%% ABSTRACT %%

What is the optimal level of taxation in a transition toward net-zero emissions? I build an endogenous growth model in which an emission limit renders the continued use of? fossil fuel more socially costly. Once the net-zero emission limit is binding, an optimal policy makes extensive use of carbon taxes. A subsidy on labor helps stabilize production. In the short run, the policy implications of pursuing this course of action differ sharply. Labor taxes rise to reduce economic activity and emissions. The carbon tax, instead, should not rise as steeply. This allows the economy to benefit from fossil research while knowledge spillovers to the green sector mitigate the costs of a green transition.

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%% Introduction %%

The Intergovernmental Panel on Climate Change highlights the need to transition to net-zero emissions by 2050 \citep{IPCC2022}. The question is what fiscal policy mix best supports this goal. The literature to date has largely focused on carbon taxes, to the exclusion of other forms of tax and their impact on…... Such taxes direct production and R&D towards activities that pollute less \citep{Acemoglu2012TheChange}. However, other fiscal instruments also affect carbon emissions. Labor taxes, for example, curb the level of production generally thereby…. Conversely, labor subsidies boost production (which do what in the context of analyzing emissions). Thus, taxes that are not specifically targeted toward the reduction of emissions must be an important part of the fiscal mix in achieving net-zero emission goals.

To analyze the optimal fiscal mix, I set up a model of directed technical change. The government chooses the dynamic path of labor income taxes and carbon taxes. In so donig, it anticipates that the net-zero emission limit will bind at some point in the future. Calibrating the model to the US economy, I can characterize the optimal fiscal mix during the transition toward net-zero emissions and in the longer term as well. My main finding is that when the net-zero emission limit binds, the optimal policy is to tax carbon heavily and to subsidize labor. During the transition phase, the optimal carbon tax is lower and a tax on labor reduces production and emissions.

The key to the optimal mix of carbon and labor taxes lie in the knowledge spillovers that result from research in both conventional carbon-based and green industries. Decreasing returns to scale in research activity in each industry mean that a rapid shift in the composition of activity is socially costly. The labor tax allows the government to reduce emissions in the short run by lowering production while, at the same time, engineering a smoother transition of economic activity across industries. In the long-run, only green production is feasible. A high carbon tax ensures this. Labor subsidies, in turn, serve to keep production high.

More in detail, the modeling follows \cite{Fried2018ClimateAnalysis}. A final consumption good is produced from energy and non-energy goods. The energy good, in turn, is composed of green and fossil energy. The fossil sector exerts emissions. Imperfectly monopolistic producers of machinery invest in research to increase the productivity of their machines. Machines are used in the intermediate sectors: non-energy, fossil, and green energy. The model builds on the directed technical change framework developed in \cite{Acemoglu2012TheChange}, where innovation profits from past technology levels within a sector. In addition to their model, returns to research decrease in the number of scientists employed within a sector, and some knowledge spills across sectors.

Relative to the study by \cite{Fried2018ClimateAnalysis}, the current paper adds the consideration of an optimal policy. The optimal policy accounts for a gradually declining net emission limit that eventually turns to zero in 2050. Where the literature has mainly focused on carbon taxes \citep{Fried2018ClimateAnalysis, Barrage2019OptimalPolicy}, the planner in my model chooses (i) a sales tax per unit of fossil energy (“the carbon tax”) and (ii) a tax on labor income. The role for the labor income tax does not arise from equity considerations. Rather, the labor tax is an environmental policy instrument next to carbon taxes because it affects the level of production. I solve for the optimal path of carbon and labor taxes using the numerical approach by \cite{Jones1993OptimalGrowth} and \cite{Barrage2019OptimalPolicy}.

To highlight the importance of endogenous growth for the optimal fiscal mix, I start with a simple pencil-and-paper setting. This has the externality from fossil energy but does away with endogenous growth. In this static setting, optimal fiscal policy only resorts to a Pigouvian carbon tax and lump-sum rebates. Labor taxes do not play a role. The reason for this is that when the carbon tax is set to the Pigouvian level, the wage rate reduces exactly by the social costs from an additional hour worked. These costs arise from more pollution as economic activity rises. Hence, households internalize the externality of work in their labor supply decision.

Then, I turn to the dynamic model with endogenous growth. I first calibrate the model to the US economy in the period from 2015 to 2019. Then, I feed an exogenous emission limit into the model that is based on the path of the global limit provided by the \cite{IPCC2022}. The emission limit for the US used in the analysis foresees a reduction by 84.5\% in net emissions in 2020 relative to 2019-levels. The value increases to 85.6\% in 2045.\footnote{\ These reduction targets are more than twice as big than the reduction foreseen by the Biden administration amounting to 38\% relative to 2019-emissions. On April 22, 2021 President Biden announced a 50-52\% reduction in emissions by 2030 relative to 2005-levels. Source: \href{https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/}{https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/}, retrieved 14 September 2022.} In 2050, the emission limit further reduces to net zero.

In this setting, I perform two quantitative exercises. First, I calculate carbon taxes that would be necessary to meet the emission limit while keeping the labor income tax fixed. Second, the planner optimally sets the carbon and the labor tax to maximize welfare.

