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E3 Models Revisited

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Abstract

This article analyses the contribution of E3 models to fully understand the complex relationship between the environment, economics and the energy sector. We present a survey of the literature on these models, analyzing the assumptions, features and scope of the main kinds of methodological approaches: bottom-up, top-down and hybrid models. Since the literature on these models is vast, complex and diffuse, our aim is to present it in a simple and compact way. We also show how bottom-up (BU) models depart from top-down (TD) ones and how that approach affects their conclusions and implications. As an attempt to solve the TD-BU incompatibilities, different kinds of hybrid models are examined and their capacity to support realistic environmental policies is criticized under a microeconomic perspective.

Keywords: E3 models; bottom-up models; top-down models; hybrid models.

JEL codes: C61, O30, Q43, Q48, Q56, Q58.

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1. Introduction

Economic growth has been historically linked to increasing energy consumption while the energy sector remains one of the main sources of polluting emissions[1] (Jaffe and Stavins, 1995; Köhler et al., 2006). On the other hand, environmental policies affect the energy sector and the economy as a whole through changes in relative prices and through incentives to the introduction of innovative technologies.

The relationships between the environment, economics and the energy sector are deep and complex. These strong connections justified the emergence of ambivalent models, known as E3 (Environment-Economics-Energy) models.

Generally, environmental policy goals are set and researchers analyze the possible actions to achieve them as well as their economic effects and costs. Then, policy makers account for efficiency and gains versus costs of each policy to take action (Hourcade et al., 2006; Bataille et al., 2006). However, achieving environmental goals also requires technical and behavioral changes, which increase the complexity of the models. Policy-makers need to know how their policies affect technical evolution and future costs, as well as long run preferences of consumers and businesses preferences in order to minimize welfare losses (Jaccard et al., 2003; Rivers and Jaccard, 2005). The difficulty of this task increases with the various kinds of uncertainty involved.

Much has been written about E3 models, but the diffuse character of these works justifies our effort to synthesize the characteristics of this vast literature in a simplified and systematic manner. Thus, after these introductory remarks, the paper proceeds to provide a general presentation of the E3 literature in section 2: in subsection 2.2.1, and 2.2.2, respectively, we analyze Bottom-Up (BU) and Top-Down (TD) models in terms of their main features and, in subsection 2.2.3, we propose some key comparisons; in subsection 2.2.4, we identify the different kinds of hybrid models which allow a better understanding of possible future scenarios, especially in what concerns energy. The challenges faced by these models related with theoretical consistency are also emphasized. Section 3 concludes the paper with an assessment of the current state of the existing literature.

[1] According to the European Environment Agency, the energy sector is responsible for about 80% of the Greenhouse Gas (GHG) emissions in Europe.

2 The E3 literature

To analyze the problems concerning the environment-economics-energy relationship in a comprehensive way, particularly from the policy-makers perspective, several models have been developed in the last decades. E3 modeling consists of a specific system model for each of the three components and formulates effects and feedbacks among them (Capros, 1995).

The taxonomy of the E3 models divides them into Bottom-Up (BU), Top-Down (TD) and hybrid models (Löschel, 2002). In general, economists study the economic effects using TD approaches while system analysts and engineers focus on the technical details using BU models (Bosetti et al., 2006; Hourcade et al., 2006). The difference between these approaches is not only conceptual, but essentially concerning the assumptions, the scope of *ceteris paribus* constraints and the different levels of industrial and technical aggregation in each model (Böhringer, 1998; Rivers and Jaccard, 2005; Böhringer and Rutherford, 2006).

Some authors (Jaccard et al., 2003; Köhler et al., 2006; Hourcade et al., 2006; Bataille et al., 2006) refer that ideally, an E3 model should be technologically explicit, microeconomic realistic (particularly in terms of the agents behavior) and should have macroeconomic completeness (including links between the energy sector, the economic structure and total output. Even if neither modeling approach fully achieves the described requirements, nor completely covers the three dimensions or even incorporate all potentially important information, relationships and uncertainties, it may help to understand the key factors determining divergent conclusions (Jaccard et al., 2003; Hourcade et al., 2006).

