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Interim report dated 12.01.2022

Optimal energy policy mix in the light of induced innovation and endogenous growth

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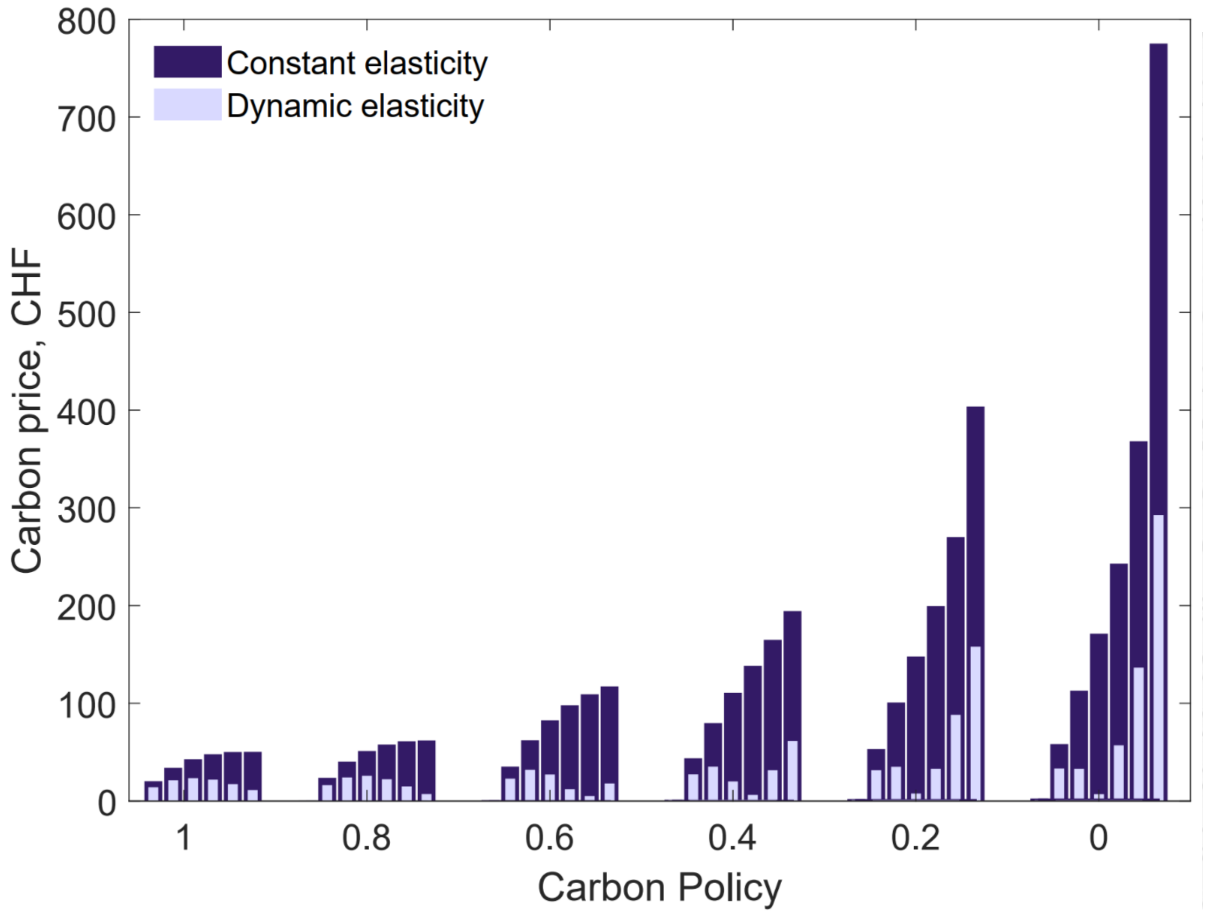

