Hedging Climate Risk

by

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Abstract

We develop a simple dynamic investment strategy that allows long-term passive investors to hedge climate risk without sacrificing financial returns. Our proposed hedging strategy goes beyond a simple divestment of high carbon footprint or stranded assets stocks. This is just the first step. The second step is to optimize the composition of the low carbon portfolio so as to minimize the tracking error with the reference benchmark index. We show that tracking error can be almost eliminated even for a low carbon index that has 50% less carbon footprint. The low carbon portfolios in existence that have been constructed in this way have so far matched or outperformed their benchmark. And the low carbon indices that have not yet been launched have similar performance based on back testing. By investing in such an index investors are holding, in effect, a "free option on carbon": as long as the introduction of significant limits on CO2 emissions is postponed they are essentially able to obtain the same returns as on a benchmark index, but the day when CO2 emissions are priced the low carbon index will outperform the benchmark.

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1. Introduction

The scientific consensus on global warming is nearly unanimous and the evidence on rising global average temperatures is mounting, yet the media continues to be filled with political debates between a fringe of climate change sceptics and a wide spectrum of politicians warning with various degrees of alarm about the catastrophic consequences of unchecked global warming. These debates are fuelled by three important considerations.

The first most obvious reason is that not all countries are equally affected by climate change. While some countries have already suffered the consequences of more severe droughts, bigger storm systems with heavier precipitations, and increased flooding, others have benefited from balmier temperatures. Similarly, not all industries are equally affected by climate change mitigation policies. Particularly hard hit by these policies will be the sectors that rely the most on fossil fuels, while those sectors that have already started their transition towards renewable energy stand to benefit substantially from the introduction of some form of carbon pricing. As in other policy areas, the existence of winners and losers from the introduction of a new tax naturally gives rise to policy debates between the losers who exaggerate the costs and the winners who emphasize the urgency of the new policy.

The second reason is that climate mitigation is typically not a “front burner” policy issue and short-sighted politicians tend to prefer to “kick the can down the road” rather than introduce policies that are costly in the short run and risk alienating their constituencies. This is easier to do if there is a perception among voters that it is not yet fully settled that there is a climate change problem that is in need of urgent attention. The debates in the media echo-chamber among climate sceptics and doomsayers help sustain this perception and allow politicians, who generally tend to favor inaction on this front, to buy precious time.

The third reason is that, although the scientific evidence on the link between CO_2 emissions and the greenhouse effect is overwhelming, there is considerable uncertainty regarding the rate of increase in average temperatures over the next 20 or 30 years and the effects on climate change. There is also considerable uncertainty regarding the "tipping point" beyond which catastrophic climate dynamics are set in motion[1]. As with financial crises, the observation of growing imbalances can alert analysts to the inevitability of a crash but still leaves them in the dark as to when the crisis is likely to occur.

While this uncertainty helps fuel the political debates on climate change and provides convenient excuses to politicians looking to postpone climate mitigation policies, it should, however, be understood to be an increasingly important risk factor for investors, particularly long-term investors. The climate science tells us at a minimum that the risks of a climate catastrophe are substantial and rising with continued massive CO_2 emissions. Moreover, as further evidence of climate events linked to global warming accumulates there is also an increased likelihood of policy intervention to limit CO_2 emissions. Thus, investors should, and are beginning to, factor in climate risk in their investment policies.

[1] See Litterman (2013) for an analysis of the consequences of this deep uncertainty for the economics of carbon pricing.

In this paper we propose a simple dynamic investment strategy that allows long-term passive investors—a huge institutional investor clientele comprising pension funds, insurance and re-insurance companies and sovereign wealth funds—to significantly hedge climate risk while minimizing the risk of sacrificing financial returns. As we have already hinted at, one of the main challenges for long-term investors is to narrow down the timing of climate mitigation policies. To again make a helpful analogy with financial crises, it is extremely risky for a fund manager to exit (or short) an asset class that is perceived to be overvalued and subject to a speculative bubble, because the fund could be forced to close as a result of massive redemptions before the bubble has burst. Similarly, an asset manager looking to hedge climate risk by divesting from stocks with high carbon footprint bears the risk of underperforming his benchmark for as long as climate mitigation policies are postponed and market expectations about their introduction are low. Such a fund manager may well be wiped out long before serious limits on CO_2 emissions are introduced.

A number of "green" financial indexes have already been in existence for some years. These indices fall into two broad groups: (i) pure-play indices which focus on renewable energy, clean-technology and/or environmental services and (ii) "decarbonated" indices, whose basic construction principle is to take a standard benchmark such as the S&P 500 or MSCI Europe and to remove the companies with high carbon footprint from the list of constituents. An investor holding such a green index is then somewhat hedged against risk climate mitigation policies that are expected to hit disproportionately high carbon-footprint companies.

As Figure 1 below illustrates, pure-play, "clean energy", indexes have underperformed the S&P 500 or the NASDAQ 100 since the onset of the financial crisis in 2008.

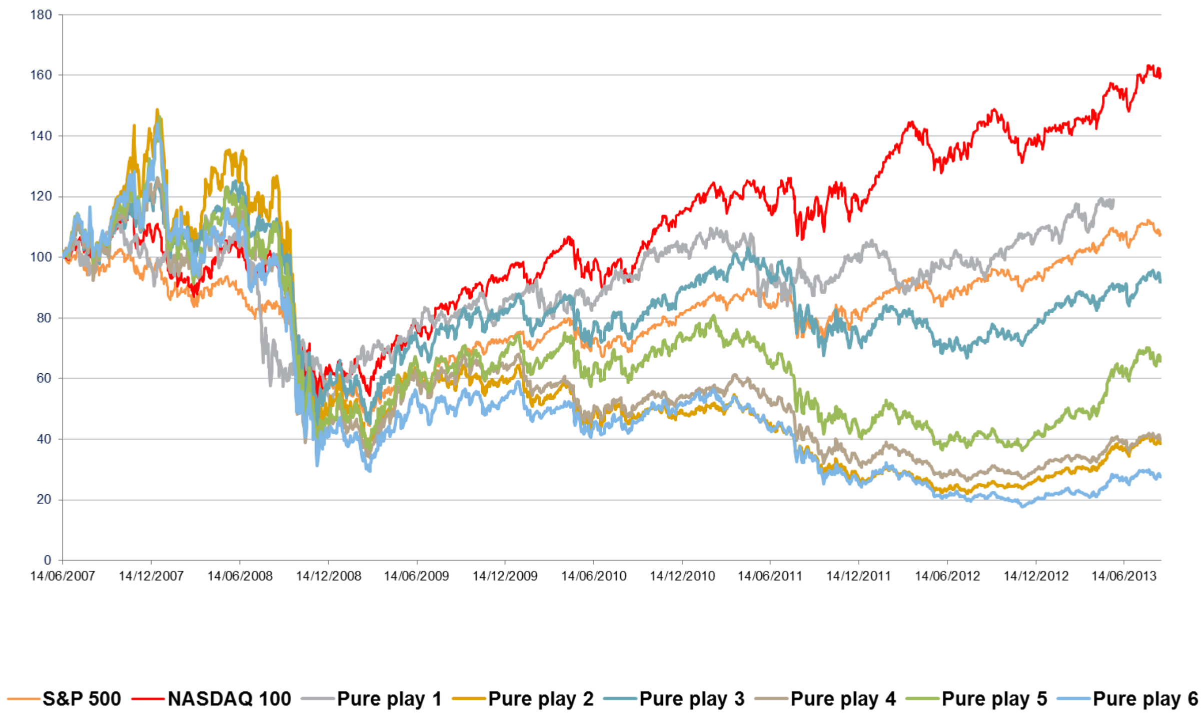

FIGURE 1.[2] Pure-play Clean Energy Indices vs. Global Indices
Source Amundi, Bloomberg as at 29/08/2013

One basic reason why these indexes have underperformed is that some of the climate mitigation policies in place before the financial crisis have been scaled back (e.g. in Spain), but more generally financial markets have rationally anticipated that one of the consequences of the financial crisis is the likely postponement of the introduction of limits on CO_2 emissions. These changed expectations benefited relatively more the high carbon-footprint companies thus

[2] Figure 1gives the financial returns of several ETFs that track leading Clean Energy Pure Play Indices. Pure Play 1 refers to *Market Vectors* Environmental Services Fund, Pure Play 2 to *Market Vectors* Global Alternative Energy ETF , Pure Play 3 to *PowerShares Cleantech* Portfolio, Pure Play 4 to *PowerShares* Global Clean Energy Portfolio, Pure Play 5 to *First Trust* NASDAQ Clean Edge Green Energy Index Fund and Pure Play 6 to *PowerShares WilderHill* Clean Energy Portfolio. , , and. All but *PowerShares* Global Clean Energy Portfolio underperformed both the S&500 and the NASDAQ 100 from June 2007 to August 2013.

explaining the relative under-performance of the green indexes. As for "decarbonized indices", which focus only on a strictly limited number of highly polluting sectors –say fossil fuel Energy or fossil fuel Utilities – and fully divest from these sectors, one commonly heard objection of institutional investors to divestments of high carbon-footprint stocks is the price of such a policy in terms of lower financial returns. The analogy with tobacco and alcoholic drinks stocks is often made, for which the evidence suggest that there has been a price in terms of lower returns from divestments of those stocks.

