中英（广东）CCUS 中心
UK–China (Guangdong) CCUS Centre

THE UNIVERSITY OF EDINBURGH

Discounting Rates and Investment Appraisals for Emerging Low-Carbon Technologies: **Carbon Capture, Utilisation and Storage & Offshore Wind**

Part I

Lead Author
Seth Armitage

Co-Author & Editor
Hasan Muslemani

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[1] Business School, The University of Edinburgh, 29 Buccleuch Place, Edinburgh, EH9 9JS, UK

[2] UK-China CCUS (Guangdong) Centre, Guangzhou, China.

[3] Guangdong Electric Power Design Institute (GEDI), Guangzhou, 510600, China.

[4] British Consulate General, Guangzhou, Guangdong, China.

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[1] 爱丁堡大学商学院，英国爱丁堡Buccleuch Place29号，EH9 9JS

[2] 中英（广东）CCUS中心，中国广东省广州市科学城天丰路1号，510600

[3] 中国能建广东省电力设计研究院（GEDI），中国广东省广州市科学城天丰路1号，510600

[4] 英国驻广州总领事馆，中国广东省广州市天河区珠江新城珠江西路 5 号，510000

Executive Summary

As China expects its economic growth to continue growing rapidly for the foreseeable future, its electricity demand is predicted to simultaneously witness an abrupt increase (by 150% in 2030 relative 2010 levels), with coal-fired power generation remaining an integral part of the energy mix in the coming decades. The Chinese Government forecasts its national greenhouse gas emissions to peak by 2030 and has internationally committed to reducing its emissions by significant proportions. In this respect, it has considered the promotion of Carbon Capture and Storage (CCS) as s serious climate mitigation strategy, one that would also allow its economy to sustainably prosper. The further utilisation of captured carbon for alternative industrial purposes (CCUS) also promises to considerably reduce the high investment costs incurred at this early stage of technology development. In a similar vein, China's high-potential offshore wind power was also identified as a prime candidate to complement the electricity demand of the most energy-consuming coastal cities.

Part I of this report delineates the financial metrics utilised in appraising the financial viability of low-carbon technology projects. Most significantly, we investigate the implications of adopting social discount rates instead of commercial discount rates to evaluate low-carbon technologies, the profitability of investments in such technologies, the risks perceived in the process and alternative methodologies of determining social discount rates. The attention devoted to the controversial choice of an SDR is largely justified by the practical realities of decision-making in public investments. Although not explicitly portrayed as such in the media, the debate about the scale of government financial support for carbon-reducing investments is in large a reflection of the debate regarding the optimal value of the SDR. Guided by the Ramsey Formula, the choice of the SDR reflects society's weighing of utility of consumption today as opposed to that of future utility, i.e. of future generations' welfare, and is therefore a debate fraught with ethical predicaments. While the Stern Review adopts very low values for an SDR (i.e. 1.4%), critics acknowledge that future generations will be richer and thus better equipped to mitigate, and adapt to, the effects of climate change, subsequently suggesting the endorsement of higher SDRs in cost-benefit

analyses. Alternative SDR computational methods are suggested, such as applying declining discount rates for projects running further away into the future. Social discount rates are much lower than the commercial ones computed using conventional finance packages, and so the stock market undervalues long-term emissions-reducing projects in favour of short-term higher-earning investments. The adoption of SDRs in cost-benefit analyses of green projects would eventually decrease the support received from the government, and would also require some de-risking strategies for investments in low-carbon technologies.

The study's Part II undertakes a holistic approach to present the financial, political, and social cases for CCUS and offshore wind (OSW) within China. This entails a detailed investigation of the current status quo for both markets, policy reforms and their effectiveness, and economic and social developmental barriers. This is supplemented by two theoretical case studies to appraise the financial viability of typical CCUS and OSW projects in China (in Guangdong and Jiangsu, respectively). Sensitivity analyses and Monte Carlo simulations are further applied using varying discount rates to better inform investors of the potential riskiness and likelihood of investment profitability under different mid-to-longer term scenarios. Our findings suggest that CCUS could become economically feasible if a suite of supporting schemes were exploited, namely the financial benefits generated by sale of carbon credits under the CDM, the sale of liquid carbon to CO_2-EOR gas and oil companies, and through raising public money in the form of governmental grants or CCUS-dedicated funds. It is imperative that, in the absence of these mechanisms, an on-grid tariff of US$87.5/MWh is required to generate desirable returns on investment. This figure could be lowered to US$67 if a 30% grant towards capital was attainable, with a Guangdong ETS carbon price held at US$8/$tCO_2$.

