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PERFORMANCE

CEP POLICY ANALYSIS

The Impact of ‘Clean Innovation’ on Economic Growth: Evidence from the Transport and Energy Industries

- Policies on climate change that encourage ‘clean innovation’ while displacing ‘dirty innovation’ could have a positive impact on short-term economic growth while avoiding the potentially disastrous reductions in GDP that could result from climate change over the longer term.

- Our research looks at innovation in the car industry related to electric, hybrid and hydrogen vehicles (‘clean patents’) versus the internal combustion engine (‘dirty patents’) – and innovation in electricity generation related to renewables versus fossil fuels.

- We examine the changes in firms’ stock market value as they innovate (measured by applications for clean and dirty patents – those that help or hinder efforts to reduce carbon emissions). All else equal, we find that a firm’s value increases by more if they apply for a patent that cites a clean patent rather than a dirty patent. In other words, clean patents are more economically valuable.

- The citations and value of patents give an indication of whether there are significant ‘knowledge spillovers’ from a given innovation. An example of such a spillover is the Android-based smart phone: it was Apple that first launched the now dominant design of smart phones but other companies such as Google have also been able to benefit from the original investment in research and development (R&D) by Apple by copying or improving the original design.

- We find robust evidence that clean technologies generate stronger economic spillovers than dirty technologies. The spillover gap is stronger for more radical clean technologies, those that depart entirely from fossil fuels. What’s more, there are geographically localised spillover effects, which should undermine concerns that unilateral climate policies will lead to negative effects on the competitiveness of a country’s industries.

- Effective climate policies are likely to induce clean innovation but also reduce innovation in polluting activities by making them less attractive. Our previous research has documented that outcome for the automotive industries: an increase in exposure to fuel prices – the likely consequence of the introduction of carbon pricing – raises innovation related to electric, hybrid and hydrogen vehicles but depresses innovation related to the internal combustion engine.

- Overall growth will be determined by the net effect of the increase in clean innovation and the reduction in dirty innovation. Our new study provides evidence suggesting that the overall growth effect could be positive. It also finds evidence of a clean innovation advantage over ‘grey innovation’, which corroborates the idea that governments should focus any direct support in this area on radical technologies rather than mere efficiency improvements of fossil fuel-based technologies.

Introduction

Are climate policies good or bad for growth? Many policy-makers seeking to implement such policies are promising positive growth effects not only in the long run of 50 to 100 years, when effective climate policies will help to mitigate potentially catastrophic consequences of climate change, but also in the short run, when such policies are primarily seen as a cost burden on businesses. For example, Ed Davey, the UK government's secretary of state for energy and climate change has said: 'Climate change policies are not an unbearable burden on the economy but unashamedly good for growth.'

Sustained economic growth of per capita incomes can only be achieved by continued innovation: we need to come up with ever more sophisticated ways to transform a limited set of resources into economic value.

Effective climate policy is likely to induce 'clean innovation', helping to reduce carbon emissions. But it can also reduce innovation in polluting activities by making them less attractive. Our research has documented that outcome for the automotive industries: an increase in exposure to fuel prices – a likely consequence of the introduction of carbon pricing – raises innovation related to electric, hybrid and hydrogen vehicles but depresses innovation related to the internal combustion engine (Aghion et al, 2012).

Overall growth will be determined by the net effect of the increase in clean innovation and the reduction in dirty innovation. Should we expect this effect to be positive? Clean technologies comprise a range of new and relatively unexplored technology fields. This could imply that there are opportunities for large economic gains similar to the emergence of information and communication technology (ICT) over the last 40 years.

But this does not necessarily mean that climate policies will have a positive effect on growth. What matters for growth are not the overall economic gains between clean and dirty technologies but if there is a significant difference in the *non*-private economic returns – what economists call 'knowledge spillovers' or 'innovation spillovers'.

An obvious example of such a spillover is the Android-based smart phone. It was Apple that first launched the now dominant design of smart phones. But other companies such as Google were also able to benefit from the original investments in R&D undertaken by Apple by copying or improving the original design.