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Zusammenfassung

Das Projekt hat zum Ziel, optimale Kombinationen von markt- und technologiebasierten Politikinstrumenten für die Schweizer Wirtschaft zu finden. Ein besonderer Schwerpunkt liegt dabei auf der Rolle der Innovationen für das erfolgreiche Erreichen stringenter politischer Ziele. In diesem Projekt erweitern und untersuchen wir den Mechanismus des politikinduzierten technologischen Wandels in einem quantitativen allgemeinen Gleichgewichtsmodell. Wir erweitern diesen Rahmen, um zusätzliche Kanäle einzubeziehen, über die politische Instrumente die Wirtschaft beeinflussen könnten. Im ersten Jahr des Projekts haben wir drei Hauptmechanismen entwickelt, die bisher wenig erforschte Wirkungskanäle aufdecken sollen. Der erste Mechanismus der endogenen Substituierbarkeit zwischen sauberen und schmutzigen Inputs wird im Rahmen der Arbeit entwickelt und in den numerischen Rahmen integriert. Die Analyse deutet darauf hin, dass eine strenge Klimapolitik die Substitutionselastizität erhöht und dadurch die Gesamtkosten der Energie- und Klimapolitik senkt. Der zweite Mechanismus für ein schnelleres Wachstum ausgewählter sauberer Energiesektoren zielt darauf ab, das durch die Politik induzierte zusätzliche Wachstum zu reflektieren. Der dritte Mechanismus über höhere Energieeffizienz in Nicht-Energie-Sektoren wird zeigen, wie politische Massnahmen Investitionen in höhere Energieeffizienz anregen können. Die ersten Ergebnisse des Projekts wurden auf einer internationalen Konferenz vorgestellt, und nach weiterer Verbreitung wird das daraus resultierende Arbeitspapier eingereicht und schließlich in einer von Experten begutachteten Fachzeitschrift veröffentlicht.

Résumé

Le projet vise à trouver des combinaisons optimales d'instruments politiques basés sur le marché et sur la technologie pour l'économie suisse. Il met particulièrement l'accent sur le rôle de l'innovation dans la réalisation d'objectifs politiques stricts. Dans ce projet nous améliorons et examinons le mécanisme de changement technologique induit par les politiques dans un cadre d'équilibre général quantitatif. Nous étendons ce cadre pour inclure des canaux supplémentaires par lesquels les instruments de politique pourraient affecter l'économie. Au cours de la première année du projet, nous avons conçu trois mécanismes principaux qui révéleront des effets de politique autrement obscurs. Le mécanisme de substituabilité endogène entre les intrants propres et sales est entièrement développé et implémenté dans le cadre numérique. Son analyse suggère qu'une politique climatique stricte augmente l'élasticité de substitution et réduit ainsi les coûts globaux de l'atténuation. Le mécanisme de croissance plus rapide de certains secteurs d'énergie propre vise à refléter la croissance supplémentaire induite par les politiques. Le mécanisme pour une meilleure efficacité énergétique dans les secteurs non énergétiques montrera comment les politiques peuvent stimuler les investissements dans une meilleure efficacité énergétique. Les premiers résultats du projet ont été présentés lors d'une conférence internationale et, après une diffusion plus large, le document de travail qui en résulte sera soumis et finalement publié dans une revue internationale.

Summary

The project aims to find optimal combinations of market-based and technology-based policy instruments for the Swiss economy. It places a special emphasis on the role of innovation in successful achievement of stringent policy targets. To achieve the project's goals, we enhance and scrutinize the mechanism of policy-induced technological change in a quantitative general equilibrium framework. We extend this framework to include additional channels through which policy instruments might affect the economy. In the first year of the project, we have designed three main mechanisms that will reveal otherwise obscure policy effects. The mechanism of endogenous substitutability between clean and dirty inputs is fully developed and implemented into the numerical framework. Its analysis suggests that stringent climate

policy increases the substitution elasticity and thereby lowers the overall costs of mitigation. The mechanism for faster growth of selected clean energy sectors aims to reflect the additional growth induced by policies. The mechanism for higher energy efficiency in non-energy sectors will show how policies can spur investments in higher energy efficiency. The first results of the project have been presented at an international conference and, after further dissemination, the resulting working paper will be submitted and eventually published in a peer-reviewed journal.