The debate around divestments, whether from tobacco or high carbon-footprint stocks, is typically cast in terms of ethics, with the proponents of divestments arguing that the financial returns of those stocks are immoral, and asset managers retorting that they have a fiduciary duty well-disposed towards their investors to maximize financial returns. Although we are well-disposed towards the ethical argument for divestment, we shall show that there is no need to invoke this argument to justify an investment strategy that hedges climate risk. We shall show that we can construct a simple dynamic asset allocation policy that is justified purely on financial grounds: it not only significantly reduces exposure to "carbon risk" (i.e. exposure to high carbon footprint stocks) but also matches or outperforms the benchmark index.

The basic idea underlying our climate risk hedging strategy is to go beyond a simple divestment policy. Under our approach divestment of high carbon-footprint stocks is just the first step. The second key step is to optimize the composition of the green index and the weighting of stocks in the green index so as to minimize the *tracking error* (TE) with the reference benchmark index. It turns out that TE can be virtually eliminated, while at the same time the overall carbon footprint of the green index is substantially lower than the reference index (close to 50%). Moreover, the track record of this constructed green index so far has been to match or outperform the benchmark index[3]. In other words, investors holding this green index have been able to significantly reduce their carbon footprint exposure without sacrificing any financial returns. They are, in effect, holding a "free option on carbon": as long as the introduction of significant limits on CO_2 emissions is postponed they are essentially able to obtain the same returns as on a benchmark index, but the day when CO_2 emissions are priced and limits on CO_2 emissions are introduced the green index should outperform the benchmark. The climate risk hedging policy we propose is essentially an unlevered minimum risk arbitrage policy taking advantage of a currently mispriced risk factor (carbon risk) in financial markets. Granted, larger arbitrage gains are obtainable by taking larger risks and if anything our strategy errs on the side of caution. However, this strategy is particularly well suited for a long-term passive investor clientele that seeks to maximize long-term returns while limiting its market participation over time.

Our paper is organized as follows. We begin by describing the current context in terms of climate risk, both surveying the likely economic consequences of climate change and the existing investment strategies to limit exposure to climate risk. We then describe in greater detail our basic concept of a *green index without relative market risk* and the advantages and potential concerns with this investment strategy. We continue by describing how the green portfolio put in place by AP4 has been constructed and how it has performed so far. We then address the public policy implications of this climate risk hedging strategy. Finally, we offer concluding remarks on the general thrust of our proposed climate risk hedging strategy and how it links to climate change mitigation policies.

[3] See parts III and IV for performance results on "decarbonized" versions of the S&P500 and MSCI Europe.

2. The Current Context

The latest report by the Intergovernmental Panel on Climate Change (IPCC) provides the strongest evidence yet of accelerating global warming caused by growing CO_2 emissions and other heat-trapping gases from human activity in the past fifty years. The report further links several manifestations of climate change, in particular rising sea level, wind patterns, extreme temperature swings, droughts, and heavier precipitations to global warming. These increasingly severe climate events, in turn, are expected to threaten the survival of larger and larger affected populations and to produce mounting costs for the world economy.

The United Nations Framework Convention on Climate Change (UNFCCC) coordinates global policy efforts towards the stabilization of greenhouse gas (GHG) concentrations in the atmosphere. Despite a promising early start with the adoption of the Kyoto protocol, the process led by UNFCCC has stalled in recent years, with the notorious failures to reach new global agreements to limit GHG emissions at the meetings in Johannesburg, Copenhagen and Cancun.

A widely assented policy target for the coming decades reached through the UNFCCC is to limit GHG emissions in order to keep rising average temperatures under a 2°C threshold. However, no concrete policies limiting GHG emissions have yet been agreed that make this target a realistic prospect. To give an idea of what this target entails, scientists estimate that an overall limit in the concentration of CO_2 in the atmosphere between 350parts per million (ppm) and 450 ppm should not be exceeded to have a reasonable prospect of keeping temperatures from rising by less than 2°C. Maintaining CO_2 concentrations below that limit, in turn, would require keeping global CO_2

emissions below roughly 35 billion tons a year, which is more or less the current rate of emissions (it was 34.5 Gt in 2012 according to the European Commission).

Although the process led by UNFCCC has stalled following the adoption of the Kyoto protocol, a number of countries have taken unilateral steps to limit GHG emissions in their respective jurisdictions. Thus, a very wide array of local regulations, and carbon and clean-energy focused legislations have been introduced in the past decade, with for example 490 new regulations put in place in 2012 against only 151 in 2004 and 46 in 1998 (UNEP FI, 2013). Moreover there are promising recent signs of greater urgency concerning climate policies in both the US[4] and China, the two largest economies responsible for a large fraction of global GHG emissions. The most ambitious policy initiative to date has been the creation of a carbon market in Europe, which is currently the world's largest emission trading market (it accounts for over three quarters of international carbon trading) and covers about 45% of total EU emissions, with 28 EU member states involved as well as Iceland, Liechtenstein and Norway.

If the prospect of a global market for CO_2-emission permits - or even of a global carbon tax - seems far off and even if Australia has recently rescinded its carbon tax, the prospect of the establishment of a national market for CO_2-emission permits in China in the next few years could be a game changer. Indeed, China's 12th Five-Year Plan adopted in 2011 devotes considerable attention to energy and climate change and delimits stringent targets, such as a 17% reduction in carbon intensity of its economy in the short to medium-run, with a target of reducing

[4] Prominent voices from the business community have recently expressed their concern that the debate over climate policy has become too politicized. Also, in June 2014, the US EPA unveiled an ambitious program, which involves deep cuts in carbon emissions from existing power plants at a 30% national target by 2030, which is equivalent to 730 million tons of carbon emission reductions, or about 2/3 of the nation's passenger vehicles annual emissions.

China's economy's carbon intensity by 40-45% by 2020. Moreover, following the launch of seven pilot emission-trading schemes (ETS), which are currently in operation, China's National Development and Reform Commission (NDRC) has stated that it aimed to establish a national ETS during its Five-Year Plan (2016-2020).

Yet, despite China's impressive stated climate policy goals, significantly more reductions in CO_2 emissions need to be implemented globally to have an impact on global warming trends. In particular, the global cost of CO_2 emissions must be significantly higher to induce economic agents to reduce their reliance on fossil fuels, or to make Carbon Capture and Storage worthwhile (current estimates are that a minimum carbon price of about $25-30 per ton of CO_2e is required to cover the cost of Carbon Capture[5]). Therefore, with the continued rise in global temperatures and the greater and greater urgency of strong climate mitigation policies in the coming years it is possible that policy makers will at last come to the realization that they have little choice but to act by implementing radical climate policies resulting in a steep rise in the price of carbon.

Of course, other plausible scenarios can be envisioned. There has been some talk recently that temperatures seem to have stopped rising in the past decade, at least for measured temperatures on land. This has prompted some analysts to conjecture that temperatures may have plateaued and that intervention to limit GHG emissions may not be so urgent or may even not be needed. It is, of course, far from clear whether there has been a change in global warming trends in recent years; in particular, measurements of sea water temperatures suggest that the trend of rising

[5] The current price level is far below $30, with average carbon prices ranging from RMB23.95 to RMB77.00/t CO_2e (as of 20/05/2014) in China, average EUR6.50/t (as of 31/08/2014) in Europe, and $12 in the different regional initiatives in North America.

average temperatures has continued unabated. Still, partial evidence of a slowdown in warming can feed into the policy debate and provide ammunition to politicians reluctant to support climate mitigation policies that will hurt their constituencies. Thus, an equally plausible scenario is that no global agreement on introducing comprehensive policies to significantly limit global GHG emissions will be reached in the next Climate Conference in Paris in 2015[6], or in the foreseeable future.