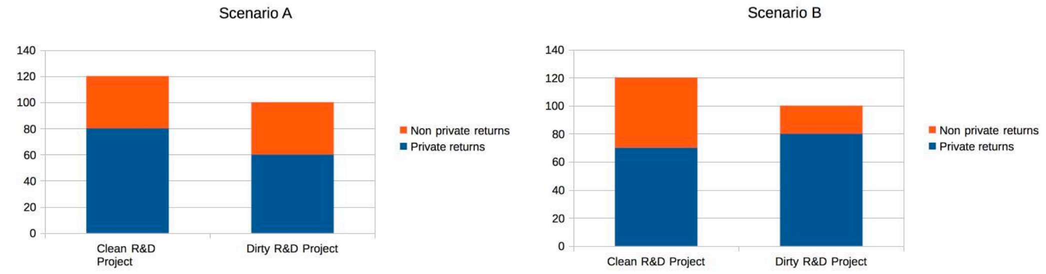
When deciding about R&D investments, companies only take account of private returns. The presence of spillovers implies that R&D investments might not be undertaken even though it would be socially efficient (when considering both private and non-private returns) to do so, because the private returns are lower than the costs.

Consider two scenarios (A and B) that might present themselves to a firm deciding about their next R&D investment project (as illustrated in Figure 1). In both cases, we compare two R&D investment opportunities: a clean option and a dirty option. In both cases, the combined private and non-private returns of the clean project are higher. In scenario A, combined returns are higher because of higher private returns; but in scenario B, non-private returns are higher whereas private returns are lower for the clean project.

Now consider a climate policy that requires firms always to invest in the clean option. In scenario A, this would not have an impact on growth or economic value as the firm would already choose the clean option. But in scenario B, the climate policy would bind as the private returns are lower in the clean R&D project. As a consequence, the value of the firm would drop but the social economic value would increase.

Thus, a necessary condition for positive growth effects from climate policies is higher spillovers for clean technologies. Examining whether this condition is met is the subject of our research programme.

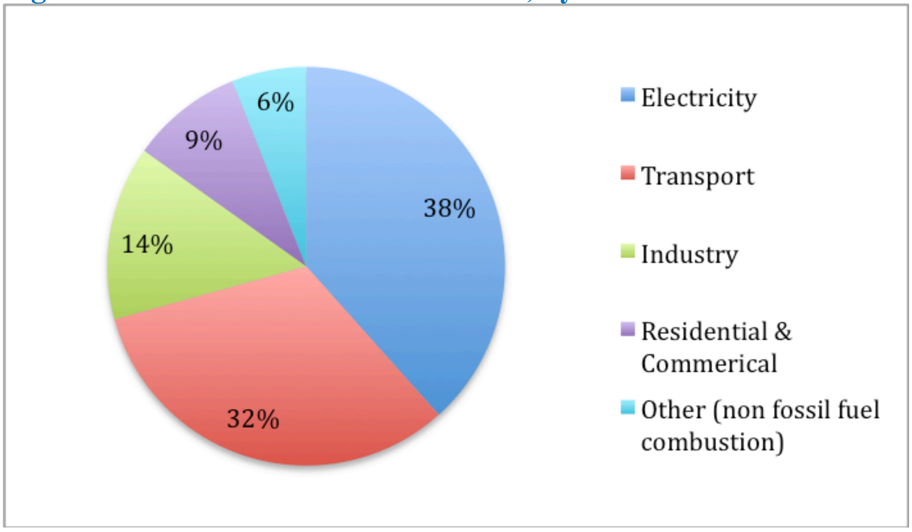
Figure 1: Potential scenarios



Measuring dirty and clean spillovers

Measuring innovation spillovers is not an easy task. The simplest approach relies on the citation information contained in patent data. Any innovator applying for a patent is required to reference all previous innovations – so-called prior art – on which the new innovation is based. Patent examiners have the right to add any prior art the patent applicant may have left out. A citation indicates that the knowledge contained in the cited document has been useful in the development of the new knowledge laid out in the citing patent and thus represents a knowledge flow. In a recent study, we compare citations of clean patents with those of dirty patents (Dechezleprêtre et al, 2014).

Figure 2: US carbon dioxide emissions, by source



Source: The United State Environmental Protection Agency, all the emissions estimates from the Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2012.

