ_k is levied on the carbon intensive assets only, but no use is made of the revenue thus generated. This allows us to assess the effect of pure taxation, and is relevant for fiscal adjustment scenarios where the government uses revenues to repay debt. In this case, the safe and green returns are thus not affected by it. Conversely, the second case considers the case where the tax revenue is converted into subsidies investment in green assets, effectively raising its return.

Finally, to allow comparison to the classical carbon tax, we consider to a *ad-valorem* excise tax τ_c that falls on the consumption goods (Barrage 2020). In principle, to consume the same basket the investor would have to dedicate a higher proportion of their wealth, impacting its dynamic negatively. The result, shown in Equation 6, is a modified state equation, as it is done in Bovenberg and Goulder (2002) and Bovenberg and Goulder (1996).

$$\dot{W}(t) = \pi_t^1 \pi_t^2 W_t r_t^g + \pi_t^1 (1 - \pi_t^2) W_t r_t^c + (1 - \pi_t^1) W_t r_t^f - (c_t + \tau_c) W_t - X(\Pi_t, W_t) \tag{6'}$$

4 Estimation, Results and Discussion

4.1 Estimation

For the asset prices, we use daily data from the SP500, the market index that tracks the 500 largest companies listed in United States. To create a monthly series, we picked the last day of each month. The period covered is from January 2010 until September 2021, resulting in 141 observations. The individual companies were aggregated into the green and brown portfolios using linear combination with the respective SP500 weights. The resulting portfolio prices were used to obtain annual logarithmic returns.

We classified the SP500 companies as brown or green according to the following criteria. MSCI ESG index database assesses, among other things, environmental performances of over 8000 companies and bonds based on two metrics. The first one grades the companies individually by the amount of carbon emissions (using the three-scope approach also used by the Bank of England) and climate mitigation efforts. The second is a emissions weighting index that captures the importance of the company's *sector* to environmental issues. We filtered the dataset to keep only the 25% higher weights. In practice, this means that we are selecting companies whose sectors are the most important for climate efforts. After that, in the remaining subset, we then classified the 30% that had a higher grade in CO2 pollution as green, and the 30% lower as brown.

After this process, we cross the two groups of companies with the SP500. In the end, we were left with 38 green companies and 40 brown companies. The list is reported in the Table 1 and 2 below. Although cumbersome, this process prevents us from classifying as green a company that emits little CO2 just because it is in an irrelevant or a low-emitting sector. Instead, we pick as a green company those with low emission that are in high-polluting sectors. We performed a robustness check comparing the firms selected through our process to an alternative process based on input-output data (See Appendix).

As discussed in the previous section, asset returns are a central variable in dynamic portfolio model. We obtained harmonic estimations of returns on green and brown following the methodology in Semmler and Hsiao (2011), a method that relies on Fast Fourier Transform (FFT) of the time series (see also Chiarella et al. (2016)). The advantage of FFT is that it captures low-frequency movements on the returns, subtracting the effect of short-term noises that often are not used in portfolio allocation decision.

Tables 1 and 2 below report the estimations for the relevant coefficients. i indicates the frequency, α_i and β_i are the coefficients for the sine and cosine arguments, respectively, whereas ω_i is the period adjustement factor. We selected the number of sine-cosine functions k based on the Sum of Squared Errors (SQE) indicators (see Appendix).

Figure 1 plots both estimations of the low-frequency behavior of green and brown assets. Consistent with other findings, brown assets are more volatile. Notably, green returns are more resilient to downturn.