Contents

Abbreviations

CGE	Computable General Equilibrium
CITE	Computable Induced Technical Change and Energy

1 Introduction

1.1 Background information and current situation

The full decarbonization goal announced by the Swiss Federal Council in January 2021 requires an imposition of stringent and efficient carbon and/or energy policy measures. At the same time, the lack of acceptance by the society demonstrated by the vote in June 2021 places a bound to further reinforcement of the existing policies. Hence, policymakers face the task of designing an updated efficient and feasible package of policy measures that would ensure the compliance with the Net-Zero emissions target. The key challenge in designing such a package is the assessment of the specific effect of each policy instrument and their joint impact on the economy.

The climate–economic literature that supports this decision-making process comes to a conclusion that ambitious policy targets require combining policy instruments that regulate market prices with those that facilitate technological progress (Popp, 2019). Additional, innovation-stimulating measures turn out to be a necessary supplement to the prevalent uniform carbon taxation (Acemoglu et al., 2012). Though insightful, such theoretical conclusions are too generalized to yield specific policy advice. The economic mechanisms and overall outcome for a sophisticated real-world economy such as Switzerland stay unclear.

Despite their clear importance for policy outcomes, innovation-stimulating measures are omitted from most of the policy analyses. Traditionally, innovation is modelled as exogenous technological learning, which leaves no room for policy interventions. The endogenous induced innovation framework addresses this weakness and shows how innovation drives economic growth. Yet, it is rather generalized and cannot reflect the innovation channels specific to energy transition.

This project will address these limitations by incorporating key innovation channels that reflect policies' effects on innovation. The ultimate goal is to combine comprehensive policy analysis with implementation of induced-innovation mechanisms to infer the best policy profile for the Swiss economy.

1.2 Purpose of the project

The project aims to explore the mechanisms through which various policy instruments would efficiently direct the Swiss economy towards its stringent climate policy target. We will employ the endogenous growth framework to highlight the role of innovation for climate and energy policies. We will extend this framework with several mechanisms critical for an adequate assessment of stringent climate and energy policy measures. These mechanisms will reflect the changes to the production processes induced by the policies. Examples of such mechanisms are rapid energy technology development, easier substitution for carbon-intensive production inputs, and higher energy efficiency of the production processes.

We intend to find optimal combinations of policy measures for Switzerland that would stimulate the investment in clean energy and ease the transition to a carbon-free economy. The optimality of the design implies a balanced and efficient mixture of price-regulating and innovation-inducing instruments. It also considers the social fairness of the distribution of policy proceedings.

1.3 Objectives

The project addresses three general research questions,

1. How can policy coordinate technological investment and, consequently, the economy's growth to promote clean energy use?
2. How does the interplay of innovation-inducing and market-regulating policy instruments affect the economy's welfare and growth?
3. What is the optimal time-profile for the mix of market-based and technology-based policies for the Swiss economy?

Within these general considerations, we aim to explore how both market-based and technology-based policy instruments can work in the Swiss economy through the following extensions of the growth mechanism:

1) The mechanism of improving substitutability between clean and dirty production inputs,
2) The mechanism of higher growth potential for younger technologies as opposed to mature ones,
3) The mechanism of increasing energy efficiency in non-energy sectors.

2 Description of facility

Not applicable

3 Procedures and methodology

The project uses the computable general equilibrium model CITE (Bretschger et al., 2011), which features endogenous growth and is calibrated to the Swiss economy. CITE is the first and to date the only general equilibrium model that fully incorporates endogenous, innovation-driven growth in a multi-sector economy. Yet, the ability of the model to reflect the effects of specific policy measures is limited by its structure and a few generalizing assumptions. These assumptions include pre-specified CES production functions at all levels of production—including energy generation and the production of intermediate goods.