Assuming carbon prices in the range of US$20-25/$tCO_2$, or liquid CO_2 sold at US$16-20/$tCO_2$ to EOR-CO_2 utilising industries, with preferential tax status and/or tax exemption policies, the required on-grid tariff for CCUS investments could reach levels as low as US$55-58/MWh, rendering CCUS projects more economically attractive than alternative power sources (e.g. nuclear, onshore wind, and gas-fired plants). By virtue of its lower total investment and low labour cost advantages as compared to international projects, China has the opportunity to enforce strong carbon pricing policies through its anticipated national ETS in 2017. However, a clear and long-term climate mitigation policy should be executed as early as possible to avoid carbon lock-in investments. It is also crucial to note that, with a persisting lack of CCUS knowledge amongst the Chinese lay people, governmental authorities in conjunction with project developers could smoothen out the integration of CCUS into industrial practices by acquiring a social license prior to, and during, project development phases. This could be attained via the promotion of communication exchange programmes, engagements in public education classes, and the enhancement of information exchange and project disclosure strategies.

For offshore wind power, despite its immense power generation potential and the priority status it receives from the Chinese Government, technologies remain highly costly at this nascent stage of development. Those OSW projects already consented had received bidding feed-in-tariff (FiT) levels of 0.62-0.73CNY/kWh, proving too low to produce sensible returns, attract investors, and drive a long-term deployment plan for offshore wind in China. Policy support for offshore wind is normally expected to undergo trial-and-error phases, as was the case for onshore wind. Nevertheless, the present work deems a minimum FiT level of 0.85-1CNY/kWh indispensable to capture the globally renowned potential that the Chinese offshore wind sector boasts. Supply chain companies and relevant stakeholders in offshore projects seem ready to deliver but are awaiting the appropriate market signal before they lock-in investments within the industry. The government can potentially reduce perceived risks by implementing appropriate taxations cuts, announcing preferential loan policies, improving the quality and technical level of wind-power enterprises, assisting small and medium enterprises (SMEs) to penetrate the market, alleviating approval barriers for wind projects under the CDM, and meticulously revising the feed-in-tariff levels necessary to ensure an orderly and accelerated development of the Chinese offshore wind sector.

摘要

在未来一段时间内，中国经济预计将保持持续快速增长趋势，相应的，国内电力需求预计也将急剧上升（预计 2030 年将在 2010 年水平上增加 150%）。而在未来几十年，燃煤发电仍将是中国能源结构中不可或缺的组成部分。中国政府在国际上承诺将大幅减少温室气体排放，并预计将在 2030 年达到温室气体排放的峰值。为此，中国政府认为推广碳捕集与封存（CCS）技术是一项在抑制气候变化的同时实现经济持续繁荣的重要策略。CCS 捕集到的二氧化碳可以进一步应用到工业生产过中，能够极大降低碳捕集技术早期开发所需的高额成本。同样还有在中国具有很大发展潜力的海上风电技术，该技术被认为是能够满足能耗最大的沿海城市电力需求的主要来源。

本报告第一部分描述了评估低碳技术项目的财务可行性的财务指标。最重要的一点是，本文作者采用社会贴现率替代商业贴现率，研究了其对低碳技术评估的影响、投资该技术的盈利能力、投资过程中的感知风险，并确定了社会贴现率的替代方法。公共投资决策的实际情况极大的引起人们对社会贴现率争议性的选择的关注。虽然没有像媒体那样进行明确描述，但是关于政府对碳减排投资的财政支持力度的讨论，在很大程度上是对最佳社会贴现率的讨论的反映。根据拉姆齐模型，社会贴现率的选择反映了社会对当前消费效用和未来消费效用（也就是后代福利）的权衡，是一项充满了道德难题的讨论。虽然《斯特恩报告》中采用的社会贴现率数值很小（1.4%），评论家承认未来后代拥有的财富更多，能更好地缓解和适应气候变化的影响，所以建议支持在成本效益分析中采用更高的社会贴现率。本报告还建议了其它的社会贴现率计算方法，包括对那些时间跨度很长的项目采用逐渐递减的贴现率。社会贴现率比利用传统融资方案计算出来的商业贴现率要低得多，因此股票市场低估了长期减排项目的价值，而偏好那些短期高回报的投资项目。在对环保项目的成本效益分析中采用社会贴现率的概念将最终减少政府的支持，同时需要采取策略消除低碳技术投资的风险。

本报告的第二部分对 CCUS 和海上风电技术经济、政治和社会案例进行了全面分析，包括对 CCUS 和海上风电的市场现状、政策改革及其效果、经济和社会发展障碍进行的详细分析。此外，本报告还分析评价了中国两个（分别在广东和江苏）典型 CCUS 和海上风电项目案例的经济可行性。通过敏感性分析和蒙特卡罗模拟，采用不同的贴现率数值，让投资者更了解不同的中长期情景下可能存在的潜在风险和投资收益。

研究结果显示，如果能开发出一系列支持机制，例如在清洁发展机制下出售碳排放权的收益、出售液态二氧化碳给油气公司用于提高石油采收率以及通过政府拨款或 CCUS 专项基金的方式募集公共资金，CCUS 技术能够实现经济可行。但是在这些机制还未开发之时，上网电价需要定为 87.5 美元/兆瓦，才能产生理想的投资回报。而如果资本成本的 30%来自拨款，在广东碳排放交易市场的碳价为 8 美元/吨时，上网电价可降低至 67 美元/兆瓦时。