2.2.1 Bottom-up models

<u>Structure</u>

BU models are generally partial equilibrium models (Böhringer, 1998; Löschel, 2002) which provide a precise technological description of the energy system but neglect the interactions with the rest of the economy. Their engineering-based description of the energy sector covers all phases of the energy generation process from primary energy processing (conversion, transport and distribution processes) to final energy use systems. The large number of discrete energy technology options (current and prospective ones) captures the impacts of exogenous policy constraints, possibilities of substitutions (at different levels of the generation and consumption processes) and improvements (efficiency, energy savings, emission reductions) both in the supply and the demand sides (Böhringer, 1998; Hourcade et al., 2006; Bataille et al., 2006; Böhringer and Löschel, 2006).

For instance, BU models analyze how changes in energy efficiency, choice of fuel type, equipment, building, infrastructure or land-use practices affects GHG emissions (Jaccard et al., 2003).

Generally, BU models use real information on costs and performance characteristics of each technology to achieve the least cost energy supply-mix that satisfies a given demand, subject to several economic and environmental constraints (Löschel, 2002; Rivers and Jaccard, 2005).

These models have been criticized for the lack of a realistic representation of microeconomic choice of technologies by firms and consumers and the macroeconomic feedbacks of alternative energy systems and policies (Hourcade et al., 2006; Bataille et al., 2006). The choices among different technologies are not based on agent behavioral aspects. Technologies providing the same energy service (for instance, heating, lighting or motive force) are assumed to be perfect substitutes except for the differences in financial costs and emissions. This assumption may not be realistic, it abstracts from many aspects involving, for instance, preferences and risks for consumers and firms (Jaccard et al., 2003).

Macroeconomic effects

BU models focus on technology and lack a proper representation of the economy as a whole. The relationships and feedback effects among the economic sectors are missing or represented in a simplified way.

Among the features neglected are price distortion effects, economy-wide interactions, income effects (Böhringer and Rutherford, 2006) as well as trade and structural repercussions of changes in energy prices that result in changes in intermediate and final products prices (Jaccard et al., 2003).

Lacking macroeconomic spillovers may be problematic, for instance, in the presence of existing tax interaction and tax recycling effects. This aspect is emphasized by some authors. Goulder (1995) shows that welfare losses rise in the presence of pre-existing taxes, if another tax is introduced. Goulder (1995) and Böhringer and Löschel (2006) find a reduction in a carbon tax costs, if its revenues are used to cut other taxes, such as income ones. There are also effects on international trade. In large open economies, carbon abatement policies affect not only the allocation of domestic resources, but also the prices in international markets through changes in exports and imports. Such change on the terms-of-trade affect all trading countries and generate spillovers with welfare implications. While some countries may be able to pass domestic abatement costs to trading partners (the so-called “beggar-thy-neighbor” policies), others will have even higher welfare losses through the deterioration of terms-of-trade. Consequently, the abatement policy benefits fossil fuels importers and harms the exporters welfare through terms-of-trade changes (Böhringer and Rutherford, 2002; Böhringer and Löschel, 2006). Finally, energy policies, such as CO_2 emission constraints combined with R&D may have impacts on the economic structure through technological change (Böhringer and Löschel, 2006; Otto et al., 2006). For instance, sector differentiated CO_2 constraints encourage growth in non-CO_2 intensive sectors and discourage growth in CO_2 intensive sectors.