Before carrying out a comprehensive policy analysis, the model will be extended to include the mechanisms that would reveal currently undetectable effects of policy measures. Specifically, the mechanism of endogenous substitutability between clean and dirty inputs will demonstrate how stringent policies benefit the economy by easing the substitution for dirty inputs. The higher growth potential for selected clean energy sectors will reflect the additional growth-stimulating effect of policies. Finally, the mechanism for potential energy efficiency improvement will show how policies can induce R&D in higher energy efficiency.

The inference from the project will mainly build on numerical analysis of combinations of policy instruments. Whenever necessary and possible, theoretical analysis and empirical estimations will corroborate quantitative assessment. For example, in the first Working Package, empirical analysis strongly supports the endogenous mechanism for substitution between clean and dirty production inputs. The details of this empirical and numerical analyses are outlined below.

4 Activities and results

The Working Package 1 of the project is now finalized with the following activities carried out:

1. Comprehensive literature review.

   We extensively surveyed the recent literature to make sure that our work builds on state-of-the-art insights. Our literature catalog currently contains 500+ papers, reports, and other texts related to various parts of the project.

2. Development and implementation of the mechanism for increasing substitutability between clean and dirty production inputs.

   This part of the project is developed far beyond mere formulation of the mechanism for increasing substitutability. Both empirical and numerical analyses have been successfully carried out and yielded important insights. Below we describe the main approach and findings of this stage of the project.

   In this part of the project, we challenged the assumption of constant elasticity of substitution between clean and dirty energy. We first empirically documented the intertemporal variation in the substitutability and showed the empirical relevance of a variable elasticity of substitution that depends on the share of clean inputs. Next, we extended the CITE model to include endogenous elasticity of substitution potentially stimulated by climate policies. The results show that taking into account the positive feedback from policy to substitutability leads to substantially lower economic costs of climate change mitigation.
   Our empirical estimation is based on the detailed French plant-level survey on energy consumption and expenditure. These data suggest that the estimate of the elasticity of substitution almost doubles from around 2.8 in the 1990s to 5.2 in the 2010s.

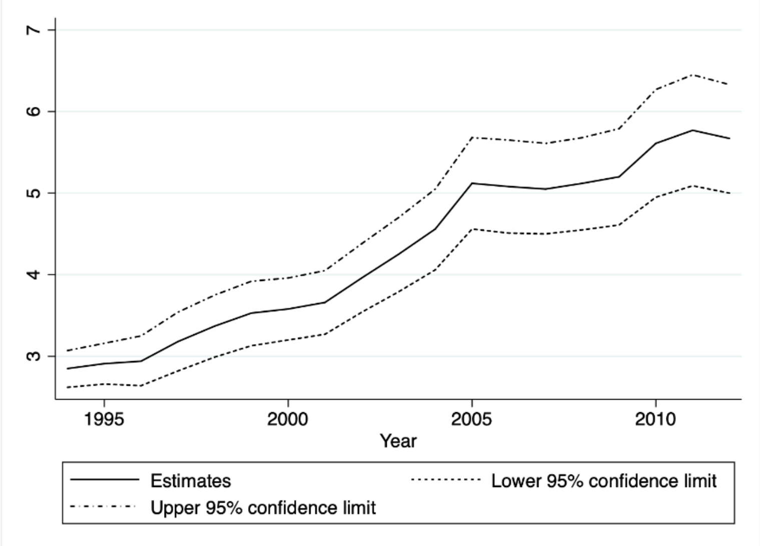

Figure 1. Time variation in the estimates of the elasticity of substitution between clean and dirty energy on a 10-year rolling window.

Figure 1 shows the estimation on a rolling-window, where we observe a clear increasing trend in the elasticity of substitution. In our investigation of a variable substitution elasticity that depends on the factor shares, we also find strong evidence that the elasticity of substitution increases as the share of clean energy rises.