The dynamic portfolio optimization problem is solved numerically using the Nonlinear Model Predictive Control (NMPC) algorithm introduced by Grüne and Pannek (2012) and Grüne, Semmler, and Stieler (2015). We run the simulation for 40 periods for different

	Brown Companies	Green Companies
1	Exxon Mobil Corporation	NextEra Energy Inc.
2	Chevron Corporation	United Parcel Service Inc. Class B
3	Linde plc	Duke Energy Corporation
4	Union Pacific Corporation	Southern Company
5	ConocoPhillips	FedEx Corporation
6	CSX Corporation	Dominion Energy Inc
7	Norfolk Southern Corporation	Ecolab Inc.
8	Air Products and Chemicals Inc.	Johnson Controls International plc
9	EOG Resources Inc.	Exelon Corporation
10	Dow Inc.	Carrier Global Corp.
11	Marathon Petroleum Corporation	Sempra Energy
12	Pioneer Natural Resources Company	American Electric Power Company Inc.
13	Kinder Morgan Inc Class P	Schlumberger NV
14	Nucor Corporation	DuPont de Nemours Inc.
15	Williams Companies Inc.	PPG Industries Inc.
16	Phillips 66	Xcel Energy Inc.
17	Southwest Airlines Co.	International Flavors & Fragrances Inc.
18	WEC Energy Group Inc	Public Service Enterprise Group Inc
19	Old Dominion Freight Line Inc.	Ball Corporation
20	Valero Energy Corporation	Charles River Laboratories International Inc.

Table 1: List of Green and Brown Companies

	Brown Companies	Green Companies
21	Delta Air Lines Inc.	International Paper Company
22	Kansas City Southern	DTE Energy Company
23	Occidental Petroleum Corporation	Ameren Corporation
24	LyondellBasell Industries NV	Expeditors International of Washington Inc.
25	PPL Corporation	Baker Hughes Company Class A
26	FirstEnergy Corp.	Amcor PLC
27	KeyCorp	Halliburton Company
28	Devon Energy Corporation	CMS Energy Corporation
29	AmerisourceBergen Corporation	Avery Dennison Corporation
30	United Airlines Holdings Inc.	AES Corporation
31	Diamondback Energy Inc.	Evergy Inc.
32	American Airlines Group Inc.	Alliant Energy Corp
33	Atmos Energy Corporation	Allegion PLC
34	CF Industries Holdings Inc.	FMC Corporation
35	NRG Energy Inc.	C.H. Robinson Worldwide Inc.
36	Comerica Incorporated	A. O. Smith Corporation
37	Marathon Oil Corporation	Sealed Air Corporation
38	Cabot Oil & Gas Corporation	Pinnacle West Capital Corporation
39	APA Corp.	
40	Alaska Air Group Inc.	

Table 2: List of Green and Brown Companies (cont.)