Discount rates, cost of shifting to low carbon technologies and the "energy-efficiency gap"

BU models use a cost-of-capital based discount rate to compare financial costs and emissions of different technologies and determine emissions reduction costs. This discount rate (generally between 3% and 12%, as pointed by Rivers and Jaccard (2005) and Bataille et al., (2006)) ignores several factors related to consumer and firm behavior and does not capture the full social or welfare cost of switching technologies. New technologies represent greater risks and longer payback periods (usually aggravated by high initial costs) since consumers and firms have less diversified portfolios than the society as a whole, and do not have perfect information about all technologies available (Sutherland, 1991; Jaccard et al., 2003; Rivers and Jaccard, 2005; Bataille et al., 2006). Even though the regulatory framework may significantly reduce risk, ex-post financial costs may be higher that the ex-ante estimated ones, since new technologies have a higher chance of premature failure than conventional technologies. These two factors relate to consumers option value, which is the expected gain obtained from delaying or avoiding an irreversible investment while waiting for new information that might lead to a better decision (Pindyck, 1990). Another relevant aspect is the heterogeneity of consumers and firms in terms of their preferences and financial costs. Acquisition, installation and operating costs may vary with location and type of facility. Therefore, a technology that is cost-effective on average may not be cost-effective for everyone (Rivers and Jaccard, 2005; Jaffe and Stavins, 1995; Jaccard et al., 2003). Finally, consumers and firms may find two similar technologies providing the same service not perfectly substitutable as usually assumed in BU models. Non-financial and subjective attributes affect the consumers' surplus, that is, the extra value realized by the consumer above the financial cost of the technology. These factors represent a higher discount rate than the one usually used. The revealed discount rates, accounting for extra costs, risks and externalities are of 20-50% for industrial applications and 80% for residential ones (Nyboer, 1997; Bataille et al., 2006).

Another crucial distinction is between social and private discount rates. Social discount rates are generally lower than private ones, because of the public good nature and externalities associated with energy efficiency investments (such as environmental costs), which justifies governmental intervention in these types of goods (Sutherland, 1991). Additionally, these investments are a type of insurance against risk (of high energy prices) and therefore should have a lower discount rate. In fact, without governmental intervention there will be underinvestment in conservation measures. By ignoring those factors, BU models tend to be very optimistic and find many cost-effective opportunities for energy-related emission reduction. Emerging technologies available for emission abatement appear to be profitable or just slightly more expensive than previous technologies (Jaccard et al., 2003; Bataille et al., 2006). Besides underestimating the costs, these models overestimate the willingness of firms and households to switch technologies and reduce GHG emissions. As a result, they usually identify the existence of an energy efficiency potential achievable without extra costs. Empirically, there is no evidence of this potential which creates the so-called "energy efficiency gap" (Capros, 1995; Rivers and Jaccard, 2005). A microeconomic view suggests that this gap may be explained by market conditions and imperfections as well as by the behavior of economic agents.

2.2.2 Top-down models

Structure

Usually, TD models are general equilibrium models with a global and highly aggregated view of the economy, including different sectors, markets and feedback effects among them. The treatment of the energy sector, on the other hand, is very rudimental (Böhringer and Rutherford, 2006). Market shares of energy and other inputs are usually determined using estimated relative costs on sectoral and total economic outputs (Bataille et al., 2006). By explaining the income origin and application of all major economic agents (households, firms, government and abroad), TD models depict matters of efficiency and equity of several policies (Böhringer, 1998).

The simplified energy sector includes a constant elasticity of substitution (CES) representation of consumers' preferences and production functions. The possibilities of technical substitution are captured only by that elasticity (Capros, 1995; Böhringer and Rutherford, 2006).

Classifications

Löschel (2002) classifies TD models as open (demand driven Keynesian) or closed (general equilibrium, neo-classical) ones. General equilibrium models may be used to normative policy analysis but not as a descriptive tool, since they formulate price-driven market equilibrium regimes.

On the other hand, neo-keynesian models allow for disequilibrium conditions and provide short/medium term projections (Capros, 1995).

The most common approach is to use general equilibrium TD models and apply them as Computable General Equilibrium (CGE) models (Böhringer, 1998; Hourcade et al. 2006). CGE combine behavioral assumptions, such as rationality of economic agents, with the analysis of equilibrium conditions (Böhringer and Löschel, 2006).