From an investor's perspective this means that there is a *risk* with respect to both climate change and climate mitigation policies. However, it is fair to say that there is still very little awareness among (institutional) investors about this *risk factor*. Few investors are aware of the carbon footprint of the companies in their portfolios and among those holding oil and gas company stocks equally few are aware of the risks they face with respect to these companies *stranded assets*. The notion of stranded assets was first introduced by the Carbon Tracker Initiative (Carbon Tracker 2011, 2013[7]) [and Generation Investment 2013]. It refers to the possibility that not all known oil and gas reserves are exploitable should the planet reach the peak of sustainable concentrations in the atmosphere before all oil and gas reserves have been exhausted. A plausible back-of-the-envelope calculation goes as follows: Earth's proven fossil fuel reserves amount to approximately 2,800 Gt of CO_2 emissions (Carbon Tracker, 2011). But to maintain the objective of no more warming than 2°C by 2050 (with at least a 50% chance) then the maximum amount of allowable emissions is roughly half, or 1,400 Gt of $CO_{2.}$ In other words, oil companies' usable proven reserves are only about ½ of reported reserves. Responding to a shareholder resolution, ExxonMobil published for the first time ever a report in 2014 describing how it assesses the risk

[6] The 21st Conference of Parties on Climate Change (UNFCC Conference) will be held in Paris in November-December 2015.
[7] See Kepler (2014) for a recent study on the risk of stranded assets.

with respect to stranded assets. Much of the report is an exercise in brushing the problem away. Nonetheless, it cannot entirely be ruled out that a growing fraction of proven reserves will be seen by investors to be unexploitable, especially as temperatures continue to rise and climate mitigation policies increasingly become a concrete reality.

Investor awareness regarding climate risk has been raised in recent years thanks to a number of initiatives promoting *green investments*. Thus, a handful of organizations are now systematically measuring and reporting the carbon footprint of the largest publicly traded corporations. Based on these carbon footprint measures, a number of green indexes have been constructed by removing from standard indexes the composite shares of companies with the highest carbon footprint, and these green indexes have been marketed to investors as a simple strategy to reduce exposure to *carbon risk*. The first 'green' index was launched in 2004 and since then the universe of green indices has significantly expanded.

The existing green indices differ in terms of focus, geography, and how they weight composite stocks. The broadest indices are *socially responsible investment* (SRI) indices, which screen firms not only on environmental impact, but also on social, and governance factors (in short ESG factors). Thus, one of the earliest SRI indices, MSCI KLD 400 Social Index (it was launched in 1990 as the Domini KLD 400 Social Index), includes 400 companies with high ESG ratings relative to the constituents in the MSCI USA Investable Market Index. It excludes, in particular, companies with significant business activities in alcohol, tobacco, firearms, gambling, nuclear power or military weapons.

The narrower environmentally focused indices are “pure-play” environmental company indices. These consist of firms having the majority of their businesses related to clean technology, energy efficiency, renewable energy, waste management, and water treatment. The earliest clean energy index, *WilderHill Clean Energy Index* (ECO) was launched in 2004 (see *PowerShares WilderHill* Clean Energy Portfolio which tracks this index in Figure 1). It tracks US publicly traded companies that stand to benefit substantially from the introduction of carbon pricing and that have taken the lead in the transition alternative energies such as wind, solar, ethanol and hydrogen fuel cells. Stocks and sector weightings within ECO are selected based on their contribution towards the development of clean energy. Some indices focus on US companies only while others track clean energy companies globally. For example, *WilderHill* Clean Energy Index (ECO) and *WilderHill* New Energy Global Innovation Index (NEX, see *PowerShares* Global Clean Energy Portfolio, which tracks this index in Figure 1) both focus on pure-play new energy stocks. While the former tracks US public stocks, the latter consist of clean energy firms worldwide.

Another key dimension along which green indices differ is how they weight constituent stocks. There are, for example, equal-weighted indices, which offer greater exposure to smaller-cap companies. One example is DB NASDAQ OMX Clean Tech Index, which equally weights 119 publicly traded firms identified from around 4,000 firms worldwide, aiming to represent the global clean tech industry (the *Cleantech* Index tracked by *PowerShares* Cleantech Portfolio is another equally weighted index). There are also market capitalization-weighted indices, which better reflect firms’ economic significance. One example is the NASDAQ Clean Edge Green Energy Index (CELS, see the First Trust NASDAQ Clean Edge Green, which tracks this index in

Figure 1 [8]), a modified market capitalization-weighted index designed to track the performance of publicly traded US companies that are primarily manufacturers, developers, distributors, or installers of clean-energy technologies. Finally, some indices use green score based weights. For example, the JENI-Carbon Beta Index based on the JPMorgan US Liquid Index (JULI) of investment-grade corporate bonds, tilts JULI's constituents by Carbon-Beta, a relative carbon score provided by *Innovest* (which has since been integrated with MSCI ESG Research) measuring the issuer's exposure to climate change risks. Another example is *WilderHill* Clean Energy Index (ECO), where weights are based on firms' significance in the clean tech world.

The success of these green index funds has so far been limited. One important reason, as we have highlighted in Figure 1 is that since the crisis of 2008 these index funds have significantly underperformed market benchmarks and consequently these funds have faced substantial redemptions. More importantly, the reach of the pure-play green funds is very limited as it concentrates investments in a couple of subsectors.

[8] The Market Vectors Global Alternative Energy ETF and Market Vector Environmental Services Fund in Figure 1 are two other examples of trackers of global capitalization-weighted indices (respectively the *Ardour* Global Index and the NYSE Arca Environmental Services Index).

3. A Green Index without Relative Market Risk: the Basic Concept

Investor perceptions of lower financial returns from green index funds could explain why green indexes have to date remained a niche market. But, another reason may be the design of most existing green indices, which lend themselves more to a bet on clean energy than a hedge against carbon risk. In contrast, the design we propose is primarily to allow passive long-term investors to hedge carbon risk. Thus, our first goal is not to minimize exposure to carbon risk by completely divesting from any companies that have a carbon footprint exceeding a given threshold. Instead, our first goal is to minimize the tracking error of our green index with the given benchmark market index, while at the same time significantly reducing the carbon footprint of the green index relative to the benchmark index.

The basic idea behind our Low-TE green index is, thus, to construct a portfolio with fewer composite stocks than the benchmark, but with similar aggregate risk exposure than the benchmark index to all priced risk factors. The only major difference in aggregate risk exposure between the two indices would then be with respect to the carbon risk factor, which would be significantly lower for the green index. As long as carbon risk stays unpriced by the market, the two indices will generate similar returns (offer the same compensation for risk demanded by the representative investor), thus achieving no or minimal TE. But, once carbon risk is priced by the market the green index should start outperforming the benchmark index.

Our central underlying premise is that financial markets currently underprice carbon risk. Moreover, our fundamental belief is that eventually, if not in the near future, financial markets will begin to price carbon risk. If one accepts our premise and fundamental belief one is inevitably led to the conclusion that our Low-TE green index is bound to provide superior financial returns to the benchmark index.

We believe that the evidence in support of our main underlying premise is overwhelming. Virtually all financial analysts currently overlook carbon risk. For the first time this year did a discussion of stranded assets make it into a report of a leading oil company. And the report mostly denied any concern that a fraction of proven reserves might ever become stranded assets. As far as we know, no financial analyst[9] has yet introduced an analysis with respect to stranded assets into their valuation models of oil company stocks. Nor, apart from a few exceptions, do financial analysts ever evoke carbon pricing risk in their reports to investors. In sum, the current consensus analyst forecasts assume by default that there is no carbon risk. Under these circumstances one would have to stretch one's imagination to explain that somehow financial markets currently price carbon risk correctly. It is even more implausible that in some way financial markets currently price carbon risk excessively. It is only in this latter scenario that investors in the low-TE green fund would face lower financial returns than in the benchmark index.