假定碳价的波动范围是 20-25 美元/吨（或液态二氧化碳用作提高石油采收率的售价为 16-20 美元/吨），在实施税收优惠和/或免税政策的情况下，CCUS 投资所需上网电价至少为 55-58 美元/兆瓦时，这样 CCUS 项目才比其他能源资源（如核电、陆上风电和燃气电厂）项目更具经济吸引力。与国际项目相比，中国由于项目的总投资较低且有廉价劳动力成本优势，将有机会通过碳定价政策，该政策计划在 2017 年在全国碳排放交易市场推行实施。然而，为避免碳投资被锁定，需要尽早执行清晰、长期的应对气候变化政策。另外至关重要的是，由于中国公众长期缺乏对 CCUS 的认知，政府部门和项目开发商应通过在项目开发之前或过程中获得社会认可来解决将 CCUS 融入工业实践的问题。这可以通过开展沟通交流项目、公共教育类活动以及加强信息交流和项目信息公开来实现。

就海上风电而言，尽管其发电潜力巨大且被中国政府认可为优先发展行业，但是在初期阶段技术成本仍然很高。对已获批的海上风电项目，政府给出的上网电价

水平是 0.62-0.73 元/千瓦时，但是这个价格过低，无法产生合理的回报来吸引投资者及推动海上风电在中国的长期发展。正常情况下，预计和陆上风电一样，对海上风电的政策支持将处于试行阶段。尽管如此，目前的研究认为中国需要制定至少 0.85-1 元/千瓦时的上网电价水平，才能把握住国内海上风电行业蕴藏的巨大潜力。海上风电项目的供应链企业和利益相关者已经做好投资准备，但仍在等待合适的市场信号出现才会将投资锁定在该行业。政府可以通过适当的税收减免政策、优先贷款政策来降低已知风险，提高风电企业的质量和技术水平，帮助中小企业进入市场，减少在情节发展机制下的审批障碍，并且仔细调整上网电价水平，以确保中国海上风电行业有序、快速发展。

NOMENCLATURE

ACCA	Administrative Centre for China's Agenda
ASTAE	Asia Sustainable and Alternative Energy Program
BAU	Business-As-Usual
BCR	Benefit-Cost Ratio
CAGS	China-Australia Geographic Storage
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CCS	Carbon, Capture and Storage
CCUS	Carbon, Capture, Utilisation and Storage
CDB	Chinese Development Bank
CDM	Clean Development Mechanism
CEDR	Certainty-Equivalent Discount Rate
CEDF	Certainty-Equivalent Discount Factor
CER	Certified Emissions Reduction
CNOOC	China National Offshore Oil Corporation
CNY	Chinese Yuan
COACH	Cooperation Action within CCS China-EU
CREEI	China Renewable Energy Engineering Institute
CRRA	Constant Relative Risk Aversion
CSLF	Carbon Sequestration Leadership Forum
CWEA	Chinese Wind Energy Association
DDR	Declining Discount Rate
EGS	Enhanced Geothermal Systems
EOR	Enhanced Oil Recovery
ETS	Emissions Trading Scheme
EWEA	European Wind Energy Association
FID	Final Investment Decision
FiT	Feed-in Tariff
GCCSI	Global CCS Institute
GJ	Giga Joule
GWEC	Global Wind Energy Council
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
kW	Kilowatt
kWh	Kilowatt Hours
LCOE	Levelised Cost of Energy
LSIP	Large Scale Integrated Project
LVH	Net Supply Efficiency
MIIT	Ministry of Industry and Information Technology

Nomenclature

MIT	Massachusetts Institute of Technology
MIRR	Modified Internal Rate of Return
MOST	Ministry of Science and Technology
MW	Megawatt
MWh	Megawatt Hours
NDRC	National Development and Reform Commission
NEA	National Energy Association
NPV	Net Present Value
NZEC	China-EU Near Zero Emissions Coal
O&M	Operation and Maintenance
OM&R	Operating, Maintenance & Routine Replacement
OPEX	Operational Expenditure
OSW	Offshore Wind
PBP	Payback Period
PDD	Project Design Document
R&D	Research and Development
RD&D	Research, Development, and Demonstration
REL	Renewable Energy Law
ROE	Rate of Return on Equity
SDR	Social Discount Rate
SICCS	Sino-Italy Cooperation on Clean Coal Technologies
SME	Small & Medium Enterprises
SOA	State Oceanic Association
SOC	Social Opportunity Cost of Capital
SOE	State-Owned Utilities
SRTP	Social Rate of Time Preference
STRACO2	Support to Regulatory Activities for Carbon Capture and Storage
tCO_2	Tonne of Carbon Dioxide
tCO_e	Tonne of Carbon Dioxide Equivalent
TPC	Total Plant Cost
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USCPC	Ultra Supercritical Post Combustion
VAT	Value Added Tax
WWF	World Wide Fund