Macroeconomic effects

Price-dependent interactions and feedback effects between all markets are depicted in TD models. Those interactions may be induced by policies which change relative prices and incomes. Hence, energy policies cause direct energy market adjustments and indirect spillovers to other markets (Böhringer, 1998; Böhringer and Löschel, 2006). For instance, TD models simulate the economy's response to a policy increasing the relative cost of intensive GHG technologies, taking into account feedback effects between the energy sector and the economy as a whole or energy supply and demand. The marginal cost of achieving a given GHG reduction target is the magnitude of total economic impacts necessary to achieve that target (Jaccard et al., 2003).

Parameters estimation

CGE models are extremely dependent on empirical parameters estimates which unfortunately are rare and imprecise (Böhringer, 1998). The key TD parameters describing technological change (TC) are the elasticity of substitution (ESUB) and the autonomous energy efficiency index (AEEI). The former defines how easily one input may be substituted by another when relative prices change (this substitution may be in terms of aggregate inputs such as capital, labor, energy, materials or between different energy forms such as coal, oil, gas and renewable energy sources). The later defines how quickly energy efficiency increases autonomously in the future, that is, the rate at which price independent technological evolution improves energy efficiency (Jaccard et al., 2003; Rivers and Jaccard, 2005; Bataille et al., 2006). The AEEI is a function of technology improvements and capital stock turnover. The higher the ESUB and the AEEI the lower will be the cost of shifting to lower emission technologies.

These key parameters and the aggregate relationships between relative costs and relative market shares of inputs are usually estimated from historical data (Jaccard et al., 2003; Rivers and Jaccard, 2005). The parameters consider actual consumers' and businesses' preferences since they are estimated from real agents' behavior data. This allows TD models to include factors excluded by BU ones.

Problems raised by the use of parameter estimations

Sometimes the ESUB and AEEI cannot be properly estimated due to serious lacks and inconsistencies of data. In these cases they may be guessed using expert judgment, for instance based on the best data available for ESUB or used as tools to calibrate to base-year statistics or a growth forecast in the case of AEEI (Bataille et al., 2006). Yet there is another problem with these parameters. Even if they could be properly estimated form historical data, it may be impossible to calculate long run ESUB and AEEI. Future production possibility frontier is constantly changing in response to fluctuation of input prices, technological advances and actual energy and environmental policies. Typically, parameters are fixed in TD models misrepresenting economic evolution and possibly overestimating policy costs. There is no guarantee the estimations will remain valid in the future, probably they will not (Jaccard et al., 2003; Rivers and Jaccard, 2005; Bataille et al., 2006). As the economy changes so will the ESUB and AEEI. Particularly, policies aim has changed over the last decades and has become environmental oriented. Promoting the creation and commercialization of low emission technologies may have lowered these technologies' financial costs and risks (for instance, with economies of scale and economies of learning). Also, consumers' preference for such technologies has changed over time. All this affects the model's parameters (Jaccard et al., 2003; Hourcade et al., 2006).

As a result, some authors propose alternative solutions for the problem. Griffin (1977) suggests an alternative estimation method to avoid looking at historical data.[2] Other TD modelers have tried to find ways of including endogenous TC in their models to have long-run parameter dynamics, but with little success so far (Löschel, 2002; Bataille et al., 2006).

2.2.3 Comparison

As a result of different structures and assumptions, TD and BU models predict very distinct outcomes which restrain their policy utility (Rivers and Jaccard, 2005).

[2] Griffin (1977) demonstrates that the optimal input and output quantities have a corresponding vector of input and output prices. He determines the shape of the production possibility frontier by solving the model for alternative price vectors. Then he estimates the dual of this production possibility frontier, the price possibility frontier, allowing the long-run ESUB calculation.