A sceptic might object that our fundamental belief that financial markets will price carbon risk in the future is not very plausible. After all, the evidence following Kyoto of foot dragging in international negotiations on controlling GHG emissions suggests if anything that carbon pricing in the near future is extremely unlikely. That may be so, but if that is the case our investor in the low-TE green fund would simply match the returns of the benchmark index, a worst case

[9] Aside from ESG analysts, who are unfortunately generally not integrated with mainstream equity analyst teams.

scenario. Any concrete progress in international negotiations from the current status-quo will change financial market expectations on carbon risk and is likely to result in higher financial returns on the low-TE index relative to the benchmark index.

The low-TE green index optimization problem. Accepting our basic premise and fundamental belief, the next question is how one goes about constructing the green index. There are several possible formulations of the problem in practice. One formulation is to begin by eliminating high carbon footprint composite stocks with the objective of meeting a target carbon footprint reduction for the green index, and then to reweight the stocks that remain in the green index so as to minimize tracking error with the benchmark index. The dual of this formulation is to begin by imposing a constraint on maximum allowable tracking error with the benchmark index, and subject to this constraint, to exclude and reweight composite stocks in the benchmark index so as to maximize the carbon footprint reduction of the green index. Although there is no compelling reason to choose one of these formulations over the other, we have adopted the formulation that seeks to minimize tracking error subject to meeting a carbon footprint reduction target.

Another relevant variation in the design of the constrained optimization problem is whether to impose constraints at the outset on the complete exclusion of composite stocks of the worst performers in terms of carbon footprint, or whether to allow the construction of the green index to simply underweight high carbon footprint stocks without completely excluding them. The latter formulation is of course more flexible, but it has some other drawbacks which we shall discuss below.

Although there are many more possible formulations of the constrained optimization problem for the construction of a green index that trades off exposure to carbon, tracking error and expected returns, we confine our analysis to essentially two alternative formulations. We describe each of these formulations more formally below, under the simplifying assumption that there is only one sector represented in the benchmark index.

The two portfolio optimization problems can then be represented as follows. Suppose that there are N constituent stocks in the benchmark index, and that the weight of each stock in the index is given by $w_i^b = (\frac{Mkt\ Cap\ (i)}{Total\ Mkt\ Cap})$. Suppose next that each constituent company is ranked in decreasing order of carbon intensity, q_l^i, with company l = 1 having the highest carbon intensity and company l = N the lowest (each company is thus identified by two numbers (i,l) with the first number referring to the company's identity and the second its ranking in carbon intensity).

In the first problem, the green portfolio can then be constructed by choosing new weights w_i^g for the constituent stocks to solve the following minimization problem:

$$Min\ TE = sd(R^g - R^b)$$

subject to:

$$w_j^g = 0\ for\ all\ j = 1, \dots k.$$

$$0 \leq w_i^g \quad for\ all\ i = k+1, \cdots, N\ .$$

That is, the green index in this first problem is constructed by first excluding the k worst performers in terms of carbon intensity and reweighting the remaining stocks in the green portfolio so as to minimize TE.[10] This "decarbonization" method follows transparent rules of exclusion, whatever the threshold k.

In the second problem the first set of constraints, $w_j^g = 0\ for\ all\ j = 1, \dots k$, is replaced by a constraint that the green portfolio's carbon intensity should be smaller than a given threshold: $\Sigma_{l=1 \dots N} q_l w_l^g \leq Q$. In other words, the second problem is a design which potentially does not exclude any constituent stocks from the benchmark index, and only seeks to reduce the carbon intensity of the index by reweighting the stocks in the green portfolio. While the second problem (*pure optimization*) formulation dominates the first (*transparent rules*) for the same target aggregate carbon intensity Q, as it has fewer constraints, it has a significant drawback in terms of opacity of the methodology and lack of a clear signal on which constituent stocks are excluded on the basis of their relatively high carbon intensity.

As all issuers well understand, inclusion or exclusion in an index matters and is a newsworthy event. We believe that inclusion in a green index ought to have a similar value. Clearly communicating which constituent stocks are in the green index not only rewards the companies included in the index for their efforts in reducing their carbon footprint but also helps discipline the companies that are excluded. Indeed, these companies could face selling pressure arising from their exclusion from the index and their stock price might be negatively affected.[11] This pressure in turn might induce these companies to take actions to reduce their carbon footprint

[10] A multi-sector generalization of this optimization problem can also break down the first set of constraints into companies that are excluded on the basis of their poor ranking in carbon intensity across all sectors, and for the remaining constituent firms, companies that are excluded within each sector based on either their relatively poor carbon intensity score or their relatively high stranded assets relative to other companies in their sector.

[11] As a simple illustration based on a back-of-the-envelope calculation, if 10% of the $8 tn. passive index investment market gravitates towards a green index in Europe (an admittedly ambitious level) then exclusion from such an index could mean as much as a 3% increased daily selling pressure of the company's stock.

and to reward their CEOs for any carbon footprint reductions[12]. As companies' exclusion from the index will be reevaluated on a yearly basis, it will also induce healthy competition to perform on carbon footprint, with the goal of rejoining the index. Finally, a clear communication on exclusion criteria based on carbon footprint will inspire a debate on whether GHG emissions are properly measured and lead to improvements in the methodology for determining a company's carbon footprint.

Risk mitigation benefits of low tracking error. To explore more systematically the potential benefits of achieving a bounded tracking error, we have run a number of simulations with the pure optimization methodology and determined a TE-carbon efficiency frontier for a green index constructed from the MSCI Europe. As we illustrate in Figure 2 below, achieving a nearly 100% reduction in the MSCI Europe carbon footprint would come at the price of a huge tracking error of more than 3.5%[13].

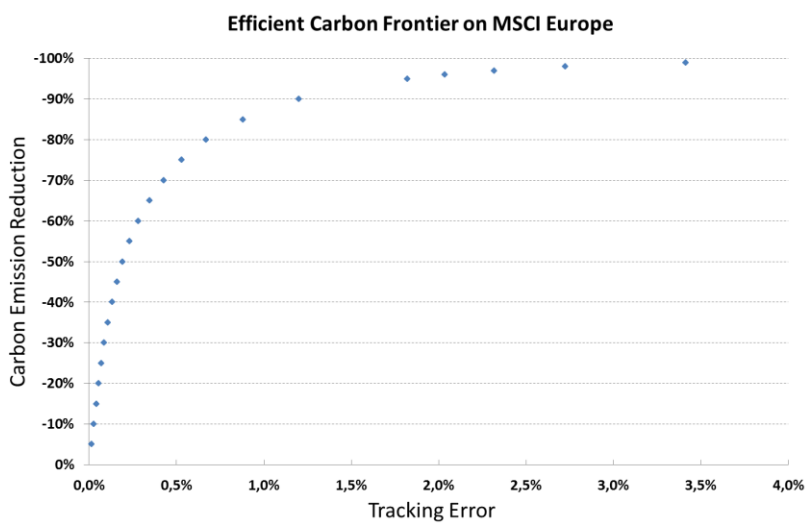

FIGURE 2. Carbon Frontier on MSCI Europe

Source Amundi Quantitative Research as of 31/05/2014

[12] In this respect it is worth mentioning that *Veolia* and *Danone* have already included carbon footprint improvement targets into their executive compensation contracts.
[13] When not specified, the tracking error is calculated ex ante.

Such a large TE would expose investors in the green index to significant financial risk relative to the benchmark even in a good scenario where, as a result of climate mitigation policies, the green index is expected to outperform the benchmark. An illustration of the risk investors might be exposed to with a large TE, and how this risk can be mitigated by lowering the TE, is given in the two Figures 3 and 4 below. In figure 3, we posit a scenario where the expected yearly return from the green index is 2.5% higher than the benchmark[14] and show that, according to a two standard deviation confidence interval, such a 3.5% TE could expose investors to losses relative to the benchmark in the negative scenario.

