International Review of
Accounting, Banking and Finance
Vol 11, No. 1/2/3, Spring/Summer/Fall, 2019, Pages 21-26

IRABF
ⓒ2019

Optimal Asset Replacement During the Transition to a Low-Carbon Economy: A Discussion of Key Variables

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**Accepted September 2019*

A B S T R A C T

With the 2050 target under the UN Paris Climate Accord to keep temperatures from rising above 2°C, almost all energy sources will need to emit close to zero CO2. Thus, companies need to mitigate CO2 emissions by making their transportation, manufacturing processes and machinery all less carbon intensive. For this to be done effectively, new analytic tools must be developed. Financial analysis provides an excellent method for making cost-effective asset replacement decisions, but these decisions must also be carbon-effective. In addition to being lowest cost or highest profit, replacement decisions must also target the lowest possible carbon emission path. We denote this as being transition carbon-efficient. In this paper we explore the key variables and policy adaptations that should be considered to make carbon-efficient asset replacement decisions during the transition to a low-carbon economy.

Keywords: Climate Change, Capital Budgeting, Environmental Economics, Sustainability
JEL classification: G31, Q51, Q56, Q59

1. Introduction

Addressing climate change requires changing many aspects of the economy to mitigate CO2 emissions. Buildings, transportation, manufacturing processes and machinery must all become less carbon intensive. By 2050, to approach the 2°C target agreed to at the 2015 Paris Climate summit, almost all energy sources will have to emit close to zero CO2. The decarbonization of the global economy is a massive enterprise. For this to be done effectively, new analytic tools will have to be developed. Financial analysis provides an excellent method for making cost-effective asset replacement decisions, but these decisions must also be carbon-effective. That is, in addition to being lowest cost or highest profit, replacement decisions must also pursue the lowest possible carbon emission path. We denote this as being transition carbon-efficient. In this paper we explore the key variables and policy adaptations that should be considered to make carbon-efficient asset replacement decisions during the transition to a low-carbon economy.

2. The Financial Replacement Decision

The standard asset replacement decision relies on net present value (NPV). An asset should be replaced if the present value of the incremental benefits generated by the new asset – the added after-tax cost savings, cash flows from enhanced revenues and additional depreciation tax shields – exceed the new asset's cost. This type of analysis shows whether replacing an existing asset with a new asset creates value for an organization.

Standard net present value analysis can be adjusted to recognize climate change by including a price for carbon. This can reflect national or regional carbon tax regimes or be an internal price of carbon developed by a company. Ideally, the price of carbon follows the trajectory of the social cost of carbon (SCC) (Rennert and Kingdon, 2019). Though, as shown in Rennert and Kingdon (2019) the SCC is at best an estimate and depends crucially on discount rate assumptions.

Adjusting NPV with a carbon price shifts investment decisions away from assets with higher carbon intensity toward low-carbon alternatives. But adjusting the NPV with a carbon price does not assure that investment decisions are carbon-effective. How the carbon price is applied is important. Does it apply only to fuel consumption and operating costs, or is it more broadly applied to the carbon embedded in the manufacture and end-of-life disposal of the asset? Without taking a life-cycle approach to carbon emissions, important impacts of asset replacement could be omitted. For example, the cash-for-clunkers program (Consumer Assistance to Recycle and Save (CARS) Act) of 2009 offered a subsidy of $3,500 to $4,500 to replace older, less efficient light vehicles with new, more efficient models. The vehicles turned in were scrapped. Lenski, Keoleian and Bolon (2010) estimate that about 15% of the CO2 emission reduction of participants switching to more efficient cars was offset by emissions from the premature manufacturing of the new cars and the earlier disposal of the old cars. In fact, The US GAO criticized the evaluation of the Act by the National Highway Traffic Safety Administration (NHTSA) for not including these life-cycle emissions (US GAO, 2010).

3. Carbon Efficiency in the Transition to a Low-carbon Economy

We have identified at least four concerns that should be considered when developing a carbon efficient asset replacement strategy. Others will doubtless emerge when the shift to a low carbon economy begins in earnest.

(1) ***Embedded emissions***: As suggested by the cash-for-clunkers example, life cycle emissions must be considered. The carbon emissions from manufacturing an asset, including all emissions from the mining, refining and transport of raw materials, are considered embedded emissions. Life-cycle analyses suggest that the manufacturing emissions for internal combustion vehicles are on the order of 15% to 20% and 40% to 50% for electric vehicles. For example, see Girardi et al. (2015) or Del Peroa et al. (2018). However, Natali, Greene and Toledano (2019) argue that the green house gas emissions from the mining, refining and transport of metals is likely to be severely understated. Their initial estimates suggest that the raw materials phase of the life cycle for an internal combustion vehicle may approach the vehicle's life-time operating emissions. If so, premature replacement generates significant emissions, making the net emissions reduction much smaller than anticipated.

(2) ***Renewable Energy Penetration***: The environmental gains from switching to electric vehicles depend largely on how the electricity for battery charging is generated. Nealer, Reichmuth and Anair (2015) estimate that in the United States the miles per gallon (mpg) equivalent of electric vehicles ranges from just over 30 mpg in regions with a high proportion of electricity generated using coal to almost 100 mpg where electricity is largely from renewables, mainly hydropower.

With renewable energy supplying a larger portion of all electricity, the benefits from switching to electric vehicles increases. Currently 29 states and the District of Columbia have Renewable Portfolio Standards, which establish targets for clean energy sold within the state. The renewable energy does not have to be generated within the state, but often when it is a premium is attached to that energy toward fulfilling the RPS. Barbose (2017) estimates that these RPS programs will require about a 50% increase in renewable energy generation by 2030.