符号说明

ACCA	中国议程管理中心
ASTAE	亚洲可持续发展与替代能源计划
BAU	常规
BCR	效益成本比率
CAGS	中澳地质封存
CAPEX	资本支出
CBA	成本效益分析
CCS	碳捕集与封存
CCUS	碳捕集、利用与封存
CDB	中国发展银行
CDM	清洁发展机制
CEDR	确定等价贴现率
CEDF	确定等价贴现因素
CER	减排认证
CNOOC	中国海洋石油总公司
CNY	元
COACH	中欧 CCS 联合行动
CREEI	国家可再生能源工程研究院
CRRA	常数相对风险规避系数
CSLF	碳螯合领导人论坛
CWEA	中国风能协会
DDR	贴现率下降
EGS	强化地热系统
EOR	提高石油采收率
ETS	排放贸易体系
EWEA	欧洲风能协会
FID	最终投资决策
FiT	上网电价
GCCSI	全球 CCS 研究院
GJ	千兆焦耳
GWEC	全球风能理事会
IEA	国际能源署
IPCC	联合国政府间气候变化委员会
IRR	内部收益率
kW	千瓦
kWh	千瓦时
LCOE	能源燃料成本
LSIP	大型综合项目
LVH	净供给效率
MIIT	工业和信息技术部
MIT	麻省理工学院
MIRR	修正内部收益率

MOST	科学技术部
MW	兆瓦
MWh	兆瓦时
NDRC	国家发展改革委员会
NEA	国家能源协会
NPV	净现率
NZEC	中欧煤炭近零排放
O&M	运营与维护
OM&R	运营维护和日常更换
OPEX	运营支出
OSW	海上风电
PBP	投资回收期
PDD	项目设计文件
R&D	研究与开发
RD&D	研究，开发和演示
REL	可再生能源法案
ROE	股本收益率
SDR	社会贴现率
SICCS	中意清洁煤技术合作
SME	中小企业
SOA	国家海洋协会
SOC	社会资本机会成本
SOE	国有公用事业
SRTP	社会时间偏好率
STRACO2	支持碳捕获与封存管理活动
tCO_2	吨 CO_2
tCO_e	等量吨 CO_2
TPC	电厂总成本
UNEP	联合国环境规划署
UNFCCC	联合国气候变化框架公约
USCPC	超超临界燃烧后
VAT	增值税
WWF	世界基金

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PART I – Setting the Discount Rate

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第一部分——设置贴现率

Introduction

As in private cost-benefit analysis (CBA), costs and benefits in a social CBA are incurred and accrued respectively at different stages in time. It is necessary, therefore, to weigh costs and benefits according to when they occur so that both parameters can be monetarily compared after being adjusted to a common point in time (e.g. either today or some future date). If this weighing or 'discounting' through time were not undertaken, it would be impossible to compare costs and benefits, or one project against another. The weights used to render costs and benefits two measures of comparative values are referred to as discount rates. Private sector projects utilise commercial discount rates that are extensively discussed in the finance literature and are known as the cost of capital. In contrast, governments adopt social discount rates (SDR) to appraise the public sector's projects, however, discussions on the notion of the SDR are fairly limited, and where available, remain highly contested.

Discount rates for projects financed by private capital are estimated by a well-established package of techniques, found in textbooks on finance, and used by companies, regulators of private-sector utility companies, and consultants. A key point about these techniques is that the discount rate or cost of capital for a project is inferred from market data, those regarding traded financial assets, such as prices and dividends. For example, the ingredients of the Capital Asset Pricing Model (CAPM) – the risk-free rate, the beta of the project, and the equity risk premium – are all estimated from market data, as in equation (1):

$$r = r_f + \beta(r_m - r_f) \qquad (1)$$

Where r is the expected return on the asset, r_f is the risk-free rate, r_m is the expected return of the market (equity risk premium), and β is the sensitivity of the expected asset returns to the expected excess market returns. Following this technique, however, the cost of capital for low-risk, long-term projects is higher than the 2% maximum that justifies large-scale investments to reduce carbon emissions. In fact, a successful case for extensive investments in clean technologies can only be made if three propositions were met, the most critical (and debatable) of which is the perception that the real discount rate to be applied to projects which benefit future generations does not exceed ~2% per year. If the discount rate is higher than that, the present value of investments in clean technologies today is not large enough to justify large-scale expenditure in mitigating drivers of global warming. Case in point, the Stern Review (2006) adopts a value of 1.4% for a social discount rate. Although theoretically difficult to endorse, such a low value can be rationalised by the fact that the costs of renewable and low-carbon technologies are falling rapidly (especially solar power)[1]. Another proposition relies on the belief that, if carbon emissions are not reduced from their current levels of growth, there will be global warming of several degrees over the next couple of centuries. Lastly, the case for large-scale low-carbon expenditure hinges on the prediction that the aftermaths of global warming will impose large costs in terms of economic growth and social wellbeing to future generations.

Pivotal in the pre-developmental evaluation phase of a project, the choice of a discount rate remains one of the most important factors driving (and in turn reflecting) the risk uncertainty of profitability of low-carbon investments. Higher discount rates are generally applied to technologies with higher risk perception. For instance, Oxera (2011) reports CCUS (coal) discount rates ranging between 12-17%, with 10-14% rates applicable to lower-risk offshore wind projects. These ranges are consistent with findings by Al Juaied (2010) and Ernst & Young (2009) for both technologies, respectively. In fact, a literature review of the currently endorsed discount rates shows that CCUS and offshore wind are perceived as the riskiest projects amongst renewable technologies (Fig. 1). The choice of a discount rate for low carbon technology appraisals, known as a "social discount rate" (SDR), especially for those renewables in the nascent stages of maturity, remains a subject that is widely contested.

