Policy brief:
Clean innovation and growth

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"Climate change policies are not an unbearable burden on the economy but unashamedly good for growth", Ed Davey, the Lib Dem UK Energy Secretary

Are climate policies good or bad for growth? Many policy makers who are trying 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 the potentially catastrophic economic consequences of climate change, but also in the short run when such policies are primarily perceived as a cost burden on businesses.

Sustained growth of per capita income can only be achieved by continued innovation; i.e. by continuously coming up with ever more sophisticated ways to transform a limited set of resources into economic value. It is now well established that effective climate policies induce innovation in clean technologies that help to reduce greenhouse gas emissions (GHG). However, by making polluting activities less profitable, climate policies also reduce innovation activity in polluting technologies. For example, our previous research[2] on the automotive industry has documented that an increase in fuel prices – which would also happen as a consequence of the introduction of carbon pricing – increases innovation related to electric, hybrid and hydrogen vehicles but depresses innovation related to the internal combustion engine. Therefore, the overall consequences of climate policies in terms of economic growth will be determined by the net effect of the increase in clean and the reduction in dirty innovation. Should we expect this effect to be positive? Clean technologies comprise of 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 & Communications Technologies over the last 40 years. However, 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. These non-private economic returns are what we refer to as innovation spillovers. An obvious example of such a spillover is Android-based smart phones. It was Apple that first launched the now dominant design of smart phones. However, other companies such as Google were also able to benefit from the original R&D investments undertaken by Apple by copying or improving the original design.

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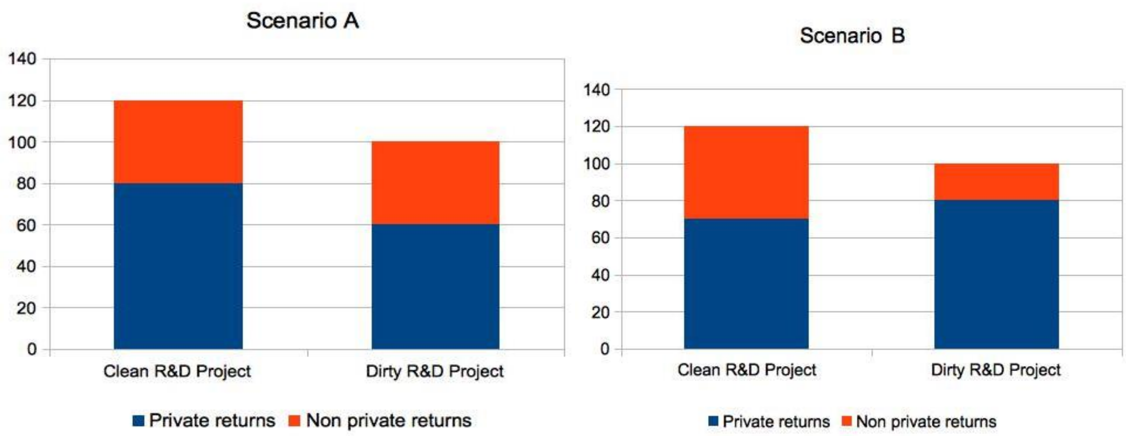
[2] Aghion, Dechezlepretre, Hemous, Martin, van Reenen, Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry, NBER Working Paper 18596.

When deciding about R&D investments companies are only taking into account private returns. The presence of spillovers implies that R&D investments might not be undertaken even though it would be socially efficient - i.e. 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 the figure below. 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 return of the clean project are higher. However, in scenario A combined returns are higher because of higher private returns. In scenario B on the other hand non-private returns are higher whereas private returns are lower for the clean project. Now consider a climate policy that requires firms to always 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 anyways. Note that the climate policy wouldn't be necessary at all in this scenario, since the market would redirect the economy toward clean technologies by itself. In scenario B the climate policy would be binding as the private returns are lower in the clean R&D project, and hence clean innovation is only conducted in the presence of climate policy. 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 compared to the dirty technologies. Examining whether this condition is met is the subject of our on-going research programme.

