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"Investments and public finance in a green, low carbon, economy"

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ABSTRACT

The paper evaluates the impacts on investments and public finance of a transition to a green, low carbon, economy induced by carbon taxation. Four global tax scenarios are examined using the integrated assessment model WITCH. Taxes are levied on all greenhouse gases (GHGs) and lead to global GHG concentrations equal to 680, 560, 500 and 460 ppm CO_2-eq in 2100. Investments in the power sector increase with respect to the Reference scenario only with the two highest taxes. Investments in energy-related R&D increase in all tax scenarios, but they are a small fraction of GDP. Investments in oil upstream decline in all scenarios. As a result, total investments decline with respect to the Reference scenario. Carbon tax revenues are high in absolute terms and as share of GDP. With high carbon taxes, tax revenues follow a "carbon Laffer" curve. The model assumes that tax revenues are flawlessly recycled lump-sum into the economy. In all scenarios, the power sector becomes a net recipient of subsidies to support the absorption of GHGs. In some regions, with high carbon taxes, subsidies to GHG removal are higher than tax revenues at the end of the century.

1. Introduction

A large literature has assessed the macroeconomic cost of stabilising Greenhouse Gas (GHG) concentrations, with various assumptions on the environmental stringency of the adopted policy tool, on the technologies available, on the cost of those technologies, on the timing and on the degree of international cooperation (Cf. Barker et al., 2007; Clarke et al., 2009; Edenhofer et al., 2009; Edenhofer et al., 2010 for some overviews). The macroeconomic cost of a climate policy – e.g. the discounted loss of Gross Domestic Product (GDP) – is an important indicator and it certainly deserves an important place in both the academic and the policy debate on climate change mitigation. However, this is not the only piece of information on the economic implications of climate policy that policy makers and the business community would need to better plan future investments and policy decisions. For example, there is a large and growing demand for estimates of investments, particularly in the power sector, needed to cut GHG emissions and for estimates of the financial implications of climate policy, both at the national and international levels.[1] Policy makers and the business community are indeed interested in knowing when and where investments should flow and how large they should be. A transition to a green economy may indeed require excessive financial resources and crowd out productive investments.

It is important to stress that estimates of macroeconomic costs and investment needs inform on two very different aspects of climate policy and should not be confused. Investments are expenditures that increase productive capital. They imply a financial transfer from one agent to another, from one sector of the economy to another sector, or from one generation to the next. If investments are re-distributed among capital assets that have the same productivity (i.e. that yield the same output per unit of investment) the level of macroeconomic

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[1] As a response of this growing interest on climate finance, the International Panel on Climate Change (IPCC) has introduced a Chapter on "Cross-cutting Investment and Finance Issues" in the forthcoming Fifth Assessment Report.

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activity is not affected. Macroeconomic costs arise when investments are redistributed from more productive uses to less productive uses. This loss of productivity generates a lower level of output, which is the true net cost of climate policy for the economy as a whole.

The Integrated Assessment Modeling community has been prolific in providing estimates of the macroeconomic costs of climate policy but has virtually neglected investment needs. For example, among the large set of papers collected in two recent Special Issues published by Energy Economics – one on the Energy Modeling Forum (Clarke et al., 2009) and the other on the Asia Modeling Exercise (Calvin et al., forthcoming) – none presents estimates of investment needs.

There is only a handful of studies that estimate investments flows and their distribution and financial implications using large-scale, sophisticated, energy-economy models (Edenhofer et al., 2009; IEA, 2010; IEA, 2011; Riahi et al., 2012). Among those, only Riahi et al. (2012) use the full potential of an Integrated Assessment Model (MESSAGE) to provide information on investment needs with a high technological detail under a mix of climate and energy policies which are consistent with a 2 °C above pre-industrial level in 2100. Edenhofer et al. (2009) provide little information on aggregate investments in the power sector. IEA (2010) and IEA (2011) provide estimates with high technological detail but the analysis is limited to 2030.[2]

This paper contributes to this embryonic literature by providing a detailed assessment of investment needs and public finance in four representative green economy scenarios generated using the Integrated Assessment Model WITCH (Bosetti et al., 2006; Bosetti et al., 2007; Bosetti et al., 2009a).[3] The transition to a green, low carbon, economy is induced by four tax scenarios stabilising GHG concentrations in the atmosphere to 680, 560, 500 and 460 ppm CO_2-equivalent (ppm CO_2-eq) by the end of the century. As a consequence, global mean temperature increases in 2100 between 3.2 °C and 2 °C above pre-industrial levels. We examine the impact of climate policy on investments and current expenditures in the power sector, on investments in Research and Development (R&D) in the energy sector, on investments in the oil sector and on other aggregate non-energy investments. Investments in the power and in the oil sectors are endogenous in the model, as are energy demand and fuel prices. R&D investments are also endogenous. We complete our assessment of climate finance by providing estimates of carbon tax revenues and their implications on public finance.