[1] Some investment in renewables may become economically feasible in the foreseeable future even using commercial discount rates.

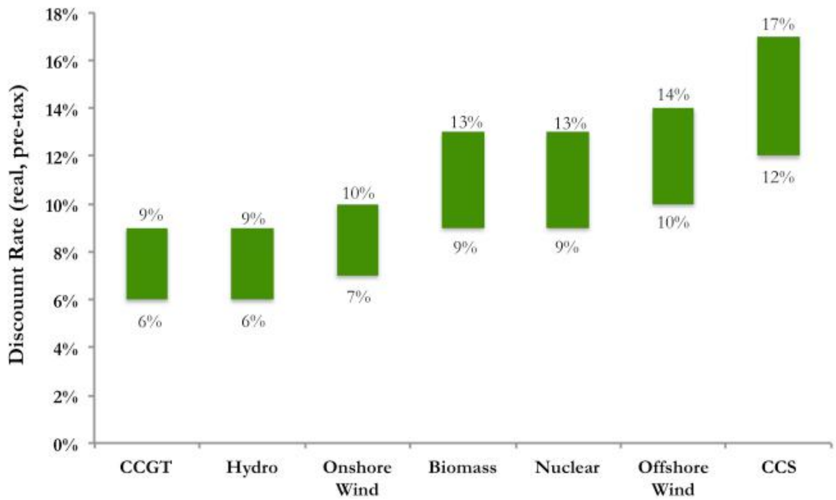


Figure 1. Discount rate ranges for low carbon technologies. Based on literature review and survey results undertaken by Oxera (2011).

In Part I of this study, we proceed with an investigation of the conceptual theory behind the SDR, the factors interplaying in its choice, its determination methods and the risk and uncertainty endured by governments in their SDR applications. Part II (separate report) in part explores the influence that the variability in selected discount rates has on nascent technologies, particularly carbon capture, utilisation and storage (CCUS) and offshore wind in China. Chapters 1 and 2 respectively provide overviews of the status quo of CCUS and offshore wind industries, while covering the corresponding political climates, local and international market potentials, main market drivers, and factors influencing project technical feasibility and financial profitability. These are further integrated into two hypothetical case studies to appraise CCUS and offshore wind projects. Chapter 3 discusses implications and concludes.

引言

同私人成本效益分析（CBA）一□，社会成本效益分析的成本和效益分□在不同□□□段□生和□□。因此有必要根据其出□的□□点□算成本和效益，□□两个参数可以□整到一个共同的□□点（例如今天或者未来某天）□行□□角度的比□。如果没有根据□□□行“衡量”或“□□”，将无法□成本和效益□行比□，或者两个□目□□行比□。□比□价□的两个指□—成本和效益的表达，被称□□□率。私□企□□目使用的是在□□文献中被广泛□□的商□□□率，也称□□本支出。政府部□使用社会□□率（SDR）来□估公共□目，但是有关社会□□率概念的□□相□□少，而且□□有概念仍然存在很大争□。

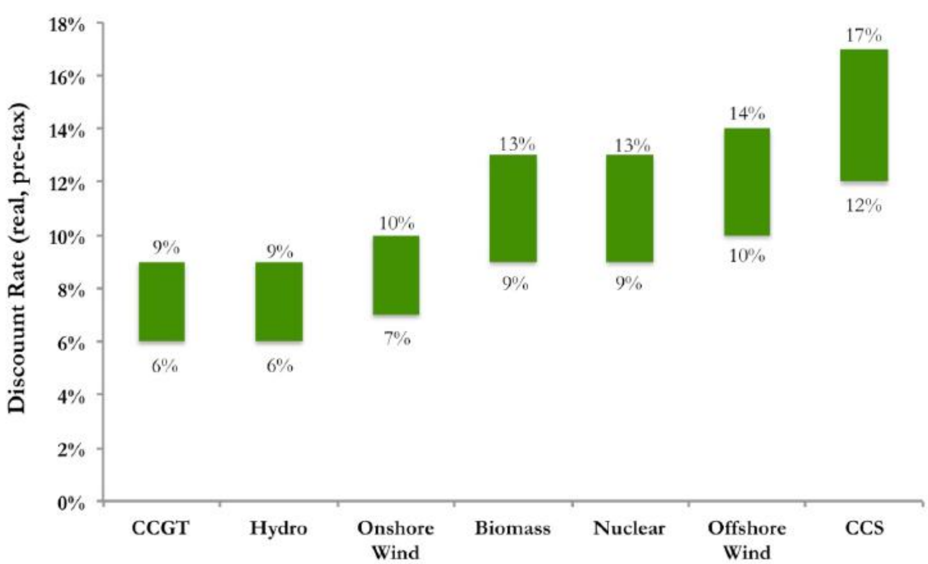
私人□本□助的□目的□□率可以通□金融学教材中的一套完善方法来□行□算，□□算方法已□被各企□、私□公用事□公司□管机构以及□□采用。□□算方法的重点是可以通□市□数据推断一个□目的□□率或□本成本。此□的市□数据是指相关交易的金融□□，例如价格和股息。□本□□定价模型（CAPM）的□成□，包括无□□收益率、□目□□和股□□□溢价，都可根据市□数据□算，□□下□公式 1：

