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The behavioural aspect of green technology investments: A general positive model in the context of heterogeneous agents

Florian Knobloch[a], Jean-Francois Mercure[a,b,*]

[a] Cambridge Centre for Environment, Energy and Natural Resource Governance (C-EENRG), University of Cambridge, 19 Silver Street, Cambridge CB3 1EP, United Kingdom

[b] Department of Environmental Science, Radboud University, PO Box 9010, 6500 GL Nijmegen, The Netherlands

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ABSTRACT

Studies report that firms do not invest in cost-effective green technologies. While economic barriers can explain parts of the gap, behavioural aspects cause further under-valuation. This could be partly due to systematic deviations of decision-making agents' perceptions from normative benchmarks, and partly due to their diversity. This paper combines available behavioural knowledge into a simple model of technology adoption. Firms are modelled as heterogeneous agents with different behavioural responses. To quantify the gap, the model simulates their investment decisions from different theoretical perspectives. While relevant parameters are uncertain at the micro-level, using distributed agent perspectives provides a realistic representation of the macro adoption rate. The model is calibrated using audit data for proposed investments in energy efficient electric motors. The inclusion of behavioural factors reduces significantly expected adoption rates: from 81% using a normative optimisation perspective, down to 20% using a behavioural perspective. The effectiveness of various policies is tested.

1. Introduction

Why are firms' investments in green technologies lower than predicted by engineering studies? Can the gap be sufficiently explained as a rational response to risky future cost-savings and information asymmetries? Or do behavioural aspects cause a further systematic undervaluation of green technologies compared to contemporary mainstream investment theory? If so, what implication does this have for policies aimed at increasing such investments?

A green technology is one that *generates or facilitates a reduction in environmental externalities relative to the incumbent* (Allan et al., 2014, p. 2). When this is achieved by reducing the input for a given output, a technology potentially reduces operating costs along with the externality. According to mainstream economic theory, a profit-maximising firm should undertake such an investment whenever these future savings outweigh the upfront cost.

However, studies based on engineering data regularly report that seemingly cost-effective green investments are not undertaken (for a discussion, see Grubb, 2014, p. 132). A reduction of environmental externalities at apparently

* Corresponding author at: Department of Environmental Science, Radboud University, PO Box 9010, 6500 GL Nijmegen, The Netherlands
E-mail addresses: knobloch@cantab.net (F. Knobloch), J.Mercure@science.ru.nl (J.-F. Mercure).

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negative cost is consistently found within the literature (Allan et al., 2014). McKinsey and Company (2009) claims that global CO_2 emissions could be reduced by 11Gt per year by investing in cost-effective green technologies, which is not currently happening. The largest potential is attributed to energy efficiency measures, and the gap between realised market outcomes and the normative cost-minimising benchmark is referred to as the *energy efficiency gap* (Jaffe and Stavins, 1994).

Considering the gradual process of technology diffusion (e.g. Geels, 2002; Rogers, 2010), it is meaningful to analyse how firms decide on a green technology investment when it is directly presented to them, such as after an energy audit. Firms apparently reject a large fraction of seemingly cost-effective project recommendations, as seen from external engineering perspectives (Anderson and Newell, 2004). Firms dismissing profitable investments in such a systematic way makes effective policy-making for stimulating technological change difficult: it becomes unclear how to create fruitful incentives for technology adoption. In the case of technologies that reduce energy use and emissions, this has important implications for climate change mitigation policy (Worrell et al., 2009).

There exists a vast quantity of literature that both analyses the scope of the gap, and suggests possible reasons — the so-called *market barriers* (Sorrell, 2004; Sorrell et al., 2011). Many studies attempt to realign the observed adoption gap with the neoclassical theory paradigm, in which the representative agent adopts cost-minimizing or utility-maximising measures. For example, Sutherland (1991) argues that firms have rational reasons to reject green technologies, but that these reasons are mostly omitted in engineering studies — such as hidden costs, risk, imperfect information and capital constraints. As a result, many investments may be less profitable than they seem to be.[1]

While economic barriers can explain parts of the gap, others question the behavioural realism of decision mechanisms assumed in theories (e.g. DeCanio, 1998; Gillingham and Palmer, 2014). First, firms might not act as profit-maximisers, but instead look for satisfactory solutions (Simon, 1955). Second, behavioural economics shows that human decisions systematically violate the axioms of expected utility theory, and are better described based on psychological foundations (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). Since decisions of firms are a combination of human decisions, they can be subject to the same behavioural biases (Grubb, 2014).

The relevance of behavioural factors for climate and energy policy is now widely acknowledged (Pollitt and Shaorshadze, 2012; Allan et al., 2014). However, there is limited knowledge on what drives people's and firms' behaviour, and how this influences aggregate outcomes.

This is particularly relevant in the perspective of sustainability transitions studies, in which the process of decision-making by agents is often not emphasised, but is at least as important as cultural, regulatory and other contextual factors that influence or limit the formation of new socio-technical regimes (e.g. as in Geels, 2002). This type of research can improve representations of agent behaviour, quantitatively and qualitatively, in the various representations of the field (i.e. the multi-level perspective and technology innovation systems), since it is ultimately agent adoption choices that determine the successful replacement of old socio-technical regimes by new ones, and the diffusion of innovations out of their niches.

To clarify current understanding and to improve quantitative analysis, we combine known behavioural facts into a simple aggregate model of decision-making by heterogeneous agents for technology adoption. This allows identification and quantification of relevant barriers and behavioural factors, without recourse to unknown variables, and aims at a higher predictive power when modelling the adoption of a green technology. Finally, it can provide key insight on the likely effectiveness of policies from a behavioural perspective.

The diverse perception by agents of the profitability of a technology can influence rates of uptake. Diversity implies varying adoption thresholds across agents, and is thus partly responsible for the typically observed gradual diffusion of innovations (Rogers, 2010). Thus, within this model, investment decisions are simulated based on the technological and behavioural diversity of firms. It is assumed that a technology has different costs and benefits, as perceived by every single firm. Due to heterogeneous decision-making parameters, investment decisions by firms differ even when faced with the same problem and data. Furthermore, behavioural aspects include systematic biases in firms' perceptions of technological opportunities. This is typically interpreted with prospect theory (Kahneman and Tversky, 1979), in which gains and losses are not valued equally. Thus we combine here both effects of *behavioural diversity* and of *behavioural biases*.

To quantify the relevance of behavioural factors compared to a normative benchmark, the model simulates technology adoption using three different possible types of decision-making — referred to as *levels of decision-making*: optimizing, satisficing and behavioural. Each level corresponds to a different point of view on the investment decision, or method for project evaluation, and thus includes different barriers and degrees of heterogeneity. The model can be used to estimate and compare the effectiveness of policies according to different levels of decision-making, or theoretical paradigms from the viewpoint of the modeller.

To demonstrate the model's abilities, we apply it to a case study of electric motors, which account for 43–46% of global electricity consumption. It is estimated that cost-effective investments could increase their average efficiency by 20–30% (Waide and Brunner, 2011). Nevertheless, firms systematically reject these investment possibilities (*ibid*). To explain this phenomenon, the model simulates these investment decisions on different levels of decison-making. The results are compared to observed decisions that have been taken by firms after energy audits.

[1] The issue with such a line of reasoning is that it allows accepting the use of an un-falsifiable theory, where cause is attributed to unknown variables.