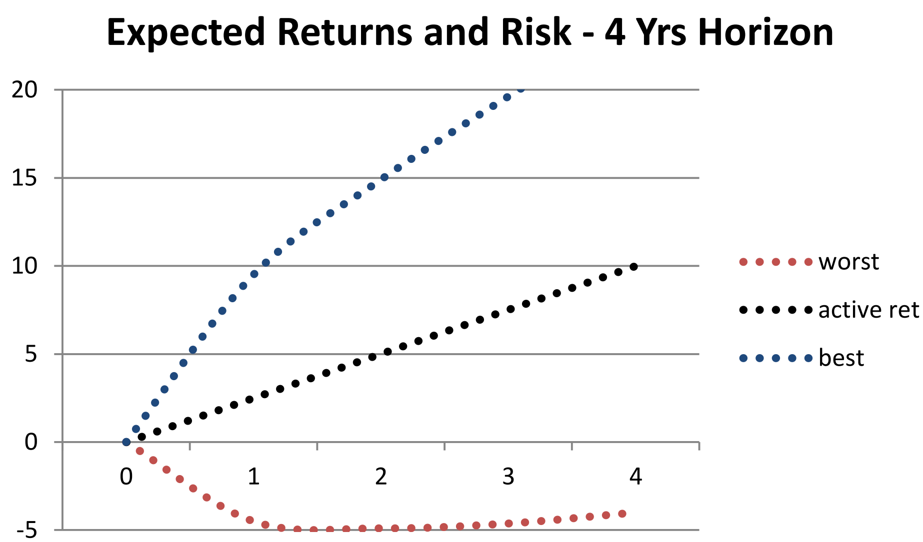

FIGURE 3. Returns and risk with high tracking error
Source Amundi Quantitative Research

[14] This level of outperformance over such a time frame is hypothetical and only for illustrative purposes. Although we are hopeful that a scenario of radical climate risk mitigation policy measures in the near future is possible (see Mercer, 2011) global climate policy implementation and its potential impact on equity valuation remains understandably a very speculative exercise.

However, even a limited "TE budget" delivers significant levels of carbon reduction, with a 1.2% of TE allowing a 90% carbon intensity reduction. As Figure 4 illustrates, if we lower the TE of the green index from 3.5% to 1.2%, then even in the worst case scenario the green index would generate returns at least as high as the benchmark.

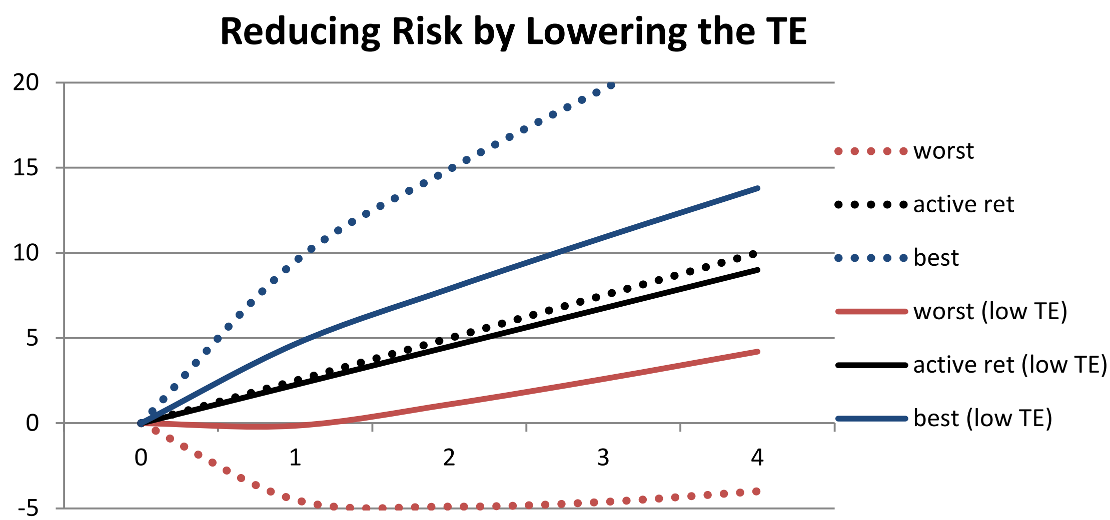

FIGURE 4. Returns and risk with low tracking error
Source Amundi Quantitative Research

Other Tradeoffs. A number of other tradeoffs are involved in the design of the green index. A first obvious balancing question concerns the sector composition of the benchmark index. To what extent should the green index seek to preserve the sector balance of the benchmark? And, while seeking to preserve sector composition, should the filtering out of high carbon footprint stocks be performed sector by sector or overall across the entire benchmark index portfolio?

It is often thought that a sector blind filtering out of companies by the size of their carbon footprint would result in an unbalanced green index that essentially excludes most Utilities and

Materials companies and not much else (including the Energy sector[15]). Obviously, such an unbalanced green index would have a very high tracking error and would not be very desirable. Interestingly, however, a study of the world's 100 largest companies has shown that more than 90% of the world GHG's emissions are attributable to other sectors than Oil & Gas (Climate Counts 2013). Hence, a sector by sector filtering approach can result in a significantly reduced carbon footprint, while still maintaining a roughly similar sector composition as the benchmark. In the next section, we will show more concretely how much reduction in carbon footprint has been achieved by the green portfolios of AP4 relative to the S&P 500 and by the MSCI Europe low carbon index relative to its benchmark index.

One simple way of addressing this issue, of course, is to look at what the TE of the green portfolio is for the different optimization problems and pick the procedure which yields the green index with the lowest TE. But there may be other relevant considerations besides TE minimization. For example, one advantage of transparent rules with a sector by sector filtering approach (subject to the constraint of maintaining roughly the same sector balance as the benchmark index) is that it will be more straightforward for the companies whose stocks have been filtered out to determine where they stand in the relevant industry ranking by carbon footprint and what it would take in terms of carbon footprint reduction for their stock to be included in the green index. In other words, a sector by sector filtering approach would foster greater competition within each sector for each company to lower carbon footprint. Another related benefit of a sector by sector filtering approach is that the exclusion of the worst performers in the sector in terms of carbon footprint is likely to generate higher financial returns not only due to the reduced exposure to mispriced carbon risk but probably also due to reduced

[15] Constituents from the Energy sector generally rank after Utilities and Materials companies.

exposure to badly governed corporations, which are likely to be the ones with relatively higher carbon footprint.

A second balancing question concerns the size of companies in the benchmark index. As the largest companies are also likely to be the companies with the largest carbon footprint, a filtering rule that excludes the stocks of companies with the largest carbon footprint will tend to be biased against the largest companies, which could result in a high tracking error for the green index. Accordingly, some normalization of companies' carbon footprint would be appropriate. Another reason to normalize the absolute carbon footprint measure is that a filter based on a normalized measure would be better at selecting the least wasteful companies in terms of GHG emissions. In other words, a normalized carbon footprint measure would better select companies based on their energy efficiency. A simple, comprehensive but somewhat rudimentary normalization would be to divide each company's carbon footprint by sales. Normalizations adapted by sector are preferable and could for example take the form of dividing CO_2 emissions by: i) tons of output in the oil and gas sector; ii) sales*kilometer distance in the transport sector; iii) total GWh electricity production in the electric utility sector; iv) square footage of floor space in the housing sector; and v) total sales in the retail sector.

A third important balancing question concerns the rate of change of a company's carbon footprint. Ideally the green filter should take into account expected future reductions in carbon footprint resulting from current investments in energy efficiency and reduced reliance on fossil fuels. Similarly, the green filter should penalize more oil and gas companies that invest heavily in exploration with the goal of increasing their proven reserves, which increases the stranded asset risk for these companies. This would provide immediate incentives to companies with exceptionally high carbon footprint to engage in investments to reduce it and it would boost financial returns of the green index relative to the benchmark.

Illustrative Example. The following simple example illustrates in greater detail how a low-TE green index might be constructed and how its financial returns of relative to the benchmark would vary with (expectations of) the introduction of carbon taxes. We consider a portfolio of four stocks (A, B, C, D) each priced at 100. The first two stocks (A, B) are oil company stocks, say; stock C is outside the oil industry but has earnings that are perfectly correlated with oil companies' earnings, and stock D is a company which is uncorrelated with the oil industry. The respective returns on each of these stocks before carbon taxation are respectively: 20%, 20%, 20%, and 30%. We take stocks A and B to have relatively high carbon footprint, which would expose them to relatively high implied carbon taxation, respectively 40% and 10% of their earnings. We assume, on the other hand, that stocks C and D have no carbon tax exposure. We then construct the low-TE green index as follows: i) we filter out entirely stocks A and B; ii) we treble the weighting on stock C to maintain the same overall exposure to the oil sector as the benchmark portfolio; iii) we leave the weighting on stock D unchanged.