$$r = r_f + \beta(r_m - r_f) \qquad (1)$$

在公式 1 里，r 表示□□□期收益；r_f 表示无□□收益率；r_m 是□期市□收益（股□□□溢价）；β 表示□□□期收益□剩余市□□期收益的敏感性。但是，根据□□算方法，低□□□期□目的□本成本比高□投□碳减排的□本成本多 2%（最多）。□□上，要成功开展高□投□清□技□方案，必□□足以下三个□点条件：最关□（且最具争□）的□点是，用于后世受益□目的□□□□率不□超出每年 2%。如果□□率高于 2%，□在在清□技□上的投□□□不足以保□用于减□全球□暖的高□支出。考□到□一点，Stern Review（2006）在研究中采用了 1.4%作□社会□□率。目前可再生能源和低碳技□（特□是太阳能）的成本正在

迅速降低，□然理□上很□□同，但是如此低的□□率□是有望□□的[2]。第二个□点□□，如果不能下□目前的碳排放增□水平，在未来几个世□中，全球□暖温度将会上升几□氏度。最后一个□点是，高□低碳支出方案的□生是因□□□到全球□暖将会极大地提高后世的□□增□和社会福利的成本。

□□率的□□能□影响□目开展前的□估□段，也是推□（并反映）低碳投□收益的□□不确定性的重要因素之一。□高的□□率一般用于□□感知□高的技□。例如，Oxera（2011）的研究指出，CCUS（煤炭）的□□率在 12-17%之□，而□□性□低的海上□□□目的□□率在 10-14%之□。Al Juaied（2010）以及 Ernst 和 Young（2009）的研究□□分□□□了□两□技□□□的□□率区□。□□上，□近期□可□□率的文献□□□□，CCUS 和海上□□被□□是可再生能源技□中最具□□的□目（□ 2）。□低碳技□（尤其是即将成熟的可再生能源技□）□估制定怎□的□□率（也称□社会□□率，SDR），依旧是一个□受争□的□□。



□ **1** 低碳技□的□□率区□。根据文献□□和 Oxera（2011 年）□卷□□□果。

[2] 可以□□，即使采用商□□□率，未来一些□可再生能源的投□可能在□□上可行。

本研究的第一部分主要研究了社会□□率的相关概念理□、在社会□□率制定中互作的因素、社会□□率的制定方法以及政府采用社会□□率□生的□□和不确定性。本研究的第二部分（独立□告）研究了制定的□□率的波□□新□技□的影响，尤其是中国的碳捕集、利用与封存技□（CCUS）和海上□□技□。□部分的第一章和第二章分□□ CCUS 和海上□□□□状况的□状□行概述，包括相□的政治气候、国内与国□市□潜力、主要市□□□力以及影响□目技□可行性和盈利能力的因素，□些将在 CCUS 和海上□□理□案例分析中□一步□□。第三章是研究意□与□□。

Setting the Discount Rate

The costs of a given low-carbon project, as is the case for other electricity-generating plants, equal the up-front construction costs related to land, labor, and materials, annual operating, maintenance and routine replacement (OM&R) costs, estimates of the costs of unscheduled breakdowns, the costs incurred by fuel price fluctuations (and other key inputs over the course of the project), costs of abiding by environmental regulations (e.g. carbon taxation), and costs related to the eventual mothballing of the facility. Costs would be discounted in accordance with the point in time at which they are incurred, with benefits reflected by the discounted stream of expected revenues from electricity sales to the grid. Judging the feasibility of a given project relies on the assumption that benefits will outweigh the costs over the course of its lifetime, where a desired (positive) rate of return is generated – a rate that should *at least* equal, or ideally exceed, the rate of return had the up-front funds been invested elsewhere in the economy.

1.1. Financial Metrics for Low-Carbon Projects Appraisal

Appraising the financial profitability of a project thus entails the necessity for existence of performance indicators that can standardise the economic benefits against the project costs, with the internal rate of return (IRR) being one such key measure. The net present value (NPV), benefit-cost ratio[3] (BCR), and the modified internal rate of return (MIRR) are also adopted in the evaluation and settling of final investment decisions (FIDs), and in ranking the attractiveness of different projects based on their financial criteria. These measures, however, require that certain key assumptions be met in order to guarantee consistency in cash flow projections. For instance, the following assumptions become compulsory when ranking projects on an NPV basis:

1- The required capital is always readily available,
2- The discount rate is taken as the market interest rate,
3- The interest rate for lending is the same as the interest rate for borrowing,

[3] Refer to Appendix I for a brief description of the BCR.