Cost of shifting to low carbon technologies and the "energy efficiency gap"

Contrasting with BU models, which usually depict an "energy efficiency gap", TD models assume competitive markets automatically allocating all inputs and final goods efficiently. This leaves no space to that "efficiency gap" (Hourcade et al., 2006). Additionally, they include market and agent behavior, factors missing in BU models, which makes them more pessimistic than the former (Capros, 1995). In concrete, TD models include all intangible value losses and predict much higher costs of GHG emission mitigation (Jaccard et al., 2003). This divergence between the two approaches is not yet completely solved in the economic literature (Hourcade et al., 2006).

Technological change

TC is a decisive element for achieving policy goals (Jaffe and Stavins, 1995; Rivers and Jaccard, 2005; Bosetti et al., 2006). The treatment of this crucial feature differs significantly among TD and BU models. With the shift to lower GHG emission technologies, police makers need to know how a specific policy behave in terms of economic efficiency, environmental effectiveness and administrative and political feasibility. They also need to know how policy influences several aspects such as long run TC, ex-ante and ex-post financial costs of carbon-free technologies, the preferences of economic agents and some major economic variables – employment, competitiveness, economic structure and trade among others – (Jaccard et al., 2003; Hourcade et al., 2006).

According to Löschel (2002) models of complex socioeconomic systems require simplifying assumptions, such as that the economic structure will remain unchanged or will change in a specified way. TC is integrated in the economy according to this assumption. In fact, the conclusions and implications of each model will largely be influenced by the treatment of TC. The incorporation of endogenous TC (ETC) (in opposition to exogenous TC) tends to reduce environmental policy costs, to accelerate abatement and to create positive spillovers. In this line of thought, Jaffe and Stavins (1995) sustain that the rates of invention, innovation and diffusion are endogenously determined within the economic system.

Notwithstanding, the treatment of TC differs according to the type of model under analysis. In TD models it is introduced through the relationship between inputs, outputs and their relative prices. New technologies replace old ones as relative prices change. The possibilities of substitution (transformation) are captured by the elasticity of substitution (transformation) in the CES functions. Furthermore, TC is induced mainly through R&D efforts (e.g., Chakravorty et al., 1997; Popp, 2006; Otto et al., 2006; Löschel and Reilly, 2006). On the other hand, in BU models TC occurs through a rapid, or even instantaneous, penetration of new, more efficient, technologies. In BU models the endogenization of TC usually requires the introduction of “learning” effects, through learning-by-doing (LBD), which reduce investment costs (e.g., Messner, 1997; Capros et al., 2001; van Vuuren et al., 2004).

Because they lack technology explicitness and limit technological evolution to historical elasticity, TD models tend to consider GHG mitigation policies, such as the promotion of carbon-free technologies, too costly (Hourcade et al., 2006). In contrast, in BU models, a shift towards low GHG emissions would seem inexpensive or even profitable, because they neglect transaction costs, inertia in the energy system and market failures on the demand side (Löschel, 2002; Hourcade et al., 2006). In this sense BU models are too optimistic. TD models are too optimistic by considering a backstop technology. This is an already known technology which is not yet commercial but that would solve the GHG emissions problems (Löschel, 2002). Additionally, Popp (2006) refers that BU with endogenous TC tend to be more optimistic than TD ones because they ignore opportunity costs. In fact, when a TD models considers R&D efforts to reduce investment costs, they often include the crowding out effect that a dollar in energy R&D creates for other R&D activities. BU models, by simply considering LBD, ignore that crowding out effect.

The state of the art in this type of modeling has moved to endogenous technical change (ETC) and induced technical change (ITC) (Köhler et al., 2006).