Should carbon taxes be expected to be introduced then the stock price of company A and B respectively will drop to 72 and increase to 108 while the stock price of companies C and D respectively will increase to 120 and 130. What are the implications for returns on the low-TE green index relative to the benchmark? Under this scenario the low-TE index would outperform the benchmark by 14%.

Caveats. Any time an investment strategy that is expected to outperform a market benchmark is pitched a natural reaction is to ask: where is the catch? As we explained above, the outperformance of the low-TE green index is premised on the fact that carbon risk is currently not priced by financial markets. An obvious potential flaw in our proposed climate risk hedging strategy is thus that financial markets currently overprice carbon risk. As this overpricing is corrected the low-TE green index would underperform the benchmark index. We strongly believe that such a degree of cynicism is irrational and is closer to a form of paranoia.

Another highly implausible scenario is that somehow the high carbon footprint companies of today will be the low carbon footprint companies of tomorrow. One story to back such a scenario could be that the high GHG emitters today have the most to gain from carbon sequestration and will therefore be the first to invest in this technology. If that were the case, the low-TE green index would underperform the benchmark precisely when carbon taxes are introduced. Apart from the fact that this is a somewhat fanciful story, this is not in itself a crushing objection, since the green filter can easily take into account investments in carbon sequestration as a criterion for inclusion in the index. Ultimately, this can simply be an argument for the carbon filtering to take into account some "forecasting" feature on the future carbon footprint of companies.

A more valid concern is whether companies' carbon footprints are currently correctly measured. Is there a built-in bias in the way carbon footprint is measured, or is the measure very noisy, so that investors could be exposed to a lot of carbon measurement risk? A number of organizations, such as *Trucost*, the *CDP* (formerly *Carbon Disclosure Project*), *South Pole Carbon*, or *MSCI ESG Research* currently provide carbon footprint measures of the largest publicly traded companies and indeed the measures differ considerably from one organization to another. It has also been observed, for example, that GHG emissions associated with hydraulic fracturing for shale gas are currently significantly underestimated, as the high methane emissions involved with the hydraulic fracturing process *per se* are not counted. Thus, what would appear as a welcome reduction in carbon footprint following the shift away from coal to shale gas according to some current carbon footprint measurements could just be an illusion. A green filter that relies on this biased carbon footprint measure, thus risks exposing investors to more rather than less carbon risk. There are three evident responses to this objection. First, drawing an analogy with credit markets, a biased or noisy measure of credit risk by credit rating agencies has never been a decisive reason for abolishing credit ratings altogether. Credit ratings have provided an essential reinforcement of credit markets for decades despite important imprecisions in their measurements of credit risk that have been pointed out by researchers of credit markets over time. Second, as with credit ratings, methodologies for measuring carbon footprint will improve over time, especially when the stakes involved in measuring carbon footprint correctly increase as a result of the role of these measures in any green filtering process. A third important response to this concern is that the design of the low-TE green index itself offers a protection against carbon footprint measurement risk, for if there is virtually no tracking error with the benchmark then investors in the low-TE green index are to some extent hedged against this risk.

Finally, a somewhat more technical worry is that the stocks that are excluded from the low-TE green index could also be the more volatile stocks, as these stocks are the most sensitive to speculation about climate change and climate policy. If that is the case, then tracking error cannot be entirely eliminated, but that should not be a reason for not investing in the low-TE green index. On the contrary, the low-TE index will then also have a higher Sharpe ratio relative to the benchmark commensurate with the higher TE[16].

To summarize, the strategy for hedging climate risk we propose is especially suitable for passive long-term investors. Rather than a risky bet on clean energy (at least in the short run) we have designed a green index with a minimal tracking error with respect to the benchmark index, which offers passive investors a significantly reduced exposure to carbon risk, while at the same time allowing them, so to speak, to buy time and limit their exposure to the risk with respect to the timing of the implementation of climate policy and a carbon tax. Thus, a key change in our approach relative to other existing green indices is to move the focus away from the inevitable transition to renewable energy to concentrate more on the timing risk with respect to climate policy. As we will illustrate in the next section, it is possible to significantly reduce carbon exposure while at the same time providing maximum insurance against the timing of climate policy by minimizing tracking error with respect to the benchmark index. We believe that our strategy is essentially a win-win strategy for all passive asset owners and managers. Moreover, should this strategy be adopted by a large fraction of the passive index investing clientele, a market representing close to $8tn in assets according to a recent study by BCG (BCG 2013), then pressure on companies to improve their performance on GHG emissions will be sure to be felt and debates on carbon emissions are sure to rise in prominence in the financial press.

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[16] Moreover, most modern optimization techniques utilize factor exposures and correlations, reducing risk from known systematic factors such as volatility, small cap or beta, therefore reducing this risk by increasing weights of high volatility/low carbon stocks to replace the high carbon stocks.

4. A Low-TE Green Index in Practice: How Small is its Carbon Footprint?

There are by now several examples of low-TE green portfolios. AP4, the fourth Swedish National Pension Fund, is to our knowledge the first Institutional Investor to adopt a systematic approach using low TE green funds to hedge the carbon exposure of its equity portfolio. In 2012 AP4 decided to hedge its carbon exposure on its US equity holdings in the S&P 500 index by switching to a "carbon lite" portfolio with low tracking error with the S&P 500 (through the replication of the S&P U.S. Carbon Efficient Index). AP4's green portfolio of US stocks excluded the 20% worst performers in terms of their carbon intensity (CO_2 / Sales) as measured by *Trucost*, one of the leading companies specializing in the measurement of environmental impacts of publicly traded companies. A first constraint imposed by AP4 was to ensure that stocks removed from the S&P 500 would not exceed a reduction in GICS sector weight of the S&P 500 by more than 50%. Secondly, AP4 readjusted the weighting of the remaining 375 constituent stocks so as to minimize the tracking error with the S&P 500. Remarkably, AP4 was thus able to reduce the overall carbon footprint of the S&P 500 by roughly 50%[17] if it accepted a TE of no more than 0.5%. This first model for constructing a low-TE green portfolio thus strikingly illustrates that significant reductions in carbon exposure are possible without sacrificing much in financial performance or TE. In fact, AP4 green portfolio has outperformed the S&P 500 by about 14 bps since its inception in November 2012, as is shown in Figure 5 below (as of September 3rd, 2014). Given the short period of time, this level outperformance is, however, not statistically significant.

[17] A 48% reduction level in carbon footprint was achieved when AP4 started investing in 2012.