An equally challenging task is to determine if an innovation is clean or dirty. Fortunately, we can rely on a recent joint effort by the OECD and the European patent office. With the help of patent examiners, they have developed a new patent classification system that identifies all climate-related patents in a comprehensive database containing all worldwide patents.

We focus our attention on two areas: transport and electricity production. These are of interest for a number of reasons. First, energy generation and transport account for the bulk of carbon emissions. As an example, Figure 2 shows the numbers for the United States.

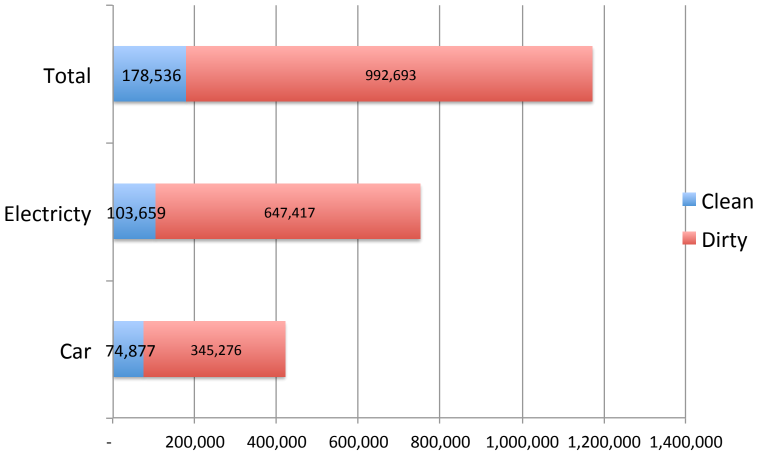
Second, in both areas a radical departure from existing technologies is required to achieve sufficient emission reductions. This requires knowledge capital that is likely to be non-complementary – for example, to develop new photovoltaic solar panels requires capabilities that are quite distinct from those required to improve a gas turbine.

This allows us to identify clearly the innovation areas that benefit and those that lose out in response to climate policy. Table 1 illustrates how we make this distinction for the two technology areas. Figure 3 reports the number of innovations in the different categories.

Table 1: Classifying technology types

Dirty	**Group**	**Clean**
Fossil fuel-based (coal and gas)	***Electricity generation***	Renewables
Internal combustion, Gasoline	***Automotive***	Electric, hybrid, hydrogen

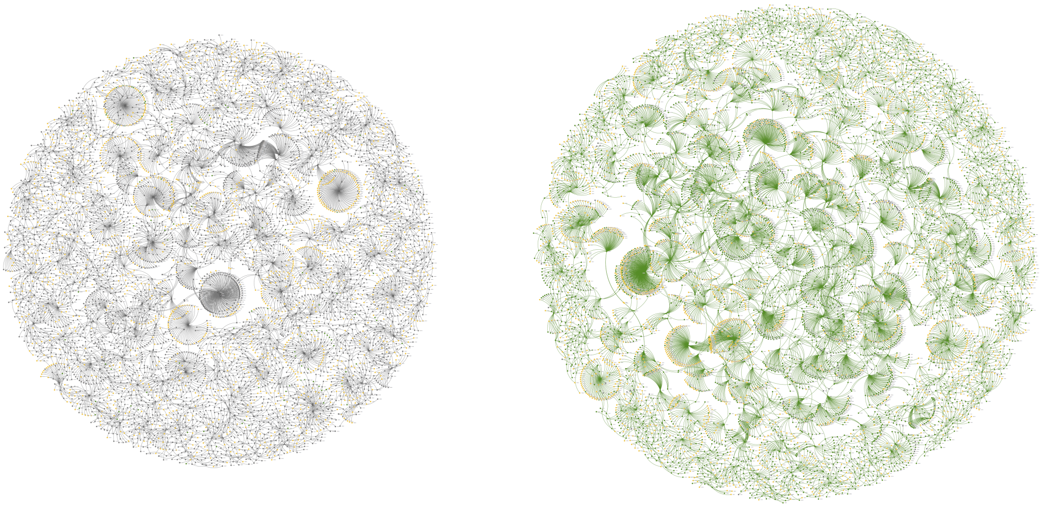
Figure 3: Number of clean and dirty innovations