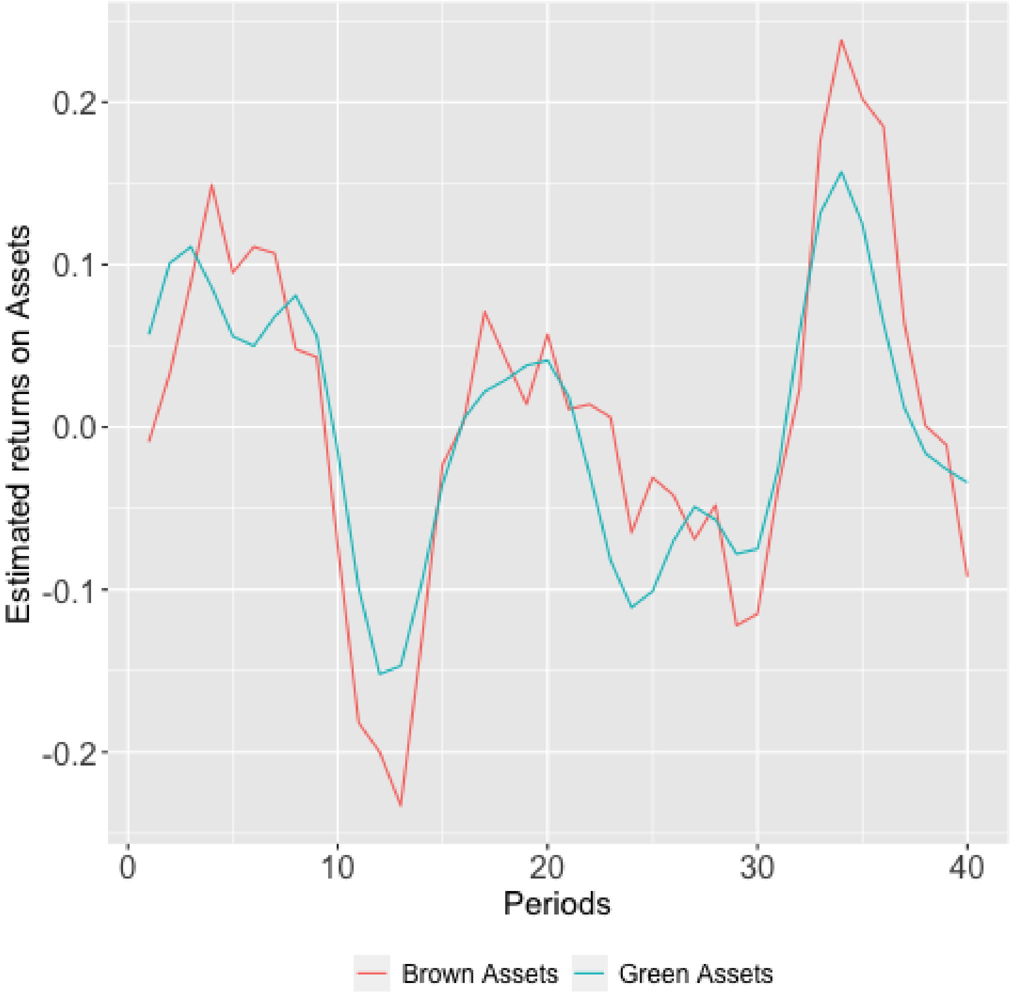
i=	1	2	3	4	5	6
ω_i	43	25.8	32.25	8.0625	18.4286	129
α_i	-0.0873	-0.0385	+0.0140	+0.0073	-0.0246	+0.0112
β_i	+0.0902	+0.0121	+0.0365	+0.0252	-0.0189	+0.0398

Table 3: Estimated harmonic coefficients for brown assets.

i=	1	2	3	4
ω_i	43	129	25.8	18.4286
α_i	-0.07245	+0.0355	-0.0281	-0.0144
β_i	+0.0428	+0.0289	+0.0213	-0.0288

Table 4: Estimated harmonic coefficients for green assets.

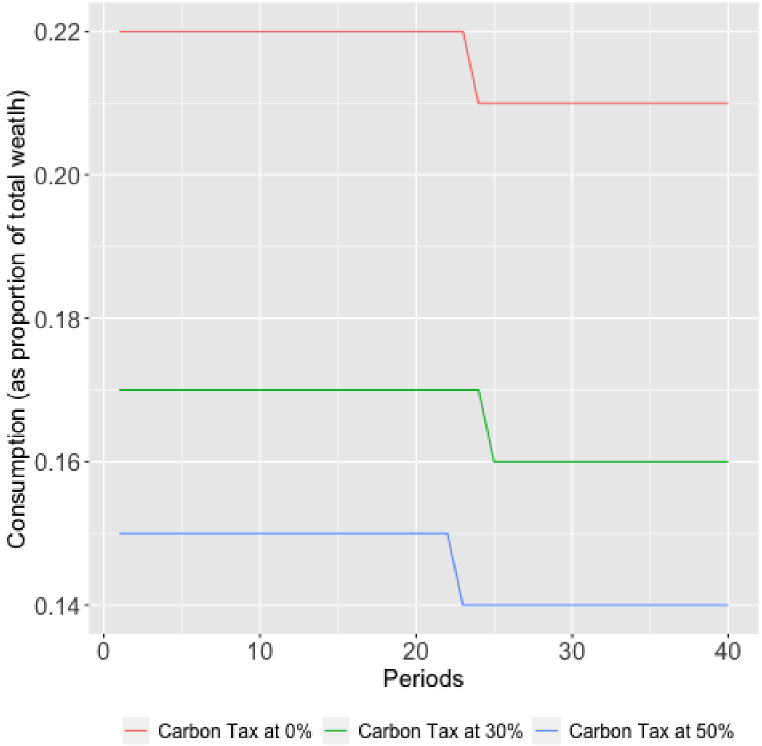
Figure 1: Harmonic Estimations for Asset Returns.