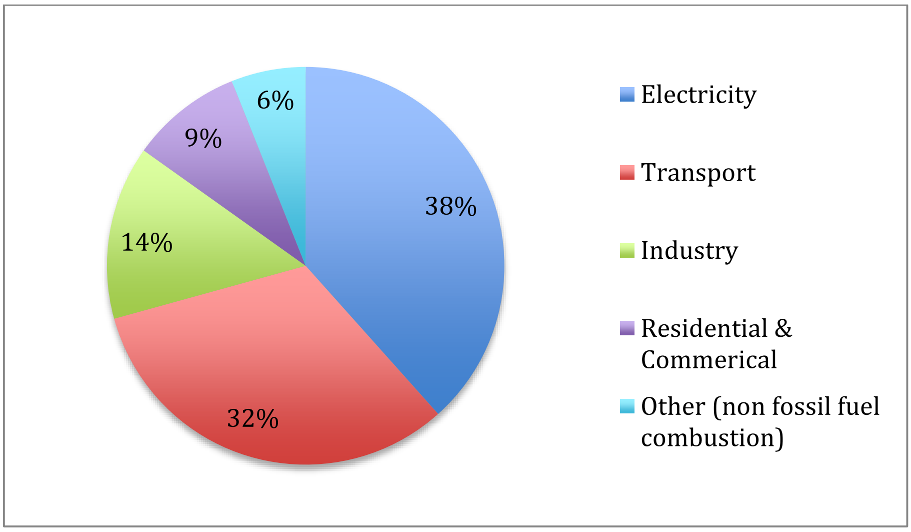
Figure 1: Potential R&D investment scenarios



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[3] we compare citations to clean patents with those to dirty patents.

Figure 2: U.S. Carbon Dioxide Emission, By Source



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

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

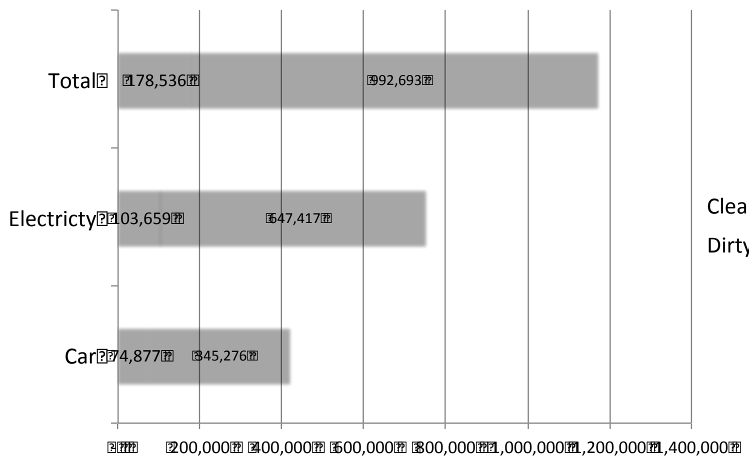
We focus our attention on two areas: transport and electricity production. These areas are of particular interest for a number of reasons: Firstly, energy generation and transport account for the bulk of carbon emissions (e.g. Figure 2 shows the numbers for the USA). Secondly, in both areas a radical departure from existing technologies is required to achieve sufficient emission reductions. This requires knowledge capital that is likely non-complementary; e.g. to develop new photovoltaic solar panels requires capabilities that are quite distinct from those required to improve a gas turbine. This allows us to clearly identify the innovation areas that benefit and those that loose 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.

[3] Dechezlepretre, Martin and Mohnen (2014), Knowledge spillovers from clean and dirty technologies. CEP discussion paper 1300 (http://cep.lse.ac.uk/pubs/download/dp1300.pdf) .

Table 1: Classifying technology types

Dirty	Group	Clean
Fossil fuel based (coal & gas)	Electricity generation	Renewables
Internal combustion, gasoline	Automotive	Electric, Hybrid, Hydrogen