In our numerical simulations, we dynamically update the value for the elasticity of substitution between clean and dirty energy according to the ratio of clean to dirty energy use in the economy. Formally, the aggregate energy production function takes the form

$$E_i = \left[\phi_i E_{C,i}^{\frac{\sigma_{E,t}-1}{\sigma_{E,t}}} + (1-\phi_i) E_{D,i}^{\frac{\sigma_{E,t}-1}{\sigma_{E,t}}} \right]^{\frac{\sigma_{E,t}}{\sigma_{E,t}-1}}$$

which combines clean and dirty energy inputs in a classical CES fashion. The key modification is the dynamic value for the elasticity of substitution determined endogenously by the ratio

$$\sigma_{E,t} = \eta \frac{E_{C,t}}{E_{D,t}} \ ,$$

where η is estimated from the data to be approximately equal 3.

The subsequent simulations show that more stringent carbon policies correspond to steeper profiles for substitution elasticity, which alleviates the overall costs of mitigation. Hence, aggressive carbon policy, apart from being more costly, ensures higher substitutability—which enables faster and less costly decarbonization.

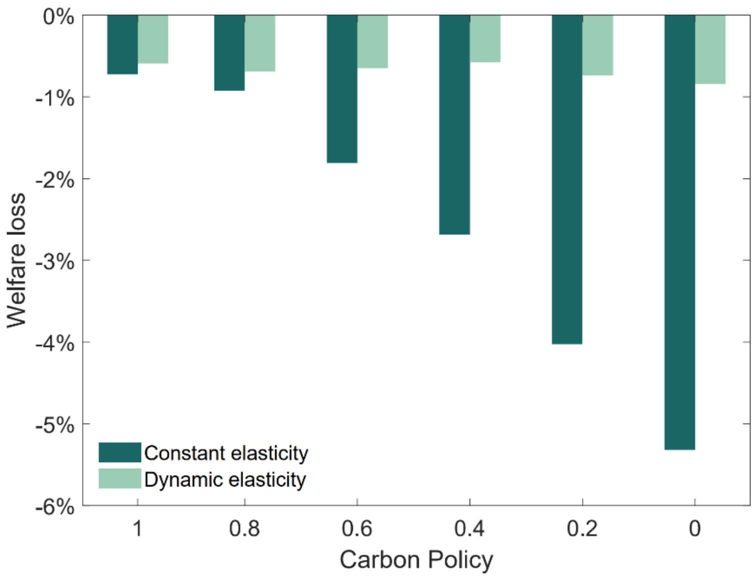

Figure 2. Welfare losses in the cases of constant (exogenous) and dynamic (endogenous) elasticity of substitution, in percentages of the benchmark welfare level and for policies of increasing stringency.

To demonstrate this trade-off, Figure 2 compares the welfare losses under constant and dynamic substitutability between clean and dirty energy for policies of increasing stringency. In the presence of the adjustment mechanism, the welfare losses only slightly increase with stricter emissions targets: they stay within one percent of the aggregate welfare level even in the case of full decarbonization. In the absence of the feedback mechanism, these costs are sharply increasing with policy stringency and are more than five times higher for the most ambitious policies.