tax regimes. To assess the impact of classical taxation, we run the model for each state equation (Equation 6 and Equation 6'), using tax rate of 30% and 50%. For the CWT, we run the model for after-tax brown returns (Equation 9) using tax rate of 20% and 40% and for after-subsidies green returns (Equation 10). We present the main findings in the next section.

4.2 Results and Discussion

Figure 2: Consumption decision in the classic carbon tax.

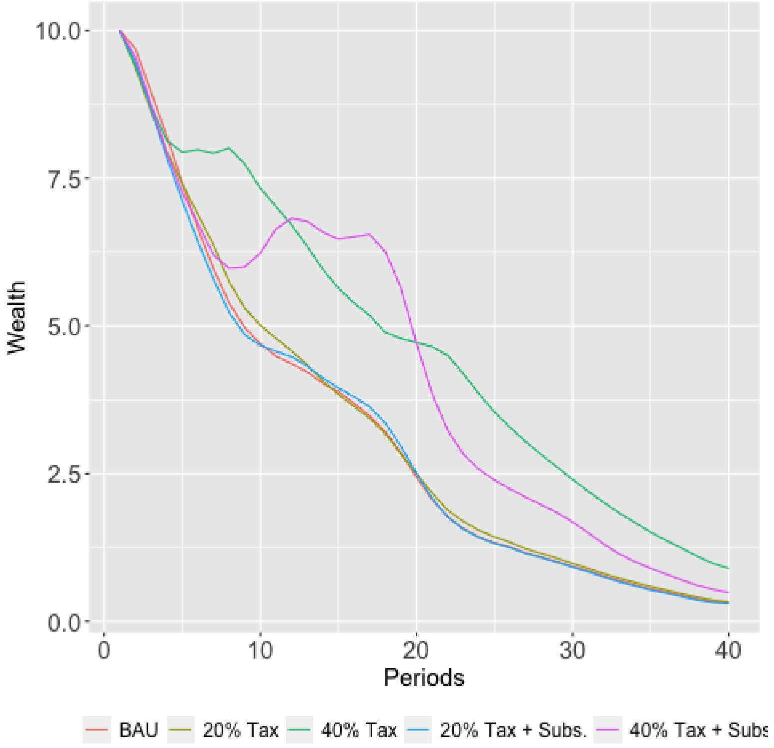


In our dynamic portfolio model, excise tax that aims at penalizing emission-intense consumption plays a very limited role in changing the wealth dynamics. The ultimate reason is that, in classic carbon tax environment, the investor lowers its consumption level so that the saved share of wealth continues the same. The adaptation behavior can be seen in Table 2 where we plotted how much of the wealth the investor opts to consume along the periods in three different tax rates: 0 %, 30 % and 50 %. The reduction on consumption virtually matches the hike in the rates, so that the share of wealth not consumed stays the same. Importantly, given that asset returns are unchanged the allocation decisions remain the same.

This result is similar to what has been found for models that incorporate household and firms, such as the Ramsey taxation model.