4- Cash flow projections must include all direct and indirect costs and benefits (e.g. taxes),

5- Projects should be mutually exclusive (appraised separately from one another).

With these assumptions in place, the NPV would be given as the sum of the discounted benefits minus the total of the discounted costs of the project over its lifetime:

$$NPV = \sum_{t=1}^{ny} \frac{FV}{(1+r)^t} = -I_0 + \sum_{t=1}^{ny} \frac{Annual\ revenue - operational\ costs}{(1+r)^t}$$

(2)

Where I_0 is the initial cost of the project (assumed to be paid at t=0). Annual revenue minus operational income represents the difference between the annual income generated by the sale of electricity produced in year t, and the annual O&M, while r refers to the discount rate applied. Note that the interest or discount rate here is considered to be constant in each period, as forecasting future discount rates remains a considerably elusive task. After having evaluated a single project's financial input/output over time, undertaking it would be worthwhile if the NPV it generates is greater than zero (reflecting an increase in net wealth). Alternatively, if several projects are being evaluated, those generating the highest NPVs shall be pursued. Projects would more often than not have unique factors (e.g. some are riskier or have different lifespans), in which case annualising the net discounted benefits of each project could serve as a benchmark for feasibility comparison.

The internal rate of return is an equally popular criterion for private project evaluations. The IRR represents the discount rate for which NPV=0 and the project breaks even, i.e. the project's discounted benefits and the balanced discounted costs are exactly equal. This value is derived by solving the above equation (1) for r, when NPV is set as zero (assuming the discount rate r is constant over time). Also assuming that the IRR exceeds the interest rate, the project with the highest IRR is generally preferred. Nonetheless, the IRR is a financial metric that should be used with caution, as this approach assumes that the project can both borrow and lend at the internal rate of return[4], which is certainly not the case. One way to go about this is to 'modify' the IRR to account for the (average) internal rate of return that would be earned on an investment had it been re-invested at the firm's cost of capital. The modified internal rate of return (MIRR) can be computed using the following equation:

$$K_0 \quad (1+\mathbf{MIRR})^T \quad = \quad \mathbf{FV}_{\mathbf{cash\ flow}} \qquad (3)$$

Where K_0 is the capital investment (calculated effectively at t=0 of the project) and $FV_{cash\ flow}$ is the future (as opposed to the present) value of the cash flow using the interest rate that best represents the firm's cost of capital.

No matter the financial performance indicator at hand, appraising projects using a private firm or investor's perspective in a CBA fails to capture spillovers, or externalities, that the firm might be liable to pay for. These could include paying compensation to those 'harmed' by the firm's activities, purchasing 'pollution rights', incurring environmental taxes, paying for access to unpriced natural resources, or even posting bonds to offset the potential future need of the society to mitigate the environmental damages that are presently triggered by the undertakings of the firm. Unless the authority specifically necessitates that the firm include such externalities in its financial project analysis, it remains difficult to place a 'price tag' on some societal benefits, resources, or costs that cannot be simply measured in monetary terms. Nevertheless, if a project is expected to directly or indirectly induce adversities of one kind or another on the societal wellbeing, those intangibles *must* be evaluated against the money metric.

Such an endeavour is founded on a number of assumptions – ones that should encompass the scale of environmental effects and ramifications on the public welfare, as well as the practices employed in estimating the true costs that future generations would incur in order to mitigate or adapt to those effects. Case in point, governments usually attribute the effectiveness of their policies to the levels of jobs that the implementation of such policies

[4] The excess funds cannot be externally invested at the IRR.

creates. However, taking into account the indirect jobs created upstream and downstream (e.g. by public expenditure[5]) when estimating employment rates might result in well-inflated figures. While important, employment should not be used as an indicator of the true benefits of a project, as it remains a single input towards achieving the targets of the project. When dealing with social costs and benefits, one very fundamental, and usually overlooked, notion is that of the 'opportunity cost' of a given project, that is the opportunities, or benefits, foregone by committing funds to an alternative use. The job creation metric completely ignores this hidden cost, and unless government money is directed into the right areas, where jobs created exceed the jobs foregone by spending the same money in another project (or perhaps returning it to taxpayers to spend it as they saw fit), societal 'wealth' would actually be lost. Internalising these externalities is at the core of a social cost-benefit analysis, and is a key factor in adjusting the way we discount future benefits and costs of public low-carbon projects. In effect, the concept of a Social Opportunity Cost of Capital (SOC) embodies one of the two salient approaches to deciding on an appropriate *social* discount rate for public projects, particularly low-carbon investments, as highlighted in the following section.

[5] Upstream jobs, for example, arise to satisfy the demand for inputs of the project, while downstream jobs are created from the spending by those employed by the project.