With respect to Riahi et al. (2012), this paper analyses four climate policy targets instead of one. By focusing on climate policy alone instead than on a mix of climate and energy policies, we can establish a relationship between the stringency of the tax (the long-term concentration target) and investment needs. We also provide estimates of R&D investments in the energy sector and an assessment of carbon tax revenues, which are not part of the analysis of Riahi et al. (2012). Finally, we present separate results for OECD and non-OECD countries. Unfortunately, we cannot provide estimates of investments in demand side energy efficiency and in power transmission and distribution as in Riahi et al. (2012), because they are not modelled in WITCH.

The rest of the paper is organised as follows. Section 2 presents an overview of the WITCH model. Section 3 introduces the scenario design and presents basic facts of the Reference scenario and of the policy scenarios. Section 4 discusses the relationship between macroeconomic costs, investments and carbon tax revenues in a green, low carbon, economy. Section 5 illustrates changes in the optimal mix of investments and current expenditures in the power sector, investments in the oil upstream sector and in other sectors of the economy. Section 6 deals with investments in innovation. Section 7 examines revenues from carbon taxes. The final section provides a brief summary of our findings.

[2] Other studies have presented estimates of investment needs without using full-fledged economic models (UNFCCC 2007; McKinsey 2009; Bredenkamp and Pattillo 2010; United Nations 2010). For a survey of this literature see Haites (2011).

[3] More precisely, we consider taxes on all GHG emissions but we use the expression "carbon tax" for simplicity.

2. An overview of the WITCH model

WITCH – "World Induced Technical Change Hybrid" – is a regional integrated assessment model structured to provide normative information on the optimal responses of world economies to climate damages (cost–benefit analysis) or on the optimal responses to climate mitigation policies (cost-effectiveness analysis) (Bosetti et al., 2006, 2007, 2009a).

WITCH has a peculiar game-theoretic structure that allows modelling both cooperative and non-cooperative interactions among countries. As in RICE (Nordhaus and Yang, 1996), the non-cooperative solution is the outcome of an open-loop Nash game: thirteen world regions interact non-cooperatively on the environment (GHG emissions), fossil fuels, energy R&D, and on learning-by-doing in renewables. Investment decisions in one region affect investment decisions in all other regions, at any point in time. In this paper the non-cooperative solution is used to build both the Reference and the policy scenarios. Since we focus on a cost-effectiveness framework, we do not include the feedback of climate change on the economy which is instead present when the model is used for cost–benefit analysis.[4]

Each region's social planner maximizes the present value of discounted log-utility of per capita consumption. WITCH's top–down framework guarantees an efficient, fully intertemporal allocation of investments, including those in the energy sector, without ad-hoc assumptions as in simulation models. WITCH is a truly dynamic model in which investment decisions are taken with perfect foresight. This means, for example, that carbon prices expected in the future affect present investment decisions. There is no uncertainty and it is possible to perfectly foresee the environment – in terms of economic growth, population, price of inputs – in which investments decisions will be taken.

WITCH is a hybrid model because it combines features of both top–down and bottom–up modelling: the top–down component consists of an intertemporal Ramsey–Cass–Koopmans optimal growth model in which the economy of each region is divided in two large sectors that are perfect substitutes. On the one side we have the oil extraction sector and on the other side the rest of the economy. The energy input of the aggregate 'non-oil' production function has been expanded by means of nested Constant Elasticity of Substitution (CES) functions to provide a rich description of energy supply.

The 'non-oil' CES production function combines a Cobb–Douglas aggregate of capital–labour and energy services with an elasticity of substitution equal to 0.5; energy services are produced combining the energy input and knowledge capital in a CES nest with elasticity of substitution equal to 1.7. The energy input is a CES combination of electric and non-electric energies. Further detail is provided in Bosetti et al. (2006, 2007, 2009a).

Energy sector dynamics is fully endogenous. Energy services demand depends on the (endogenous) relative prices of capital, labour and energy inputs. Each region's social planner determines the optimal level of electricity generation and the optimal technology mix by investing in nine different power generation capacity stocks, one for each technology.[5] Therefore investments in the power sector are an output of the model. WITCH does not use exogenous levelized

[4] The lack of a climate feedback into the economy might lead to biased estimates of future investment patterns. We might overestimate investments in the Reference scenario and underestimate investments in the carbon tax scenarios. However, the bias would likely affect years at the end of the century (mitigation measures have significant impacts on average temperature beyond 2070) while we focus most of the analysis on the first half of the century.

[5] Range of investment costs in power generation technologies across the thirteen world regions in base year (2005): wind (1467 US$/kW), nuclear (1590–2587 US$/kW), hydro-power (1777 US$/kW), pulverized coal (966–2072 US$/kW), oil (819–1365 US$/kW), natural gas (629–1050 US$/kW), integrated gasification combined cycle (IGCC) coal with carbon capture and storage (3173 US$/kW), natural gas with carbon capture and storage (2538 US$/kW). IGCC power plants with CCS can also be used with a mix of coal and biomass. There is a backstop power generation technology which becomes competitive only after investing in a dedicated knowledge stock. The backstop substitutes nuclear linearly.