Thus, precisely because of the pass-on effect, the final good carbon taxation has a (very) limited impact on wealth dynamics and investment patterns. That is, on the other hand, exactly what is achieved by taxing directly brown capital. Figure 3 evaluates how the investor's total wealth behaves over 40 periods under different tax regimes. In the Business-as-Usual scenario, wealth decreases more or less steadily, as consumption outpaces the investment's returns. Between periods 10 and 15, the decline is less pronounced as returns on both assets increase substantially (see Figures 3 and 4 below).

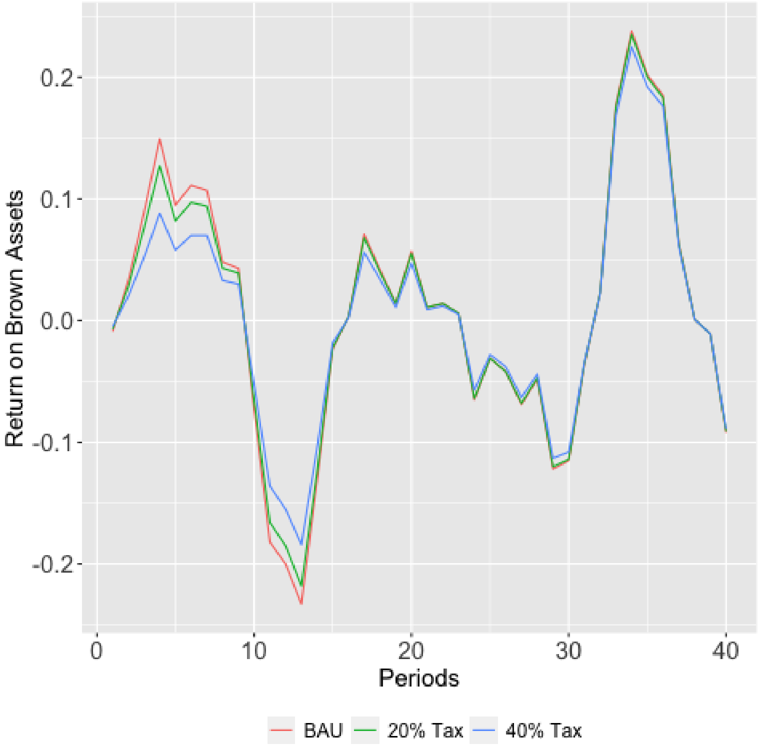
Figure 3: Wealth dynamics under different tax schemes.



CWT is capable of altering wealth dynamic through its direct impact on capital returns, but the level of taxation matters. At 20%, there are only slight changes in the wealth trajectory. By lowering brown returns, CWL makes investors shift to green investments early on, and the lower volatility of the latter contribute to a slight lesser decline. On the other hand, at 40% the taxation stronger and meaningful alterations happen. As expected, taxing asset returns impacts the trajectory negatively in the first periods. Around period 5, the trajectories diverge, with taxation decreasing more smoothly. Such early movements, moreover, have long lasting effects on wealth. Until the end, wealth under the more aggressive tax regimes are at higher levels. On the other hand, we note also that subsidies in green technology have transitory effects. Its strongest influence is felt the middle periods, where the share of green investments is greater.

Indeed, CWT alters wealth paths precisely because of its ability in changing asset returns. Figure 3 and 4 plots the calibrated behavior of brown and green yields, respectively. Common to both assets, we see that the BAU scenario is changed substantially in the early periods. This is a consequence of the fact that CWT's tax base - wealth - is bigger in the beginning, and diminishes as wealth is consumed away in the later periods. As expected, CWT decreases brown asset returns proportionally to its taxation levels, with subsidies having the opposite effect on green returns.