Policy implications

Several policies are used to reduce polluting emissions and achieve environmental goals. These include market-based approaches (such as taxes on GHG emissions, subsidies or tradable emission permits), performance standards (such as limitation to the polluting emissions of firms per unit of economic activity) and technology standards (such as the requirement to employ a certain equipment or process) (Jaffe and Stavins, 1995). The last two are usually called command-and-control regulations. Market-based policies change relative prices and are frequently avoided by policy makers for not being socially well accepted (Jaffe and Stavins, 1995; Rivers and Jaccard, 2005). Nevertheless, they provide continuous emission reduction incentives, since every reduction decreases tax costs, increases subsidies earned or permits that can be sold. Technology-oriented policies tend to be preferred by policy makers, but present some disadvantages. For instance, once a performance standard is achieved there is no incentive to further reduce emissions and the firms may even fear that the standard will become tightened. Additionally, technology standards may harm innovation by imposing a certain technology and removing incentives to develop a new technology (Jaffe and Stavins, 1995).

Distinct policies are captured differently by TD and BU models. TD models capture major economic consequences of alternative policies, for instance, in terms of public finances, economic competitiveness and employment. Therefore, they are appropriated to analyze polices changing relative prices such as taxes, tradable permits, subsidies and not technology specific regulation. They lack technological flexibility and explicitness necessary to portray technical and cost evolution realistically and are not appropriated to analyze technology-oriented policies – such as renewable portfolio standards, technology labeling programs, new-technology oriented subsidies and regulation (Jaccard et al., 2003; Bataille et al., 2006; Böhringer and Rutherford, 2006; Hourcade et al., 2006). Technology-oriented policies tend to be preferred by policy makers since they are socially accepted more easily than, for instance, taxes (Jaffe and Stavins, 1995; Jaccard et al., 2003; Rivers and Jaccard, 2005).

In contrast, BU models cannot fully capture policy implications since they lack some major economic effects and feedbacks (Bataille et al., 2006; Hourcade et al., 2006).

2.2.4 Hybrid models

Hybrid models combine the strengths of TD and BU models by simulating consumer and firm behavior at the technological level (Rivers and Jaccard, 2005). Given the limitations described, some BU modelers have incorporated macroeconomic feedbacks or estimated microeconomic parameters for technology choices in their models. At the same time, some TD modelers have incorporated technological explicitness for the energy sector or parameters for endogenous TC in their models (Hourcade et al., 2006).

Classifications

We may find several classifications of hybrid models. Concerning the structure of the model (Böhringer and Rutherford, 2006), the "soft-link" approach attempts to couple existing BU and TD models which may originate consistency problems. Alternatively, the "hard-link" approach uses a single integrated modeling framework emphasizing economic consistency. Another possible classification relates to policies type (Löschel, 2002). There are policy evaluation (or simulation) models, which estimate the effects of a given exogenous policy or optimization models which find the most efficient policy and then simulate its effects.

For Hourcade et al. (2006) hybrid models fall in one of the following categories: a TD model that does not use either CES or fixed AEEI. Instead, it uses another way of representing the energy sector as in BU models with ITC for instance resulting from LBD effects; a TD model with a higher level of disaggregation using Leontief fixed-input ration for the energy system; a BU model with functions to clear the markets based on changes in the cost of production optimizing consumers utility and firms profits; or a composite hybrid model including aspects of TD (such as the relationship and feedback effects between the economy, the energy sector and the environment) and BU modeling (such as a detailed representation of available energy technologies). This last type seems the ideal option but also it is the most challenging (Hourcade et al., 2006).

Structure

Hybrid models give a better understanding of possible future scenarios, especially in what concerns energy. They allow studying the compatibility of these scenarios with environmental and climate goals and policies. Furthermore, they are well suited for climate policy analysis since they capture the dynamics of technical change and its relationship with the main economic and policy variables. Ideally, these models should take into account inter-temporal, inter-spatial and inter-generational issues as well as externalities (Bosetti et al., 2006).

The structure and scope of the model will depend on its objectives. For instance, the spatial scale and resolution of the model will depend on whether it is meant to deal with global issues such as climate change or regional/local problems such as urban pollution. It is also dependent on the timeframe of the model which will depend on whether one deals with long-term or short-term policy (Hourcade et al., 2006).