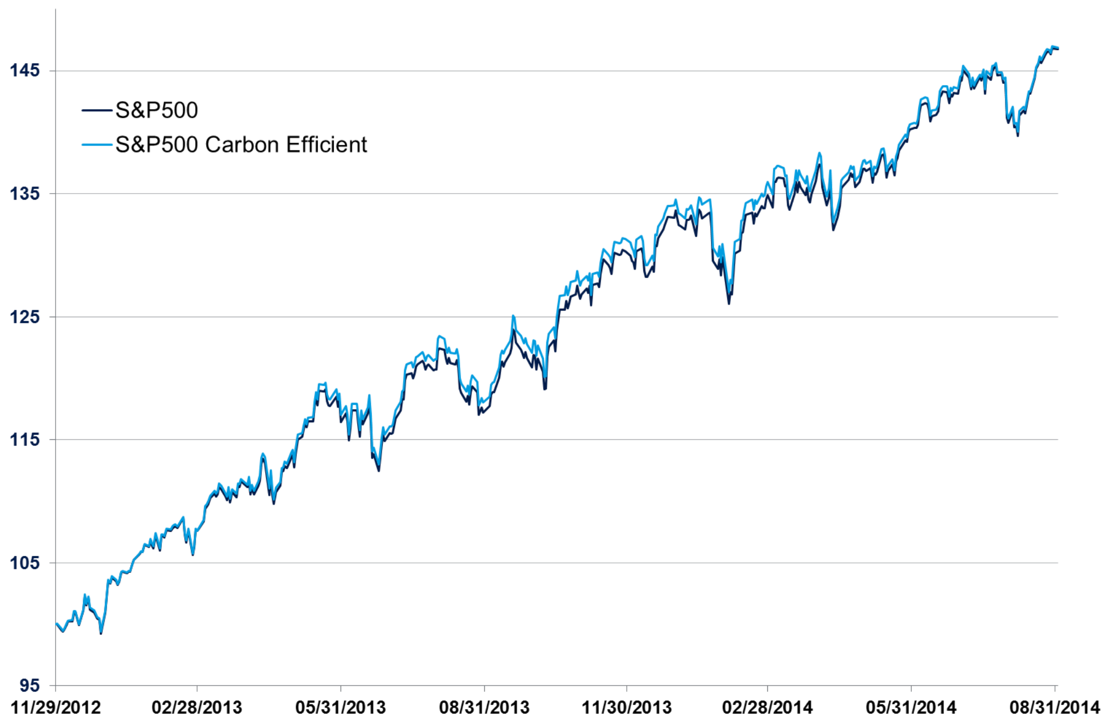

FIGURE 5 S&P500 and S&P U.S. Carbon Efficient

Source Amundi, Bloomberg as of 09/03/2014

AP4 has since extended this approach to hedging climate risk to its equity holdings in emerging markets. Relying on carbon footprint data provided by *MSCI ESG Research*, AP4 has excluded from the MSCI index not only the companies that had the highest GHG emissions but also the worst companies in terms of their carbon reserves intensity. Finally, AP4 turned to its Pacific-ex-Japan stock holdings and applied a similar methodology for the construction of its green portfolio, excluding the companies with the largest reserves and emissions intensity, subject to maintaining both sector and country weights in line with its initial index holdings for this region.

More recently AP4, FRR and Amundi have requested MSCI to develop another low-TE green index, with a slightly different design. They have constructed a low-TE green index based on the benchmark MSCI Europe index, excluding the worst performers in terms of carbon emissions and fossil fuel reserves from the index, subject to a maximum turnover constraint, and modifying sector and country weights by no more than a given threshold, and then minimizing TE with the MSCI Europe. The criteria for exclusion of a stock from the index are straightforward: First, companies that are among the largest 20% of GHG emitters (as measured by GHG emissions-to-sales) and that have a cumulative sector weighting of no more than 30% are excluded. Second, the largest carbon reserves owners (sorted by reserves divided by market cap) are excluded until the carbon reserve intensity of the index is reduced by at least 50%. After the worst performing company stocks have been excluded the remaining composite stocks are then rebalanced so as to minimize tracking error. The performance of the resulting green index based on a back-testing exercise is compared to the MSCI Europe in the table below:

Parameter	Europe	Low Carbon (Transparent Rules)
Total Return* '(%)	**11.5**	**12.1**
Total Risk* (%)	11.9	11.8
Sharpe Ratio	0.93	0.99
Active Return* (%)	0	0.7
Tracking Error* (%)	0	**0.72**
Information Ratio	NA	**0.91**
Turnover** (%)	1.9	11.3
Securities excluded	NA	91
Market cap excluded (%)	NA	23.5
Carbon *Emission* intensity reduction (tCO2/mm USD) (%)	NA	**62**
Carbon *Reserves* intensity reduction (tCO2/mm USD) (%)	NA	**81**

Table 1. Financial performance of transparent rules on MSCI Europe
Source MSCI[18]

[18] Backtests ran over a 4 year period, from 11/30/2010 to 06/30/2014. * Gross annualized returns in EUR. ** Annualized one-way index turnover.

As can be seen, the back-testing simulation delivers a remarkable 60bp per year outperformance of the MSCI Europe, with a similar volatility and a 0.7% tracking error.

AP4, MSCI, FRR and Amundi have further explored the robustness of the green index to other exclusion rules and to higher carbon footprint reductions. They found first that there is not much to be gained in performance by allowing for more flexible exclusion criteria that do not necessarily result in a 100% exclusion of a high carbon footprint stock. Indeed, the table below compares the performances of a fully "optimized" portfolio, with no strict exclusion of the worst performers, and the portfolio based on the "transparent exclusion rules" outline above. Whether it is in terms of reduced exposure to carbon or overall tracking error the two portfolios deliver similar results.

	Optimized	Transparent Rules
Carbon Emissions	-82%	-62%
Carbon Reserves	-90%	-81%
Tracking Error	0,9%	0,72%

Table 2. Financial performance of transparent rules on MSCI Europe
Source: MSCI[19]

Interestingly, however, the two methods for constructing the green index yield substantial sector by sector difference in tracking error. As the figure below illustrates, although the overwhelming contributions to tracking error are concentrated in two sectors (Materials and Energy), the

[19] Carbon emissions and carbon reserves reduction from benchmark are expressed in intensity (t CO_2 /mm USD). Back-tests were run over a four year period, from 11/30/2010 to 06/30/2014.

contribution to TE for the materials sector is significantly larger under the optimized approach than under the "transparent rules" approach.

Thus, the choice of transparent rules has been dictated by both a better tracking error quality and for the signaling effects generated by this approach.

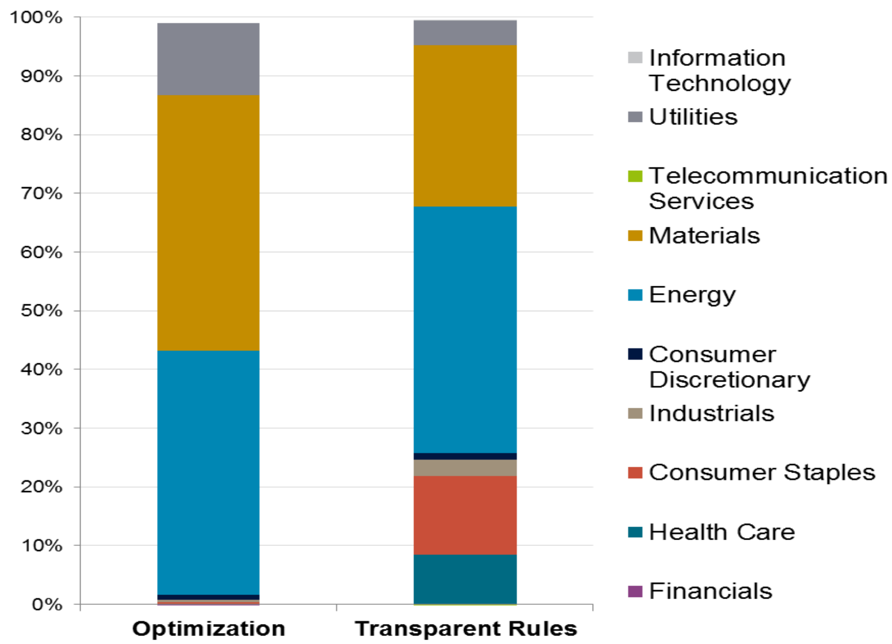

FIGURE 6. Percentage contribution to specific risk per sector
Source Amundi Quantitative Research, computed on MSCI Europe as of 31/05/2014

5. Green Index Investment: Implications for Public Policy

The low-TE green index investment strategy we propose stands on its own as a simple and effective hedging strategy against climate risk for passive long-term investors. But, it should also be emphasized that it is an important complement to public climate change mitigation policies. Governments have so far mostly focused on introducing policies to control or tax GHG emissions and to build broad international agreements for the global implementation of such policies (see Guesnerie and Stern 2012 for a discussion of the pros and cons of cap-and-trade mechanisms versus GHG emission taxes). There has, of course, been considerable resistance to a broad multilateral agreement on long-term significant climate change mitigation, and most of the recent advances on climate policy have been the result of unilateral efforts by individual countries. As we have argued in the introduction, the difficulty for politicians is that they are asked to policies involving mostly "sell short-term pain for long-term gain" to their often myopic constituencies. Sometimes politicians have sought to frame climate mitigation policies as profitable long-run investments, and as strategic moves to put their economies in a first-mover position in a future renewable energy economy. They have, thus, provided subsidies to solar and wind energy sectors and thereby boosted a small business constituency in support of climate change mitigation policies.

Similarly, our low-TE green index can help boost support for climate change mitigation policies by a large fraction of the investor community. By encouraging investments in low-TE green indices by pension funds, insurance companies, university endowments and sovereign wealth funds, governments can build a potentially large constituency in support of climate change mitigation (globally representing as much as $8 tn. of assets under management) at no cost. Moreover, as more and more funds are allocated to such indices, stronger market incentives will materialize inducing the largest corporations in the world—the publicly traded companies—to invest in reductions of GHG emissions. This is all the more attractive that the encouragement of climate risk hedging can have real effects on reducing GHG emissions even before climate change mitigation policies are introduced. The mere expectation that such policies with be introduced will have an impact on the stock prices of the highest GHG emitters, and will reward those investors that have hedged climate risk by holding a low-TE green index. Finally, the very anticipation of the introduction of climate change mitigation policies will create immediate incentives to initiate a transition towards renewable energy.