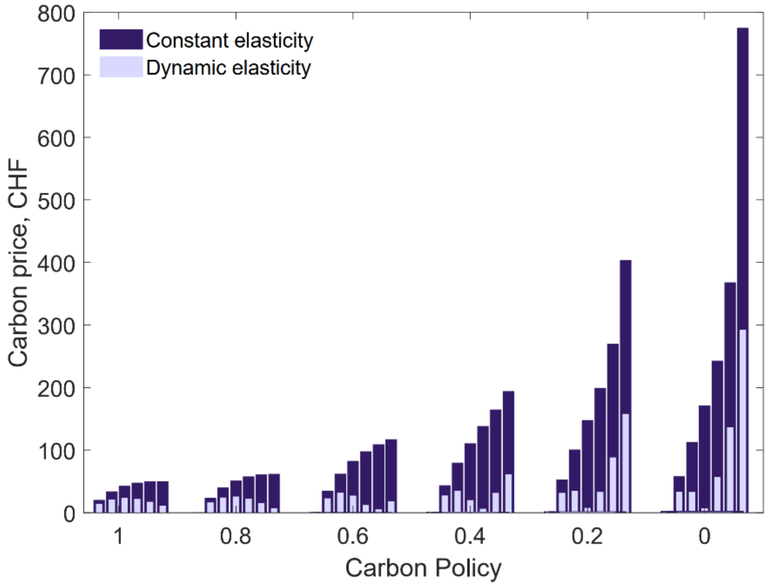

Figure 3. Carbon price dynamics for policies of increasing stringency in the cases of constant (exogenous) and dynamic (endogenous) elasticity of substitution. Each group of six bars shows the values from 2020 to 2050 from left to right correspondingly.

Accounting for the adapting elasticity also leads to very different policy profiles as demonstrated in Figure 3. For any emissions target, dynamic adjustment of the elasticity of substitution leads to lower carbon tax levels—enough to ensure substitution for dirty energy to the extent that a given policy target is achieved. Under moderate policies, carbon tax is only temporarily increasing; its hump-shaped profile reflects strong initial incentives to substitute away from dirty energy. Once a sufficient degree of substitutability is achieved, it renders the tax less relevant. However, under more stringent policies, one more effect comes into force—one of high carbon tax level towards the time of achieving policy target. This might reflect high but finite substitutability between the two types of energy: substitution gets increasingly difficult at very high and so far unobserved shares of clean energy. In the latter case, higher taxes are required to ensure the feasibility of strict policy targets. Yet, even in these cases, the value for carbon price is almost three times lower in the presence of the policy-to-substitutability feedback mechanism.

3. Formulation of heterogeneous growth mechanism for mature and developing renewable energy sectors

In this step of the project, we developed a mechanism that would distinguish the growth potential between relatively young and mature energy technologies. The implementation of this mechanism will allow to account for rapid learning and costs reduction that are typically displayed by developing technologies. This will first of all apply to solar and wind energy technologies, which are relatively well developed but have not yet reached maturity in their cost structures.

Formally, the mechanism builds on the renewable resource extraction literature and is formulated as follows:

$$N_{i,t+1} = s_{i,t}\left(\delta_{N,i} I_{P,i,t}^{\frac{\sigma_N - 1}{\sigma_N}} + (1-\delta_{N,i}) I_{N,i,t}^{\frac{\sigma_N - 1}{\sigma_N}}\right)^{\frac{\sigma_N}{\sigma_N - 1}} + (1-\delta_t) N_{i,t}$$

$$s_{i,t}(x) = rx\left(1 - \frac{x}{c}\right) + 1$$

$$x = \frac{Y_{i,t}^{CUM}}{Y_{i,t}^{CUM*}} - 1,$$

where the first equation describes capital accumulation (denoted by *N*) from physical and non-physical investments aggregated in CES manner and depreciated capital of the preceding period. The second equation captures non-linearity in the growth mechanism of younger technologies based on a logistic growth function. It reflects the potential for higher efficiency of investment that translates into faster growth for such technologies. The third equation shows how the argument of this function depends on the ratio of the actual cumulative output to its benchmark level. Hence, it provides room for policy intervention that would stimulate developing clean energy sectors and thereby increase the efficiency of investments in these sectors. The extent to which the investment efficiency can be improved depends on the parameters *r* (rate of growth) and *c* (saturation point), which will be calibrated to match the estimated rates of learning in the literature.

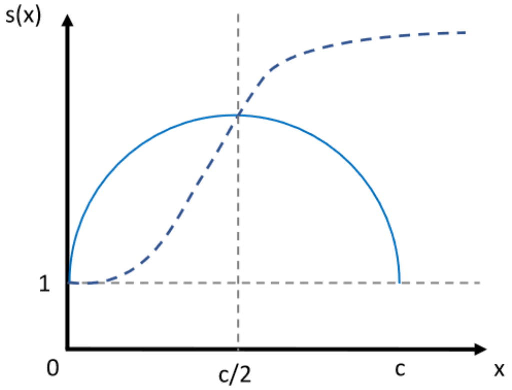

Figure 4. Schematic representation of the excessive growth mechanism. The solid line shows the degree of additional efficiency coefficient for investments, *s*. The dashed line is a stylized representation of the level of technological development.