Figure 4: Brown Asset returns under different tax scenarios



The ultimate impact of taxation regimes on the green transition can be seen in Figure 5, which plots the behavior of π^2, the share of the risky portfolio allocated to green assets. We

Figure 5: Green Asset returns under different tax scenarios

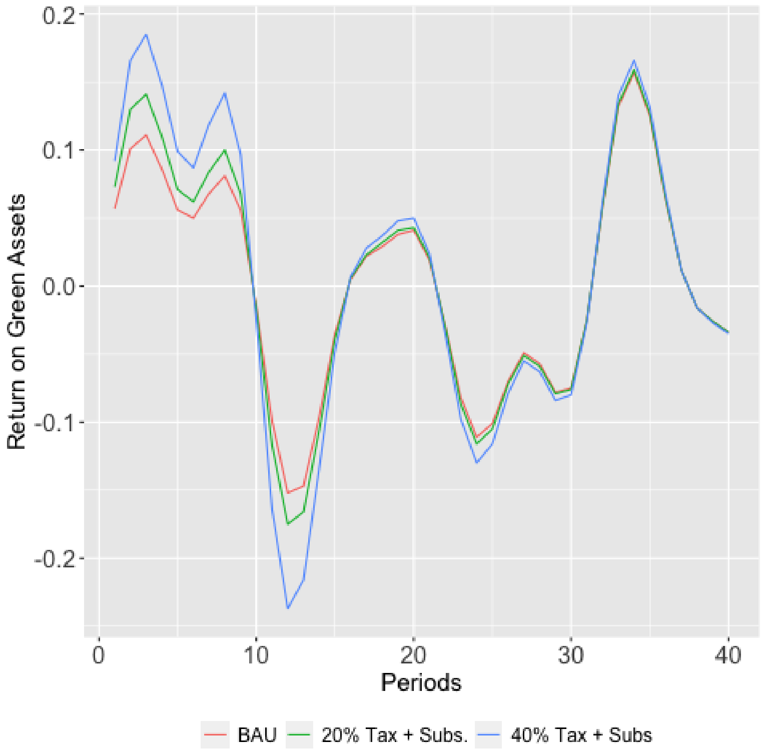
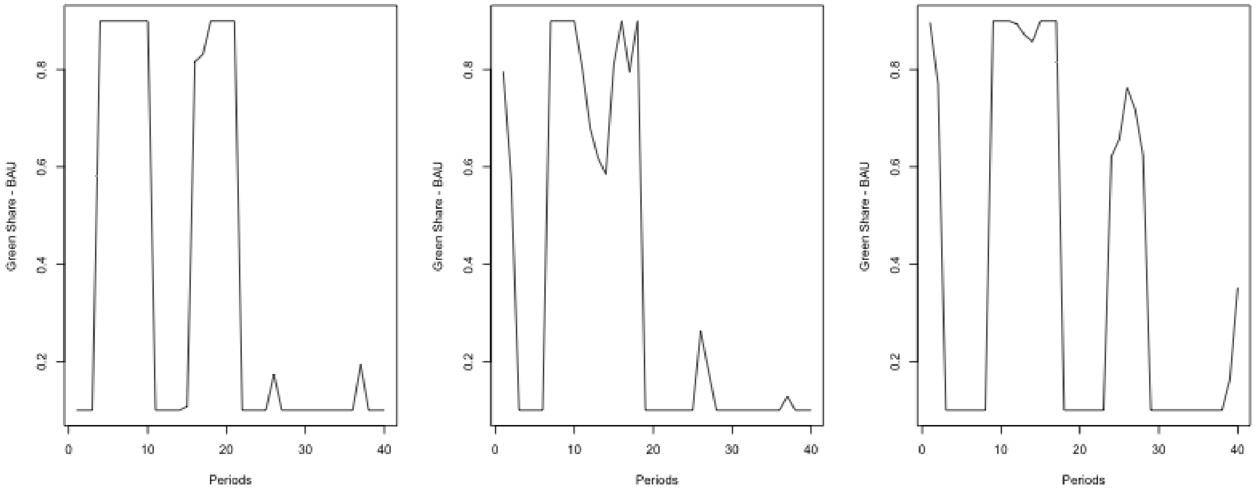


Figure 6: Allocation to Green Assets under different tax scenarios



note that as CWT increases, π^2 is higher in a bigger number of periods. Again, the effect is stronger for earlier periods because of the aforementioned tax-base effect. However, we stress that in a green transition context, this is a very meaningful result, given the importance of fast action green investment in spurring technological innovations.