Technical Change

One of the most important features of E3 models is the way they depict TC. As referred, this will have a major influence in their conclusions. Hybrid models tend to include TC in a more realistic manner than TD and BU models. Some of them consider only R&D efforts or LDB, but depict the energy system with more detail than TD models (e.g. van der Zwaan et al., 2002; Akimoto et al., 2004; Manne and Richels, 2004; Edenhofer et al, 2005).

Nevertheless, some hybrid models go even further and consider both R&D efforts and LBD (e.g., Barker et al., 2005; Bosetti et al., 2006; Kypreos, 2007).

Challenges and problems

The challenges faced by these models are related to their theoretical consistency as described above, but also concerning empirical validity, political relevance and some practical problems as computational complexity. Two additional goals are of great interest. The first is achieving a better understanding and representation of firms and consumers behavior when faced with uncertainty, diverse policy and market signals. The second is dealing with constraints caused by data gaps and inconsistencies (Hourcade et al., 2006). According to Ghersi and Hourcade (2006) little attention has been paid to the issue of consistency between TC in the energy sector and TC in the rest in the economy when hybridizing TD and BU models. These authors refer that, in general, given the small weight of the energy sector in the economy it is acceptable to keep the non-energy production functions of the original TD model. However, when policy goals are ambitious long-term objectives (such as an almost total shift to free-carbon technologies) that procedure may not be suited.

The non-linear equation methods usually used in CGE does not support the complementary conditions that describe technological options. In this sense, Böhringer (1998) shows that representing the general equilibrium as a mixed complementary problem (MCP) allows for a hybrid modeling of the economy. In this sense, the energy sectors are represented using the BU approach (i.e. mathematical programming constraints) and the rest of the economy using the TD approach (continuous neoclassical production functions) in order to restrict data requirements and dimensionality problems. The MCP approach combines the technical details of BU with economic richness of TD models.

Moreover, by often presenting increasing returns to scale, these models are highly non-linear and face the possibility of instabilities, multiple solutions and discontinuities (Köhler et al., 2006).

Despite the strong proliferation of hybrid models in the last years, some of them did not include consumers and firms' behavior in a realistic way, since they rely on linear programming models to determine energy prices and technology choices (Rivers and Jaccard, 2005).

3. Concluding remarks

The E3 literature concerns the Environment-Economics-Energy systems. TD and BU models represent the interconnections between those three systems only partially. While TD models capture the interconnections between the three components but represent the energy system over simplistically, BU models depict the energy system in great detail but miss some relationships and feedback effects with the economy and the environment. Hybrid models have emerged as an attempt to solve that problem.

In this paper we have reviewed the major distinctions and characteristics of the various models in the E3 literature, which is vast but diffuse. We have shown how BU models depart from TD ones and how that affects their conclusions and implications and how hybrid models try to solve the TD-BU incompatibilities.

Economic models are necessarily simplified representations of the real world and E3 models are not the exception. Despite that, these models provide useful insights for policy makers when implementing environmental and energy policies. In particular, they have been widely used to study how specific environmental targets affect and are affected by technological change in the energy sector and how that relates with the economy as a whole. However, if policy makers want to use the insights of the E3 models properly, they need to understand the major aspects behind the models results.

The E3 literature has faced a constant trade-off, since more complex models represent the world more realistically and therefore allow more complete analysis, but mean more analytical and computational difficulties. Over the years, authors have made increasing efforts to create more complex and realistic models and the E3 literature has evolved reflecting the effort. Some E3 models are already representing issues such as uncertainty concerning TC, returns on learning and climate change. Future models will certainly follow this path, as computational skills improve, models will be more and more complex.

In this work, we intended to provide information about the E3 literature in a simple and compact manner to allow for a better understanding of the E3 models and their functioning. With this, we hope to help researchers, namely economist, understand the major distinctions and features of this literature as well as the path new E3 modelers tend to follow.

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