(3) ***Technological innovation***: Innovations affecting carbon emissions are occurring at all levels, from energy generation and transmission, to more efficient manufacturing and product design. When combined with increased renewable energy penetration, all industrial sectors are forecast to have much lower carbon emissions in the coming decades. Krabbe et al. (2015) use International Energy Agency (IEA, 2014) data to estimate the decrease in carbon intensity for 12 broad industry sectors through 2050. Their results range from modest improvements, about 25% for air passenger transportation, to over 90% in sectors such as rail transport and building energy use. These improvements stem from a combination of access to more renewable energy and technological advances relevant to the sector.

The estimates presented in Krabbe et al. (2015) have two implications for carbon-efficient asset replacement strategies. First, sectoral differences imply that adjusting the standard financial NPV analysis with a single carbon price (or a single trajectory of carbon prices over time) will not result in the most carbon efficient transition across all sectors. For example, suppose a region must choose between investing in improved infrastructure for air transport or rail transport. Table 2 of the Krabbe et al. paper shows that over time rail transport will have greater carbon savings because of its higher opportunity for electrification and other technological improvements. Assume for this example that all non-carbon results are identical for the two investments, so the decision depends on the present value of the carbon tax over the life of the asset. If the carbon price pathway is too low, these greater improvements from rail transport will be undervalued, biasing the decision to more air transport investment than is optimal, or in our context it will delay rail investment. Conversely, a carbon price trajectory that is too high will result in less investment in air transport than is optimal. Relying solely on a carbon tax to determine the ideal timing of asset replacement requires that carbon price trajectory over time reflects technological advances of different sectors. But because those advances differ across industrial sectors a single carbon price pathway cannot be appropriate for all sectors. This confirms that additional analysis of carbon emissions should supplement the adjusted NPV analysis.

An important area of potential technological change relevant to future carbon emissions is the *circular economy*. The circular economy refers to creating an economy-wide closed-loop system in which materials are constantly reused or recycled. Haas et al. (2015) estimate that the circularity of the global economy, based on 2005 data, is about 37% and just over 40% for metals. As the ability to recycle raw materials improves, the high-embedded carbon emissions in the manufacturing and construction phase of new equipment and infrastructure will be reduced. This will be particularly true for assets built with lots of metal or mined materials given the estimates of the high emissions for virgin materials suggested by Natali et al. (2019).

(4) ***Carbon Lock-In***: Innovation and renewable energy growth both imply that there can be emissions benefits from delaying asset switching. The option to wait often has value as shown by Pindyck and Dixit (1994) in a general investment setting. Van Soest and Bulte (2001) show that rational actors will often postpone investment in energy savings technologies, waiting for future improvement if such investments are partially irreversible. Byrd and Zwirlein (1993) confirm this theoretical result empirically. They find that with the implementation of the SO2 cap-and-trade program in the eastern United States, many utilities deferred investing in existing scrubber technology to meet the pollution cap, preferring to buy emission permits and wait for the development of improved (i.e., more cost-effective) scrubber technology.

Reducing the value of the option to delay asset replacement is the risk of locking in another generation of high carbon emissions. Delaying asset replacement means some high carbon intensity assets will be put into service. Depending on the type of asset their associated emissions could continue from 5 or 6 years (household appliances and electronics) to 30 or more years (buildings and factories). While not precisely the concept of carbon lock-in developed by Unruh (2000), waiting to switch to low carbon assets will cause emissions that could have been avoided. Delay can also make achieving a 2°C or a 1.5°C much more difficult, as David Wallace Wells writes in his *New York Times* best seller *The Uninhabitable Earth*:

"If we start today, when global emissions are still growing, the necessary rate is 10 percent. If we delay another decade, it will require us to cut emissions by 30 percent each year." (Wallace-Wells, 2019)

4. Conclusion

With the 2050 target under the UN Paris Climate Accord to keep temperatures from rising above 2°C, almost all energy sources will need to emit close to zero CO2. Thus, companies need to mitigate CO2 emissions by making their transportation, manufacturing processes and machinery all less carbon intensive. For capital budgeting including making cost-effective asset replacement decisions, these decisions must also be carbon-effective. In addition to being lowest cost or highest profit, replacement decisions must also pursue the lowest possible carbon emission path. We denote this as being transition carbon-efficient. In this paper we explore the key variables and policy adaptations that should be considered to make carbon-efficient asset replacement decisions during the transition to a low-carbon economy. For this to be done effectively, new analytic tools must be developed.

This paper presents several variables that need to be considered for the transition to a low-carbon economy to be carbon efficient. These are:

- *Embedded emissions*, where the carbon emissions from manufacturing an asset, including all emissions from the mining, refining and transport of raw materials, as embedded emissions need to be accurately estimated and not understated over their life cycle.

- *Renewable energy penetration*, where the environmental gains from switching to electric vehicles depend largely on how the electricity for battery charging is generated, with electricity generated from renewable energy sources more carbon efficient.
- *Technological innovation*, where innovations affecting carbon emissions are occurring at all levels, from energy generation and transmission, to more efficient manufacturing and product design, and the ideal timing of asset replacement requires that carbon price trajectory over time reflects technological advances.
- Carbon lock-in, where companies have the option to delay asset replacement to manage the risk of locking in another generation of high carbon emissions, with new carbon emission reducing technology being developed in the future, which needs to be included for an optimal replacement analysis.

As policies are designed to support the transition to a low-carbon economy these concerns should be considered. Not doing so could result in a slower and/or more costly transition than necessary. These variables might also be used to develop analytic models for the optimal replacement of assets in the fashion of real options analysis.

The mounting evidence on the likely severity climate change makes the transition to a low carbon economy imperative. Doing so in a financially and carbon-efficient manner will speed the adjustment and reduce inevitable transition costs.

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