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# Network effects and environmental externalities: Do clean technologies suffer from excess inertia?☆

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ABSTRACT

We study the diffusion of a clean substitute to a dirty durable in a dynamic model. Consumer utility of both durables increases in their respective market shares due to network effects.

First, we characterize the optimal dirty good tax. The tax should achieve a long run optimal division of the market between the two goods. Along the transition path to this steady state the optimal tax depends on the current and future market shares of the clean durable. Thus, even if the marginal environmental damage from an additional dirty durable is constant, the optimal tax should not be constant.

Second, we study whether excess inertia can occur if the emission tax is not optimally set. We then find that a constant tax that only accounts for the environmental damage caused by the dirty good may lead to excess inertia. Excess inertia could happen even if the clean technology is proprietary, and the technology owner has incentives to sponsor the initial market diffusion of the technology.



## 1. Introduction

The solution to an environmental problem often involves replacing an old, dirty technology with a new, clean technology. For example, the depletion of the ozone layer was avoided by mandating a clean substitute to the ozone depleting substances (Barrett, 1999). In other instances, such as combatting climate change, the clean technology alternatives are not so obvious. Thus, governments could want to avoid picking winners, and rather rely on setting a price on emissions. The question then arises; can we always rely on a standard, Pigovian emissions tax to induce market diffusion of the clean technology alternatives?

According to several authors the answer could be “no”. The private sector may be reluctant to switch from the dirty technology to the socially more desirable clean technology even if the negative externalities connected to the use of the dirty technology are internalized. So far the literature has focused on potential market failures in technological development that may slow or block the shift from dirty to clean technologies.[1] In this paper we study whether *network effects* may obstruct the diffusion of existing clean technologies.

Positive network effects arise if one agent’s adoption of a good (a) benefits other adopters of the good; and (b) increases others’ incentives to adopt it (Farrell and Klemperer, 2007). For a network good, we say that there is *excess inertia* when an additional unit of this good would increase welfare, but does not successfully diffuse into the market (Farrell and Saloner, 1986). Network effects are present for a range of low emission technologies; video meetings, alternative fuel vehicles, public transport, carbon capture requiring pipeline transport services for $CO_2$ etc. Furthermore, it is generally acknowledged that clean technology diffusion is needed to solve many pressing environmental problems, such as climate change. Our research question is therefore: *Could a failure to account for network effects in emission taxes lead to excess inertia?*

In line with the recent literature on network effects, we study a dynamic model with infinitely many periods. There are two network

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[1] See for instance Acemoglu et al. (2012) and Chakravorty et al. (2011).

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goods: one dirty and one clean durable. In each period a fraction of the durables wear out, and must be exchanged with new ones; either clean or dirty. Over time the market shares of the two durables may thus change. By taxing the dirty durable the regulator aims for a long run optimal division of the market between the two durables; a steady state.

First, we characterize the optimal dirty good tax when there are network effects. One important finding is that along the transition path to steady state the tax depends on the current and future market shares of the clean durable. Thus, even if the marginal environmental damage from an additional dirty durable is constant, the optimal tax is likely not constant outside of steady state. Second, we study whether excess inertia can occur if the emission tax is not optimally set. We then find that a tax that only accounts for the environmental damage caused by the dirty durable may lead to excess inertia. Excess inertia could happen even if the clean technology is proprietary, and the technology owner has incentives to sponsor the initial market diffusion of the technology.

Network effects are only briefly covered in the environmental economics literature, and – to the best of our knowledge – all examples are currently from the market for personal transportation. Greaker and Heggedal (2010) build an explicit model of the relationship between the market share of hydrogen cars and the density of hydrogen filling stations, and show that this could lead to multiple equilibria. Conrad (2006) introduces network effects into a static horizontal differentiation model with two types of cars, and study the incentive for the dirty car producer to improve the car's environmental performance. Finally, Sartzetakis and Tsigaris (2005) also analyze network effects in the car market, and consider a model with infinitely-lived durable goods. They assume that a shift to clean cars is socially desirable, and find that the tax on dirty cars may exceed marginal environmental damage in order to accomplish the shift.

We extend this literature along many directions by including strategic suppliers of the network goods, durables with a finite life time, and consumers that choose network over and over again. We also introduce a government that maximizes welfare dependent of the current state of the market. Thus, we are able to characterize the optimal emission tax for the general case.