As schematically shown in Figure 4, this additional growth mechanism should provide an opportunity to represent learning curves that the emerging technologies typically follow. Specific calibrated parameters' values will define the speed of technological progress, *r*, and the "saturation point" *c*, beyond which the sector is considered mature and grows at the rate common for the whole economy.

4. Development of efficiency improvement mechanisms for non-energy sectors

This mechanism reflects the potential for producers in non-energy sectors to reduce the energy intensity and, correspondingly, the carbon-intensity of the production processes. The current model specification implies that emission intensity of production can be reduced only by substituting away from fossil energy within predetermined production functions. However, the producers might alternatively invest in developing technologies that reduce the carbon intensity of the fossil fuel use itself. In the literature, such possibility is usually modelled using the socalled additional energy efficiency improvement, which reduces the energy use depending on sectoral forecasts for energy intensity. We would like to endogenize this factor, such that the increases in energy efficiency would stem from additional R&D expenses on top of their benchmark level.

The mechanism can be formalized in the following form:

$$X_{i,t} = \left[\delta_{X,i} L_{i,t}^{\frac{\sigma_x - 1}{\sigma_x}} + (1 - \delta_{X,i}) \left(\frac{E_{i,t}}{1 - f_{i,t}}\right)^{\frac{\sigma_x - 1}{\sigma_x}}\right]^{\frac{\sigma_x}{\sigma_x - 1}}$$

$$f_{i,t} = h\left(\frac{I_{N,i,t}}{I^*_{N,i,t}}\right)$$

The first equation shows the production function for intermediate goods, which aggregates labour and energy inputs using the CES production function. The second equation shows the potential decrease in energy use as a function of the ratio of R&D investments to their benchmark level. The particular functional form *h* is yet to be developed. This mechanism can thus capture the effect of carbon policy that stimulates R&D in energy efficiency.

5 Evaluation of results to date

The first part of the project extends the important literature on endogenous growth and climate change in a novel way by analysing endogenous elasticity of substitution that interacts with the relative share of clean inputs in the economy. To the best of our knowledge, this project is the first to make advances on this front by endogenizing the substitution elasticity and investigating its implications in the analyses of optimal environmental policy. The broad acceptance and positive feedback at the conference presentations suggest that we address a topic highly relevant in the field.

The other mechanisms suggest strong potential for analyses of specific channels through which policy instruments might affect the economy. Their further implementation in the next Working Package of the project is expected to yield more insights into the topic.

6 Next steps

In the following year, we will implement the formulated mechanisms 3. and 4. into the CITE model and study the implications for climate policy. For each mechanism, the implementation will include

1) preparing the model (for example, disaggregating the representation of the energy sector into separate sectors that might exhibit different growth rates),
2) implementation of the designed mechanism, including calibration of the newly introduced modelling components, and
3) troubleshooting and testing to ensure the model is functioning correctly.

As a preparation for the final stage of the project, we will also develop a set of policy instruments that will be used in the simulations stage of Working Package 3.

7 National and international cooperation

Not applicable

8 Communication

The first findings of the project have been presented at the internal *RESEC seminar* at ETH Zurich in March 2021 and at the *26th Annual Conference of the European Association of Environmental and Resource Economists* in June 2021.

Further presentations are planned at the SURED-2021 conference (Ascona, Switzerland), and the *27th Annual Conference of the European Association of Environmental and Resource Economists* (Rimini, Italy) in June 2021.

9 Publications

Jo & Miftakhova, 2021. On the Role of Endogenous Substitutability between Clean and Dirty Inputs in the Costs of Climate Policy. To be openly published as a working paper after minor revisions.

10 References

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Popp, D., 2019. *Environmental policy and innovation: a decade of research* (No. w25631). National Bureau of Economic Research.

11 Appendix

Not applicable