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Avoiding carbon lock-in: Policy options for advancing structural change

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ABSTRACT

An obstacle for the transformation to a low-carbon economy is the carbon lock-in: fossil fuel-based ("dirty") technologies dominate the market although their carbon-free ("clean") alternatives are dynamically more efficient. We study the interaction of learning-by-doing spillovers with the substitution elasticity between a clean and a dirty sector to evaluate the robustness of policies averting the carbon lock-in. We find that the substitution possibilities between the two sectors have an ambivalent effect: although a high substitution elasticity requires less aggressive mitigation policies than a low one, it creates a greater welfare loss through the lock-in in the absence of regulation. The socially optimal policy response consists of a permanent carbon tax as well as a learning subsidy for clean technologies. We thus indicate that the policy implications of (Acemoglu, D., Aghion, P., Bursztyn, L., Hemous, D., 2012. The Environment and Directed Technical Change. American Economic Review 120 (1): 131–166), calling for merely temporary interventions based on the mechanism of directed technical change in the same setting, are limited in scope. Our results also highlight that infrastructure provision is crucial to facilitate the low-carbon transformation.

1. Introduction

Climate change mitigation requires drastic cuts in emissions in the 21st century and necessitates a transformation from a fossil-fuel based to a decarbonised economy. Both empirical evidence and theoretical argument suggest that an obstacle to this transformation is the possibility of a carbon lock-in (Unruh, 2000; Schmidt & Marschinski, 2009; Davis et al., 2010; Lehmann et al., 2012): the economy remains in an equilibrium in which carbon-intensive ("dirty") technologies dominate the market, although they are intertemporally inferior to low-carbon ("clean") alternatives. The size of such a market failure and the appropriate policy responses to it crucially depend on the substitution possibilities between such sectors, which are influenced by infrastructures, yet sometimes also by behavioural and institutional factors. They also depend on the mechanism underlying the development of clean production technologies. Which policy options best advance structural change towards the low-carbon economy is less clear: few studies have examined policy responses that are sufficient to avoid a carbon lock-in (Fisher & Newell, 2008; Gerlagh et al., 2009).

The purpose of this study is twofold: first, we contribute to quantifying the size of a lock-in by studying the impact of the substitution elasticity between a dirty and a clean sector. We find an ambivalent effect: a high elasticity creates a greater lock-in in the absence of regulation, but also requires less drastic policy intervention. This has implications for the effectiveness of second-best policy. Second, our article is a sensitivity study of Acemoglu et al. (2012) (henceforth: AABH), who analyse the impact of directed technical change in the framework of the present article: our results show that with learning-by-doing behaviour of clean technologies instead of directed technical change, effective mitigation policies need to be permanent, not temporary, regardless of the value of the substitution elasticity because demand for intermediate dirty production never becomes zero.

We use a two-sector intertemporal general equilibrium model and solve it numerically to identify policy options that are sufficient to avoid high welfare losses. A common stylized setting is employed to depict structural change to a low-carbon economy: there is one clean sector, without emissions, and one dirty, emitting greenhouse gases. This approach has been adopted by AABH and, for instance, also by Gerlagh & Hofkes (2002) and Cassou & Hamilton (2004). Our model set-up, including the representation of global warming, is nearly identical to that of AABH in order to be comparable in terms of policy implications: we respect all parameter choices and functional forms of AABH except those concerning the nature of technological progress. While AABH focuses on the effects of directed technical change for the transformation to a low-carbon economy, our work relies on the assumption of learning through spillover effects in the clean sector as its capacity is built up.

Such a learning-by-doing approach (Arrow, 1962) is well-established within energy economics (Kverndokk & Rosendahl, 2007): the cost of renewable technologies decreases with cumulative installed

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capacity at a stable rate (Fischedick et al., 2011, Ch.10.5.2). No comparable effect exists for dirty, mature technologies (McDonald & Schrattenholzer, 2001). It has moreover been demonstrated theoretically that – in presence of learning-by-doing externalities – optimal carbon pricing is insufficient to overcome a lock-in into mature low-carbon technologies in the energy market (Kalkuhl et al., 2012). We further discuss the differences between the assumptions of learning through increased capacity and directed technological change and their empirical plausibility in Section 2.1.3.

The carbon lock-in was originally examined from a systemic perspective highlighting the co-evolution of technology and institutions (Unruh, 2000): the technologically caused lock-in is exacerbated by institutional and policy failures. Our analysis focuses exclusively on the lock-in as a phenomenon of market failure and leaves aside institutional failures. In our model the lock-in arises through the combination of two externalities: first, learning spillovers that arise from building up capacities in the clean sector are unappropriated and are a stylized representation of positive externalities in the development of low-carbon technologies. Second, the negative effect of carbon-intensive production on utility through climate damages are ignored in the unregulated market outcome. The combination of the externalities can prevent the market from building-up the carbon-free sector and cause a delayed transition to the low-carbon economy. Different interpretations of the concept of a carbon lock-in are frequent (Lehmann et al., 2012; Page, 2006), with some focussing on the non-malleability of capital, for instance by irreversible investment in coal power plants, as an additional cause of the suboptimal share of clean production. Instead we focus here on the interplay between one cause inhibiting the development of the clean sector and the substitution possibilities: as the latter represent infrastructural and institutional limitations to produce clean instead of dirty goods, it is the interplay of both factors that captures the co-evolution of technology and institutions. Since the specific model setup matters for analysing the carbon lock-in, we rely on numerical solutions instead of using an even more stylised model that would be more amenable to analytical treatment. The model is described in Section 2.