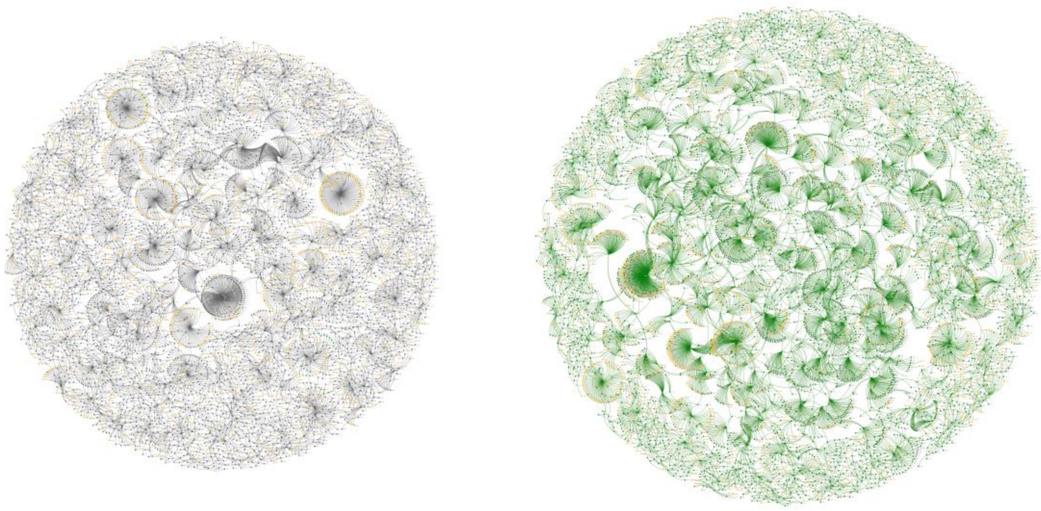
Figure 3: Number of clean and dirty innovations



Innovation flowers

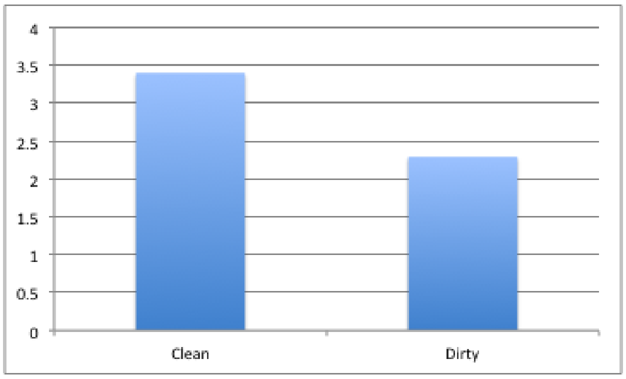
Our main result emerges in the visualisation shown in Figure 3. The left part of the figure shows all citations to a sample of 1000 dirty innovations. The nodes of the graph each represent an innovation. The edges represent citations. The right part shows all citations to a sample of 1000 clean innovations. 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 for clean patents is about 50% higher than for dirty patents (Figure 4). To ensure this really means that economic spillovers for clean technologies are higher than for dirty technologies we explore a number of potential issues.

Figure 4: Visualizing spillovers



Notes: The figure visualizes all citations to a sample of 1000 dirty (left panel) and 1000 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 can be found under here and here.

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



Potentially confounding factors

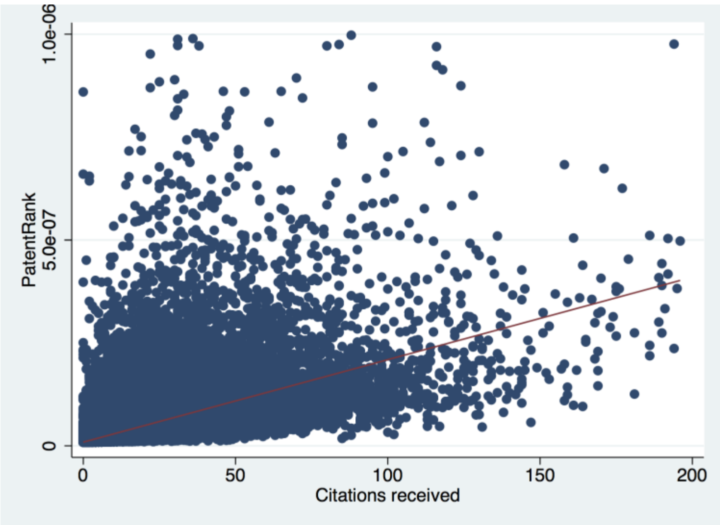
Firstly, there is a range of potentially confounding factors: the number of citations included in patents varies greatly over time and between patent offices. This is due to legal and technological changes. Moreover, clean patents are more concentrated in recent years and are also geographically concentrated. To avoid our results being driven by these factors our regressions analysis includes a wide range of control variables. Another 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 explanatory variable. However, the citation advantage found for clean technologies remains even after taking these potential confounding factors into account.