As for the first exercise, I find that the necessary carbon tax is US\$889 (in 2022 prices) per ton of carbon in the 2020-2024 period. The tax increases to US\$2,951 in the 2070-2074 period. The first value is approximately 4.4 times higher than the social costs of carbon recently calculated by the \textit{Resources for the Future} institute and the University of Berkeley: US\$203.5 \citep{Rennert2022ComprehensiveCO2}.\footnote{\ For comparability, I transformed the \textit{Resources for the Future} (RFF) estimate of US\$185 in 2020 prices to 2022 prices. The RFF measure aims to capture the damage associated with a marginal increase in CO$\_2$. It is not intended to implement a certain level of emissions. Abstracting from modeling and parameter uncertainty, the discrepancy suggests that focusing on the social costs of carbon alone would fail to achieve the emission limit designed to meet the Paris Agreement. }

The increase in the necessary tax on carbon over time follows from the tighter emission limit and market forces which direct inputs to the fossil sector, such as knowledge spillovers. I compare the necessary carbon tax in the calibrated model\textemdash which has a distortive income tax\textemdash to the necessary carbon tax absent labor income tax. Without income taxation, the required carbon tax is 7\% to 10\% higher.

As for the second exercise, results show that the emission limit is best implemented by a combination of carbon and labor income taxes. Before the net-zero emission limit binds, a positive tax on labor optimally accompanies a carbon tax. The carbon tax amounts to US\$987 in the 2020-2024 period. It increases steadily to US\$1,326 in 2045-2049. The average (income-weighted) marginal income tax rate equals 0.31\% in the 2020-2024 period and decreases to 0.01\% in the 2040-2044 period.

The role for labor taxation follows from the additional motive to use carbon taxes to direct research. The government chooses a lower carbon tax to allow for more research in the fossil sector. Knowledge accumulation in this sector in the past renders fossil researchers particularly productive. Furthermore, decreasing returns to research make a more equal allocation of scientists more productive. Technological advances in the fossil sector, in turn, benefit green growth in future periods because of knowledge spillovers. However, as the carbon tax targets the direction of research, it deviates from the Pigouvian rate and the wage rate does no longer fully capture the effect of hours on the externality. Labor supply is inefficiently high.

To mitigate the higher level of emissions, the government taxes labor income.

The optimal policy mix changes sharply once the net-zero emission limit has to be implemented. Now, the carbon tax rises steeply to direct research to the green sector. The optimal tax on carbon jumps to US\$2,833 per ton in 2050 and gradually increases to US\$3,186 in the 2070-2074 period. In addition, the government subsidizes labor. The labor income tax becomes negative already in 2045-2049: the average marginal tax rate is -0.07\%. It declines to -0.16\% in 2070-2074.

The more stringent emission limit makes it infeasible for the economy to benefit further from fossil research. Instead, more green research has to be encouraged in order to benefit from dynamic spillovers within the sector. The higher carbon tax diminishes the wage rate. The subsidy on labor helps to raise labor supply.

Knowledge spillovers are instrumental for the economy to profit from a smooth allocation of researcher. If this is true, then fossil research in early periods boosts green growth tomorrow. A more productive green sector renders a transition to net-zero emissions in future periods less costly. When knowledge is sector specific, however, the optimal policy should allocate more research to the green sector already in initial periods. This fosters green innovation tomorrow as scientists can build on green technology advances today. The optimal carbon tax is higher to bolster green research, and the labor income tax subsidizes labor throughout. While knowledge spillovers to the green sector allow the economy to profit from fossil research, overall, though, knowledge spillovers make a more aggressive environmental policy necessary. The reason is that knowledge also spills to the fossil sector thereby raising emissions.

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%% Conclusion %%

The latest IPCC report \citep{IPCC2022} stresses the need to transition to a net-zero emission limit. The economics literature has largely focused on the use of carbon taxes to achieve this goal. However, labor income taxes may contribute to lowering emissions by affecting the level of production. I ask what is the optimal fiscal mix of taxes on carbon and labor income in a transition toward net-zero emissions?

I build an endogenous growth model in which an emission limit renders fossil energy socially costly. I find that the optimal policy always chooses a combination of carbon and labor income taxes. Once the net-zero emission limit binds, the optimal policy taxes carbon extensively. A subsidy on labor serves to stabilize production.

The rationale is a distortion in the labor market as the carbon tax is chosen to also discourage fossil research. This reduces the wage rate. A subsidy on labor mitigates this side effect of the carbon tax.

In the short run, the policy implications differ.

The carbon tax should rise less. This allows the economy to benefit from fossil research. However, due to the lower carbon tax the wage rate does not fully capture the social costs of work through emissions. Labor taxes then optimally reduce economic activity and emissions.

The quantitative results show that the optimal allocation deviates substantially from the efficient one when only carbon and income taxes are available. Absent knowledge spillovers, \cite{Acemoglu2012TheChange} point to green research subsidies as an essential tool to implement the efficient allocation. With knowledge spillovers, however, my results suggest that a subsidy on fossil research might be beneficial. An important aspect of a green transition is societal acceptance. Investigating additional instruments to reduce the costs of meeting emission targets, therefore, is an important direction of future research.

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