Innovation flowers

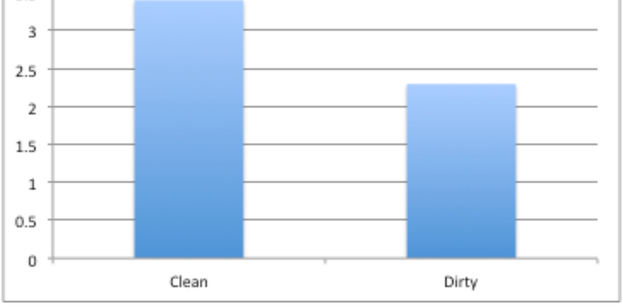
Our main result emerges in the visualisation in Figure 4. The left part of the figure shows all citations of a sample of 1,000 dirty innovations. The nodes of the graph each represent an innovation; the edges represent citations. The right part shows all citations of a sample of 1,000 clean innovations. We can see that the network graph formed by the clean sample is larger because there are more citations. On average, we find that the citation rate of clean patents is about 50% higher than for dirty patents (Figure 5).

Figure 4: Visualising spillovers



Notes: The figure visualises all citations to a sample of 1,000 dirty (left panel) and 1,000 clean (right panel) innovations. Each node represents an innovation (black=dirty innovation, green=clean innovation, orange=other innovation), edges represent citations. The samples were drawn among innovations applying for patent protection in 1995. Interactive versions of these figures are here and here.

Figure 5: Average number of citations for clean and dirty innovations



Potentially confounding factors

To ensure this really means that economic spillovers for clean technologies are higher than for dirty technologies, we explore a number of potential issues.

First, there is a range of potentially confounding factors: the number of citations included in patents varies greatly over time and between patent offices. This is due to legal and technological changes. Moreover, clean patents are more concentrated in recent years and they are also geographically concentrated. To ensure that our results are not being driven by these factors, we include a wide range of control variables.

A second potential concern is the fact that the number of citations received might be mechanically related to the number of patents in an area. Suppose any new patent cites a fixed number of previous patents, then clean patents have a much higher chance of being cited simply because there are fewer of them. We control for this by including the total number of past patents in a given technology area as an explanatory variable. But the citation advantage for clean technologies remains even after taking account of these potential confounding factors.

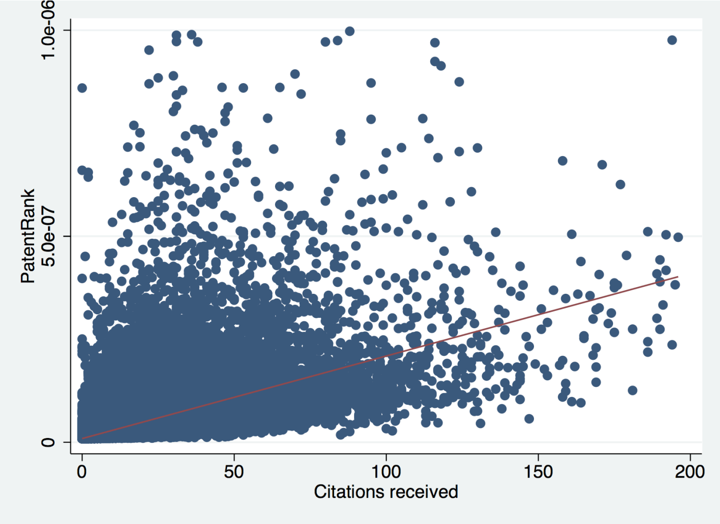
Direct and indirect spillovers

We also explore a number of ways to measure spillovers on the basis of citations. For example, instead of just counting citations, we compare the PageRank (a measure named after Larry Page, one of Google's founders) of clean and dirty innovations. We use the same criterion as the original Google search algorithm to rank web pages.

According to the PageRank algorithm, a web page gets a higher score if it is hyperlinked (receives a citation) from another web page that is itself highly cited. The PageRank score would also be higher if a citing web page hyperlinks a smaller number of pages. In contrast to citation counts, which only measure direct spillovers (those one citation away), the PageRank also measures indirect spillovers by taking citations several links away into account. This lowers the advantage of clean patents though it remains significant at 25-30%.