A simple, costless, policy in support of hedging of climate risk that governments can immediately adopt is to mandate disclosure of the carbon footprint of their state-owned investment arms (public pension funds and sovereign wealth funds). Such a disclosure policy will have several benefits: (i) given that climate change is a financial risk, it provides investors (and citizens) with relevant information on the nature of the risks they are exposed to. Remarkably, some pension funds have already taken this step and pioneered the disclosure of their portfolios' carbon footprint, in particular ERAFP and FRR in France, KPA, the Church of Sweden, AP3 in Sweden, APG in the Netherlands and GEPF in South Africa; (ii) given that ultimately citizens and pensioners will carry the costs of climate change mitigation, disclosure of their carbon exposure through their pension or sovereign wealth fund helps internalize the externalities of climate change. Indeed, investments by a public pension funds in polluting companies generates a cost carried by its government and trustees and thereby lowers the overall returns on the investment. CIC, the Chinese sovereign wealth fund has already made some statements in that direction; and, (iii) disclosure of the carbon footprint of the portfolio of a sovereign wealth fund can be a way for sovereign wealth funds of oil and gas exporting countries to bolster risk diversification and hedging of commodity and carbon risk through their portfolio holdings. Indeed, since the basic concept underlying these sovereign wealth funds is to diversify the nature of the assets of the country by extracting the oil and gas under the ground and thereby "transforming" these assets into "above ground" diversifiable financial assets, it makes sense to follow through this policy by diversifying investments held by the sovereign wealth fund away from energy company and other stock holdings that have a large carbon exposure.

Of course, a more direct way of supporting investment in low-TE green indices is to push public asset owners and their managers to undertake such investments. Governments could thus play an important role as catalysts to accelerate their mainstream adoption. It is worth mentioning in this respect the interesting precedent of the recent policy of the Shinzō Abe administration in Japan, which has supported the development of a new index (the JPX-Nikkei Index 400) based both on standard quantitative criteria, such as return on equity, operating profit, and market value, and more innovative qualitative criteria, such as governance requirements of least two independent outside directors, etc.). What is particularly noteworthy is that the Shinzō Abe administration sees this as an integral part of its "third arrow" to reform Japanese companies. Thus, GPIF—by far the largest Japanese public investor (with more than $1.4tn of AUM)—has since adopted this new index. This example illustrates how the combination of a design of a new index with a policy-making objective together with the adoption of the index by a public asset owner can be a catalyst for change.

6. Conclusion

In his book, *Finance and the Good Society*, Robert J.Shiller advances a welcome and refreshing perspective of financial economics: "Finance is not about "making money" per se. It is a "functional" science in that it exists to support other goals-those of society. The better aligned society's financial institutions are with its goals and ideals, the stronger and more successful the society will be".

It is in this spirit that we have pursued our research on how investors could protect their savings from the momentous risks associated with GHG emissions and their long-term potentially devastating effect on global warming and climate change. Climate change has mostly and appropriately been the realm of scientists, climatologists, governments and environmental activists. In comparison, there has been relatively little engagement by Finance on this important issue. But, climate change cannot just be ignored by investors and financial markets. The effects of global warming, the increasingly raging weather events it generates, and the climate change mitigation policy responses it could provoke, may have dramatic consequences for the economy and in turn for investment returns. Financial innovation should therefore be explored to leverage financial markets to address one of the most challenging global threats faced by humanity.

Besides offering investors a hedging tool against the rising risks associated with climate change, our proposed low-TE green index investment strategy can also mobilize financial markets in support of the common good. As a larger and larger fraction of the index-investing market is devoted to such green indices, a virtuous cycle will be activated and enhanced, where the greater awareness of carbon footprints and GHG emissions provides welcome disciplining pressure to reduce CO_2 emissions, and gradually builds an investor constituency in support of climate change mitigation policies. Governments, businesses, technology innovators, and society, in turn, will thus be encouraged to implement changes that accelerate the transition to a renewable energy economy.

Our basic premise and working assumption has been that to engage financial markets with climate change, it is advisable to appeal to investor rationality and self-interest. Our argument is simply that even if some investors happen to be climate sceptics, the uncertainty with respect to climate change and climate change mitigation policies cannot be waived off as a zero probability risk. Any rational investor with a long-term perspective should thus be concerned about the absence of a market for carbon and the potential market failures that could result from this market incompleteness. Our proposed dynamic green index investment strategy seeks to fill this void and offers an attractive hedging tool even for the climate skeptic.

Appendix

Carbon Data:

(i) *Nature of carbon emissions and carbon reserves data*

Carbon emissions and carbon reserves relate to a wide array of greenhouse gases (GHG) and hydrocarbon reserves. The standard unit of measurement is indeed the metric ton of carbon dioxide equivalent (MTCO2e), usually abbreviated to tons of carbon.

Regarding GHG, the most widely used international carbon accounting tool for governments and businesses is the GHG protocol. This protocol serves as the foundation for almost every GHG standard in the world, notably the International Organization for Standardization (ISO) and Climate Registry. Corporate Users include BP, Shell, General Motors, GE, AEG, Johnson & Johnson, Lafarge, Tata, etc. Non-Corporate Users include Trading schemes (EU ETS, UK ETS, Chicago Climate Exchange), NGOs (CDP, WWF, Global Reporting Initiative), Government agencies in China, US, US states, Canada, Australia, Mexico etc.

According to the protocol, GHG emissions are divided into three scopes: Scope 1 relates to direct GHG emissions, that is, emissions which occur from sources owned or controlled by the company (e.g. emissions from fossil-fuels burned on site or leased-vehicles). Scope 2 emissions are GHG indirect emissions resulting from the purchase of electricity, heating and cooling or steam generated off site but purchased by the entity. Scope 3 emissions encompass indirect emissions from sources not owned or directly controlled but related to the entity’s activities (e.g. employee travel and commuting, vendor supply chain, etc.).

The estimation of CO_2 equivalent of carbon reserves is a three-step process, which involves first the classification and estimation of hydrocarbon reserves, and then translates these reserves into CO_2 emissions. The data considered for estimation of fossil fuel reserves and stranded assets are most of the time proved reserves (90% probability that at least the actual reserves will exceed the estimated proved reserves). Those data are publicly available and must be disclosed in company's reports. Once the proven reserves are estimated in volume or masse, two steps are still required. First, the calorific value of total fossil fuel reserves needs to be estimated, and then calorific value needs to be translated into carbon reserves using a carbon intensity table.

(ii) *Carbon data providers*

At the two ends of the spectrum of carbon data providers, we find entities that simply aggregate data provided directly by companies or that are publicly available, and entities that only use their internal models to estimate carbon emissions or reserves.

Corporations themselves are the primary provider of carbon data, via two main channels: (i) CSR reports for 37% of the world's large companies (with market cap exceeding $2 bn.), which disclose completely their GHG emission information; (ii) CDP, which provides the largest global carbon related database, in partnership with Bloomberg, MSCI ESG, Trucost, etc. Companies respond to Annual Information Request Forms made by CDP for climate change related information collection, and the number of respondents has increased from 235 in 2003 to 2132 in 2011. Financial data vendors such as Bloomberg generally provide datasets with sources from CDP, CSR report, and other manually searched ones. The heterogeneity of sources explains the discrepancy that can sometimes be found in carbon footprint measurements.

Illustrative Example of Carbon Tax:

Initial situation	A	B	C	D	Total
Oil sector correlation	100%	100%	100%	0	
Estimated coming tax	40%	10%	0	0	
Weights	25%	25%	25%	25%	
Index Price					400
Low carbon fund					
Weights	0	0	75%	25%	
Impacts					
Market impact	20%	20%	20%	30%	
Carbon tax impact	-40%	-10%	0%	0%	
After market impact and tax					
Share price	72	108	120	130	
Reference porfolio					
Weights	17%	25%	28%	30%	
Basket price					430
Low carbon					
Weights	0%	0%	73%	27%	
Basket price					490
Outpermorance					*14%*

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