Moreover, our result that excess inertia may occur is contrary to much of the general literature on network effects. Farrell and Saloner (1985) find that when players have complete information about each other's payoffs, and none of the technologies enjoy the advantage of an existing base of users, an uncoordinated adoption process will lead to the efficient outcome.

In a later paper Farrell and Saloner (1986) introduced players with private information about their own payoffs, and an installed base of users of the inferior technology. The superior technology will then be under-adopted. However, Ochs and Park (2010) extend the analysis in Farrell and Saloner (1986), and find that if the most eager consumers move first and entry decisions are irreversible, then in a limiting case, any coordination problem found by Farrell and Saloner (1986) vanishes, and the equilibrium becomes efficient.

Katz and Shapiro (1986) introduced technology sponsors that have proprietary rights to the network technologies. They then found that as long as the superior network technology had a sole owner, it would dominate the market and excess inertia would not occur. This is in line with the argument put forward by Liebowitz and Margolis (1994). Liebowitz and Margolis (1994) doubt that excess inertia is likely to be a significant problem in a market economy. They argue that the definition of inefficiency is that the benefits of an unrealized outcome must exceed its costs. If so, these benefits can be exploited by private agents with profit motives.

Segal (1999) studies contracting under network externalities, and outline sufficient conditions for when a network sponsor may contract with the adopters to achieve the efficient adoption. He finds that if the sponsor makes public offers, and can commit to them, then as long as there are only network effects present for this current good, then the network sponsor can achieve efficient adoption. Taken together, these results illustrate that it may be demanding to achieve efficient adoption.

Our network model builds on Cabral (2011), however, unlike Cabral (2011), our model has a continuum of consumers, and we introduce a government that seeks to regulate the market outcome. We solve this game, and derive an expression for the Markov-perfect dirty good tax (henceforth; optimal emission tax). The optimal emission tax has three components: an environmental damage part, a network effect part, and a monopolistic pricing part in case there are technology sponsors. While a Pigovian tax would only internalize the environmental damage part, the optimal emission tax also internalizes the two other parts.

Since the level of the environmental damage affects the preferred division of the market between the two goods (steady state), the level of the environmental damage not only influences the size of the Pigovian tax, but also the two other components of the optimal emission tax. Thus, small increases in the level of environmental damage from the dirty durable, may have large effects on the optimal tax rate. This *network interaction effect* has to our knowledge not been described before.

In our simulations we find that a failure to implement the optimal tax could lead to excess inertia. In the case without private technology sponsors the clean good may never get at hold. Moreover, in the case with only a clean technology sponsor, the clean good may end up with a far too low market share. The reason for the latter result is that the regulator and the clean technology sponsor do not agree on the optimal diffusion of the clean durable. While the clean technology sponsor finds it profitable to skim the market, the regulator wants the clean good to overtake the market, which requires a much higher tax than the Pigovian tax. In our simulation the government should therefore not lean back on a Pigovian tax, and let the clean technology sponsor decide the supply of clean goods. Contrary to the argument of Liebowitz and Margolis (1994), we find that excess inertia may occur with a Pigovian tax also when there is a clean technology sponsor.

The paper proceeds as follows: in Section 2 we lay out the model, while in Section 3 we derive the main results. In Section 4 we use the model to look at a particular case numerically. Finally, in Section 5 we conclude.

## 2. Model primitives

The model, inspired by Cabral (2011), is a three-stage game that is repeated over and over again. There are two competing networks and a continuum of consumers of mass $N$. At the end of each period, the durables belonging to a randomly chosen group of consumers of mass 1 wear out. At the beginning of the next period a new group of consumers of mass 1 enters the market. The total size of the market thus remains constant. The stage game then proceeds as follows: First, the government sets a tax, then the suppliers of the networks set prices and, finally, the arriving consumers make their choice.

We assume that all arriving consumers end up in some network, in other words, the market is fully covered. Furthermore, we assume that the networks are differentiated, that is, conditional on prices and network sizes, the consumers do not all agree on which network is better. We index the networks by $k = c$ for clean and $d$ for dirty.

For each network there is an access price denoted $p_k$ that the consumer has to pay to join the network. These prices are set by the firms, and can be thought of as prices for some durable goods that grant the consumers access to the network in question.

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