The principal message of our study is that although a higher substitution elasticity requires less aggressive optimal mitigation policies, it creates higher welfare losses from a lock-in. The optimal policy response requires both a carbon tax and a learning subsidy. The ambivalent role of the substitution possibility suggests to also examine second-best policy responses: we show that even if the only policy option available is a carbon tax, it can correct most of the welfare loss from the lock-in if the tax is set much higher. Furthermore, regarding the sensitivity of the results of AABH with respect to their conception of technological progress, we find that whether climate change mitigation requires a permanent or a merely temporary policy intervention depends primarily on the mechanism governing technological progress in the clean sector and not on the value of the substitution elasticity. We show that the optimal policy suggested by AABH, which is temporary and triggers a rapid switch from the carbon-intensive to the low-carbon sector, does not reproduce the socially optimal outcome in our model, which differs only by the assumptions about the technologies. Instead, effective mitigation policies need to be permanent, regardless of the value of the substitution elasticity. This is because with a somewhat more gradual development of clean technologies, there will be permanent demand for dirty production that decreases but is never strictly zero. Further, substitution possibilities crucially influence the feasibility of different climate policy options: we find that more stringent mitigation targets require a (much) higher carbon tax if the elasticity is low. They also determine the timing of the optimal subsidy to the clean sector.

The topic of this article is thus related to, but independent of, discussions about adverse effects of green subsidies on climate change mitigation along the lines of a "Green Paradox" (Sinn, 2008, 2012). The idea of the Green Paradox (in the present context) is that green subsidies may provide an incentive for resource owners to extract a part of their fossil reserves earlier because the subsidies may devalue their assets. Whether this effect matters for climate change mitigation has been debated (van der Ploeg, 2013; Edenhofer & Kalkuhl, 2011): climate change mitigation in this century depends crucially on achieving a limit on cumulative emissions much lower than the total emissions that would be generated from burning all fossil resources. Green subsidies, in particular, may lead to a temporarily higher extraction of fossil resources, but will also decrease future resource extraction. They thus lead to more resources being left underground and the latter effect is likely to dominate the former (van der Ploeg, 2013). To focus exclusively on the specific lock-in effects due to the substitution elasticity and for comparison to the study by AABH, we abstract from these effects by not explicitly considering resource owners in our model, which would be necessary to generate effects similar to the Green Paradox. The reason is that effects related to the substitution elasticity and learning behaviour of clean energy are independent of the timing effects of resource extraction due to anticipation of policy changes by resources owners that give rise to the Green Paradox. In contrast, recent research explicitly takes into account fossil fuel extraction to also consider the optimal policy mix of carbon taxation and subsidising renewables (Rezai & van der Ploeg, 2013) or the second-best case of subsidising renewables when carbon pricing is infeasible (van der Ploeg & Withagen, 2014). However, these articles do not adopt a two-sector structure.

A substitution elasticity is not a natural constant, but an artefact of economic theory: the ease of using one technology or product instead of another one. In particular, substitution possibilities are influenced by infrastructure in relevant sectors of the economy, although behavioural and institutional effects are also important, for instance, in the transport sector, too. In the electricity sector, in which the division between carbon-free and fossil-fuel based technologies is clear-cut, the use as opposed to the generation of renewable energy is not straightforward and requires appropriate infrastructure since renewable energy production misaligns with electricity demand in time and space. Infrastructure investments can enable renewable energy use so that the misalignment across space and time is compensated for: grid extensions allow large scale transfers of electricity from generation sites to load sites. In the transport sector, substitution possibilities can also be mostly understood in terms of technology and infrastructure (Schäfer et al., 2009). However, consumer preferences are also important to determine the elasticity between carbon-intensive and low-carbon modes in the case of transportation, since mode choice also involves important trade-offs in terms of security, privacy, comfort and health as well as being driven by habituation to a single mode. Both examples highlight the need for additional policy that increases the elasticity, for example financing appropriate energy infrastructure or fostering institutional changes towards intermodal transport. We suggest that the investments in these infrastructures can be interpreted as an increase in the substitution possibilities. Thus a scenario of an increasing substitution elasticity is the most plausible scenario for the coming decades, particularly in the light of estimates that current substitution possibilities between clean and dirty sectors are very low (Pelli, 2011; Pottier et al., 2014).

2. Model

We use a discrete-time intertemporal general equilibrium model that is similar to that of AABH except for the different conception of technological progress and the different role of government policy options. There are two sectors, one emission-intensive ("dirty") and one carbon-free ("clean"). Those sectors manufacture inputs used in the production of a final good that can be freely used for investment in each sector or for consumption. Households ignore the effect of global warming, which is described by the heuristic approximation chosen in AABH. Technological progress in the clean sector is subject to a