Computing the PageRank is an obvious way of assessing spillovers with patent data. Surprisingly, our study is one of the first to do this systematically. It is therefore of interest to correlate the PageRank criterion with the more widely used citation counts, which is reported as a scatter plot in Figure 6. This shows a significant positive correlation but it is far from perfect.

Figure 6: Page rank versus citation counts



Who benefits?

At present, most climate policy is unilateral and some countries and groups of countries – for example, the European Union – are imposing more stringent policies than others. This raises concerns that climate policies are harmful to the competitiveness of these countries, inducing firms to relocate. But if there are sufficiently strong localised spillovers, such negative effects on economic outcomes could potentially be offset.

We examine this by looking separately at spillovers in the same country where the original innovation emerged and spillovers elsewhere. We find that clean innovations have an advantage in either case with a somewhat larger advantage for local spillovers. Hence, this provides a potential channel for positive home country effects from unilateral policies.

We also examine if the clean spillover advantage is confined to subsequent clean technologies. But we find that it is present both for clean technologies but also for dirty and 'other' (neither clean nor dirty) technologies, although it is largest for clean technologies.

The value of clean spillovers

Although patent citations provide a measure of knowledge spillovers, they do not tell us anything about the associated economic value. If clean citations reflect spillovers that are less economically valuable, finding higher citation counts would be of little economic relevance.

We explore this by conducting a firm-level analysis of listed firms. We look at the change in firms' stock market value as they innovate (measured by patent applications). All else equal, we find that a firm's value increases by more if it applies for a patent that cites a clean patent rather than a dirty patent. In other words, far from being less economically valuable, it would seem that clean spillovers are more economically valuable, hence reinforcing the mere citation count advantage.

Grey innovations

While our main distinction is between clean and dirty innovations, there are also technology categories that we call 'grey'. These are efforts to make fossil fuels more efficient instead of developing an alternative to fossil fuels. From a climate point of view, these are helpful but probably insufficient. In terms of the innovation process, they require capabilities that are very similar if not identical to the capabilities required for innovation in dirty technologies. For that reason, it is not necessarily easy to identify grey innovations separately from dirty innovations.

Nevertheless, by consulting with engineers in the relevant fields, we have drawn up a list of patent categories that are likely to fall into this category. Comparing the strength of spillovers between clean, grey and very dirty technologies establishes a clear ranking. Clean technologies continue to generate the highest amount of spillovers. And while grey technology spillovers are significantly stronger than very dirty ones, they are significantly weaker than clean ones.

Drivers of the clean spillover advantage

What are potential drivers of this clean spillover advantage? We explore a number of different avenues.

Generality and originality

We look at measures used in the research literature to assess the originality and generality of an innovation. An innovation is considered more original if it draws on a wider range of technological fields – so we examine how concentrated are backward citations across technological areas. Similarly, an innovation is more general if it receives forward citations from a wider range of technological areas. But we find that neither of these factors can explain the clean advantage.

Inventor capabilities

To what extent is the clean advantage driven by differences in the capabilities of the inventors behind the innovations? We examine this by looking at innovations by inventors who are active in both clean and dirty areas. It turns out that there is a clean spillover advantage even when comparing clean and dirty within the set of innovations produced by the same inventor. Hence, we conclude that the clean advantage is *not* driven by any differences in inventor capability.