5 Conclusion

Recent environmental reports have shown that the world continues to follow a warming path, despite the increase in the adoption of carbon pricing mechanisms in recent years. This suggests the need of additional and innovative measures to curb CO2 emitting activities. Our proposal for a carbon wealth tax fills this gap at the same time that it echoes recent theoretical research that shows the desirability of capital tax income. In the form of an extraordinary increase in capital income tax, its aim is to reduce capital flows to carbon intensive companies in favor of investment in green companies.

Our results indicate that taxing carbon wealth produces such behavior. In a dynamic portfolio optimization setup, we show that a 40% tax rate is strong enough to alter portfolio allocation choices in favor of green capital in the early periods. This is of particular relevance in light of the challenge of green transition, where carbon de-investment is crucial to attain the Paris Agreement goals. Moreover, as a nascent industry, green energy technology benefits from subsidies in the near future.

Secondly, we find that asset taxation and subsidies, because of their capacity in changing asset return dynamics, alter wealth trajectories. Their strongest effects happen in middle periods, when the taxation ensure a higher allocation to green assets. Nonetheless, the dynamic setup of the model ensures that these are felt until the later periods, with wealth trajectories above the BAU scenario.

Thirdly, we find that this contrasts with the classic excise taxation. Mechanisms that increase product prices are negligible in a portfolio optimization context because investors simply adjust their consumption level according to the higher price. Wealth allocation, particularly investment patterns, remain unchanged, and that suggests that carbon wealth tax is indeed a innovative instrument in addressing climate change.

Finally, our approach also addresses the wealth inequality issue from a different perspective. Wealth taxes in general have a long history and are often criticized of not having - as sometimes argued –a good welfare foundation and not being very practical in terms of the measurement of the stock of wealth. We refer to another dimension of welfare and fairness perspective, namely the greater burden sharing of public "bads" by holders of carbon intensive wealth. We also need to have only a tax on the flow of wealth, the returns from carbon intensive assets, the measurement of stocks is not needed.

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A Appendix A: Robustness check for brown sectors.

In practice, both methods converge in identifying the same brown sectors. Table 1 reports the 15 most emitting sectors by each measure. For the industry-level column, we used WIOD data for US emissions in 2009 emissions (last date availale). For the company-level, we used MSCI data on ESG companies from 2021, which takes into account both emissions and mitigation actions. Discrepancies in the sector names exist because of the differences in each classification system, but there is a consistent picture. Activities related to the production of oil and gas, transportation, chemicals, metals and paper stand out as a common source of CO2 emissions.

	Company-level	Sector-level
1	Oil & Gas Exploration & Production	Electricity, Gas and Water Supply
2	Airlines	Public Admin and Defence; Compulsory Social Security
3	Oil & Gas Refining, Marketing, Transportation & Storage	Inland Transport
4	Marine Transport	Coke, Refined Petroleum and Nuclear Fuel
5	Construction Materials	Air Transport
6	Steel	Chemicals and Chemical Products
7	Energy Equipment & Services	Mining and Quarrying
8	Paper & Forest Products	Other Non-Metallic Mineral
9	Road & Rail Transport	Renting of M&Eq and Other Business Activities
10	Containers & Packaging	Basic Metals and Fabricated Metal
11	Commodity Chemicals	Health and Social Work
12	Metals and Mining - Non-Precious Metals	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
13	Specialty Chemicals	Hotels and Restaurants
14	Integrated Oil & Gas	Pulp, Paper, Paper , Printing and Publishing
15	Air Freight & Logistics	Food, Beverages and Tobacco

Table 5: 15 most polluting sectors according to the company and sector-level methods.