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[4] of clean and dirty innovations; i.e. 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 hyper linked - i.e. receives a citation from – from another web page that is itself highly cited. The page rank 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 (i.e. one citation away), the PatentRank also measures indirect spillovers by taking citations several links away into account. Interestingly, this lowers the clean advantage although there remains a significant 25 to 30% advantage.

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 page rank criterion with the more widely used citation counts which is reported as a scatter plot in Figure 6. As is easy to see: there is a significant positive correlation but is far from perfect.

Figure 6: Page rank versus citation counts



Who benefits?

At this point most climate policy is unilateral and some countries – e.g. the EU – are imposing more stringent policies than others. This raises concerns that climate policies are harmful to competitiveness of those countries and induces firms to re-locate. If there are sufficiently strong localised spillovers such negative effects on economic outcomes could

[4] This is named after Larry Page, one of Google's founders (https://en.wikipedia.org/wiki/PageRank)

potentially be offset. We examine this by looking separately at spillovers that occur within 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. However, we find that it is present both within clean but also dirty other (neither clean nor dirty) technologies although is largest for clean technologies.

The value of clean spillovers

Although patent citations provide a measure of knowledge spillovers, they do not provide 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 of a 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 they apply 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 there are also technology categories that we have termed 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 to innovation dirty technologies. For that reason it is not necessarily easy to separately identify grey from dirty innovations. Consulting with engineers in the relevant fields we nevertheless drew 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 continue to generate the highest amount of spillovers. However, grey technology spillovers are significantly stronger than very dirty ones but significantly weaker than clean ones.

Drivers

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 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 – i.e. 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. However, 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 from 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 development of new clean technologies is central to address climate change many governments have increased direct support in this area. Even though most experts regard current support levels as in-adequate[5] it could be the case that this is driving our results if governments are more inclined to support R&D projects which can be expected to generate stronger spillovers.[6] We explore this hypothesis in several ways. Firstly we compare innovations by inventor type. Particularly we look separately at innovations by universities and private companies. One important avenue for governments to channel R&D funding is through universities and universities are more likely to be engaged in basic research. Secondly, we construct a control variable included in the regression analysis capturing 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 indeed university innovations and more subsidy-exposed innovations have higher spillovers. However, we *don't* find any evidence that this is a driver for the clean advantage.

New technology advantage

As discussed earlier, clean technologies are by and large new technology fields. New technology fields offer potentially high marginal private returns to first movers. Equally, spillovers could be higher. To examine this we compare clean and dirty technologies to 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.

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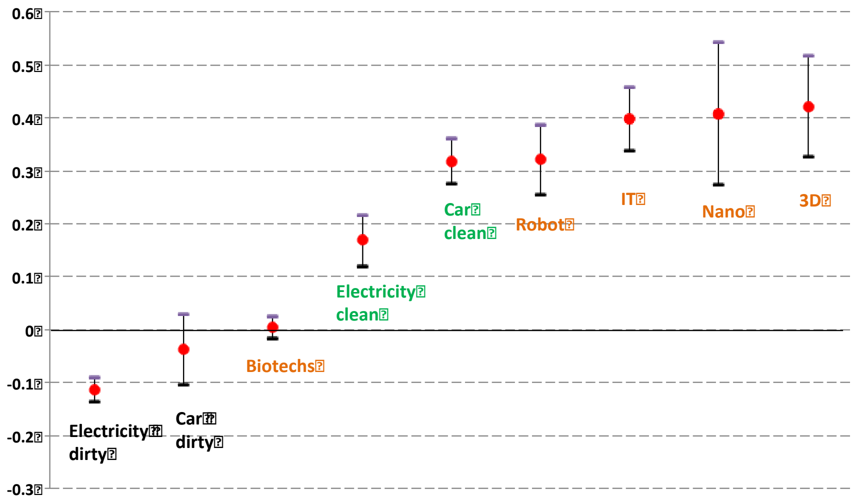
[5] King, Browne, Layard, O'Donnell, Rees, Stern, Turner (2014), "A global research programme to combat climate change", mimeo LSE. Aghion, Hemous, Veugelers, No Green Growth Without Innovation (Breugel Policy Brief)

[6] e.g. more basic research.

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 departing entirely from fossil fuels. This has a number of policy implications. Firstly, 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.

Secondly, the presence of localised spillover effects undermines the concern that unilateral climate policies led to negative competitiveness effects. Finally, the evidence of a clean advantage over grey 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.