Public support for clean technologies

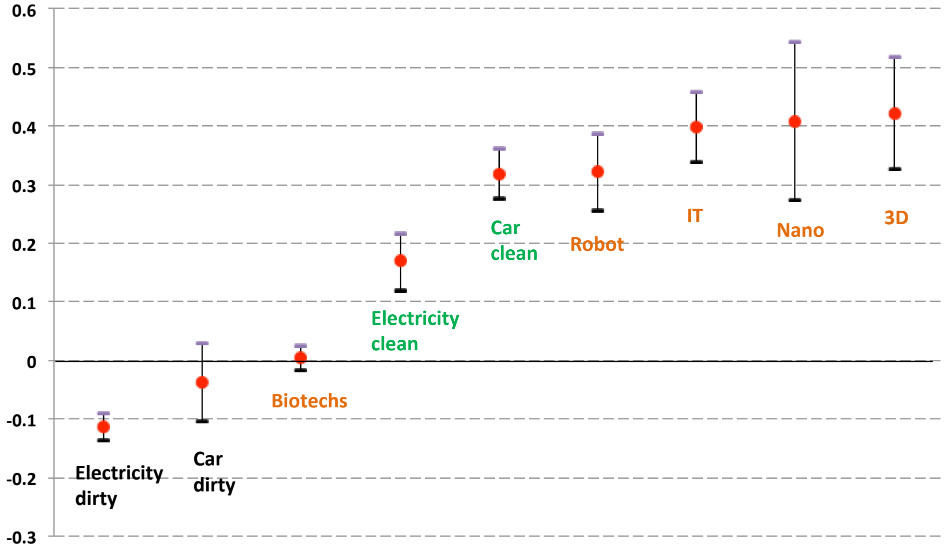
Because the development of new clean technologies is central to addressing climate change, many governments have increased direct support in this area. Even though most experts regard current support levels as inadequate (King et al, 2014; and Aghion et al, 2009), it could be that this is driving our results if governments are more inclined to support R&D projects that can be expected to generate stronger spillovers (for example, more basic research.)

We explore this hypothesis in several ways. First, we compare innovations by inventor type. In particular, we look separately at innovations by universities and private companies. One important avenue for governments to channel R&D funding is through universities and they are more likely to be engaged in basic research.

Second, we construct a control variable that captures exposure to public subsidies of an innovation. We base this on information on country-level subsidies for clean technologies collected by the OECD. An innovation's subsidy exposure is the average of these country-level subsidies weighted by the distribution of inventors associated with the innovation across countries. Results indicate that university innovations and indeed more subsidy-exposed innovations have higher spillovers. But we *don't* find any evidence that this is a driver of the clean advantage.

New technology advantage
Clean technologies are by and large in new fields, which offer potentially high marginal private returns to first movers. Equally, spillovers could be higher. To examine this, we compare clean and dirty technologies with a range of other emerging technologies such as ICT and biotechnologies. Figure 7 shows the results of this exercise. It turns out that the strength of spillovers from clean technologies is comparable to other emerging technologies. Spillovers from ICT seem stronger whereas biotechnology spillovers are weaker. Dirty technology spillovers are lagging behind.

Figure 7: Clean and dirty spillovers versus other emerging fields



Conclusion

There is robust evidence that clean technologies generate stronger economic spillovers than dirty technologies. This spillover gap emerges both within and between countries. The spillover gap is stronger for more radical clean technologies, which depart entirely from fossil fuels. This has a number of policy implications.

First, it supports the claim that climate policies that induce clean innovation while displacing dirty innovation could have a short- to medium-run positive impact on economic growth – in addition to avoiding dramatic reductions of GDP and damage because of climate change in the long-run future.

Second, the presence of localised spillover effects undermines the concern that unilateral climate policies lead to negative effects on competitiveness.

Finally, the evidence of a clean advantage over grey innovation corroborates the idea that governments should focus any direct support in this area on radical technologies rather than mere efficiency improvements of fossil fuel-based technologies.

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Further reading

Aghion, Philippe, Antoine Dechezleprêtre, David Hemous, Ralf Martin and John Van Reenen (2012) ‘Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry’, CEP Discussion Paper No. 1178 (http://cep.lse.ac.uk/pubs/download/dp1178.pdf).

Aghion, Philippe, Reinhilde Veugelers and David Hemous (2009) ‘No Green Growth Without Innovation’, Bruegel Policy Brief (http://www.bruegel.org/publications/publication-detail/publication/353-no-green-growth-without-innovation/).

Dechezleprêtre, Antoine, Ralf Martin and Myra Mohnen (2014) ‘Knowledge Spillovers from Clean and Dirty Technologies’, CEP Discussion Paper No. 1300 (http://cep.lse.ac.uk/pubs/download/dp1300.pdf).

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The Global Commission on the Economy and Climate (2014) `The new climate economy’, Report (http://static.newclimateeconomy.report/wp-content/uploads/2014/08/NCE_GlobalReport.pdf)