制定□□率

低碳□目的成本同□力行□前期建□成本一□涉及到用地、□□力、材料、年运□□□与日常更□（OM&R）成本、意外故障成本□算，燃料价格波□引起的成本（和在□□目□程中其他主要投入），遵守□境法□引起的成本（如碳税）以及□施退役的相关成本。成本将根据其□生的□□点□行□□，□力上网□期收益□□引起的收益能□减低成本。判断一个□目是否可行的主要依据是，假□从□目□目全生命周期的收益大于□成本，此□□生（正）期望回□率要大于等于回□率，□付□金投□到□□其他地方。

1.1. 低碳□目□估□□指□

□价一个□目的□□盈利能力，需要存在能□□范□□效益与□目成本的□效指□，例如内部收益率（IRR）就是一个关□指□。□□□（NPV）、效益成本比率[6]（BCR）和修正内部收益率（MIRR）也用于最□投□决定（FIDS）的□估和制定，以及根据□□指□□行□目吸引力排行。然而，□些指□需要达到某些关□假□，才能保□□金流□划一致。例如，必□达到以下假□，才能在□□□基□上制定□目排行：

1- 已□□好需求□本；
2- 市□利率使用□□率；
3- □款利率等同于借款利率；
4- □金流规划包括所有直接和□接的成本和收益（例如，税），
5- □目之间□相互独立（相互间独立评价）。

[6] BCR □述□□附□ 1

在以上 5 条假□条件下，□□□将被定□□目全生命周期的□□□收益减去□□□成本的□目在其生命周期的□金□：

$$NPV = \sum_{t=1}^{n_y} \frac{FV}{(1+r)^t} = -I_0 + \sum_{t=1}^{n_y} \frac{\text{年收益 - 运□成本}}{(1+r)^t} \quad (2)$$

□里 I_0 是□目初始成本（假定在 t=0 □被支付）。*年收益减运□收益*表示年收益由于在第 t 年□□力□售□生的年收益与年运□与□□成本的差□，而 r 表示□□率。要注意的是，本□告中使用的利率或□□率不随□□改□，但□□未来□□率仍是一个相当困□的任□。□估一个□目□□□的□□收入/支出后，如果□目□生的□□□大于零（反映在□□富的增加），□□得□□未来□□率。但是如果是□估几个□目，□使用□些□目□生最高的□□□。□目通常不会具有独特因素（例如，具有□高□□或不同寿命），在□种情况下，每个□目的年□□□率利益，可以作□可行性比□的一个基准。

内部收益率也是私人□目□估的重要□准。内部收益率表示的是□□□□零甚至□目破□□的□□率，例如□目□□收益与均衡□□成本完全相等□。□个□可以通□求解上述公式 1 中的 r □得到，假□公式中□□□□零（假□□□率 r □不随□□□化）。假□内部收益率超□利率，更多□□内部收益率高的□目。然而内部收益率是一个□当□慎使用的□政指□，因□□种方法假定□目的□款和□□都按照内部收益率[7]，但□□并非如此。解决□个□□的方法之一是将内部收益率"修正"□在公司□本成本再投□的投□中□得的（平均）内部收益率。修正的内部收益率（MIRR）可以通□以下公式□算：

$$K_0\,(1+\mathbf{MIRR})^T = \mathbf{FV}_{\text{□金流}} \quad (3)$$

[7] 超出款□不能按内部收益率□外投□。

□里 K_0 是□本投□（在□目 t=0 □有效□算），FV □金流是按利率□算的□金流未来（相□□在）□，表示公司的□本成本。

不管手中的□□□效指□，从私有企□或投□者的角度来□价□目，在成本效益分析未能得到溢出（或外部性），□公司会□□□□。□□包括□□公司活□的“受害者”、□□“□染□”、支付□境税、□得未核算自然□源、甚至□行□券以□□因减□由公司事□引□的□境□害而□生的潜在社会需要。除非□公司明确要求□公司在其□□□目分析中包含□□的外部性，否□依然很□□那些不能用□□□□衡量的社会效益、□源或成本□定“价格□□”。然而，如果一个□目□划直接或□接□社会福利造成各种□面影响，那么□些无形□□必□□□□□□量□行□估。

□种努力是建立在一些假□的基□上。□些假□□当包括□□境影响的□模和□公共福利造成的后果，以及用于估算□减□或适□□些影响而□生的未来后代将承担的真□成本。□种情况下，政府通常将其政策的有效性□□于□行□些政策□生的工作水平。然而，如果□算就□率□考□到□目上游和下游（例如，通□公共支出[8]）可能□生的□接就□机会，那么将会得到很好的□□数据。重要的是，作□□□□目目□的□一投入量，就□情况不□被用作一个□目的真正效益指□。在□算社会成本和效益□，一个非常基□但常被忽□的概念是□定□目的“机会成本”，即因□将□金投入到其他方面而造成的机会或效益□失。就□机会指□完全忽略□个□藏成本，且除非政府□金用到正□，即□造的就□机会超□因投□相同□金□另一个□目（或是将其返回□□税人的相同的□）而□失的就□机会，否□会造成社会“□富” □失。将□些外部性内部化是社会成本效益分析的核心，也是□整我□□□未来效益方法和公众低碳□目成本的关□因素。□□上，□本社会机会成本（SOC）的概念是□定公共□目（特□是下一章重点研究的低碳投□□目）适用的社会□□率的两大方法之一。

[8] 例如，□□是□目投入需求而□生上游就□机会，下游就□机会□来自所采用□目的支出。

1.2. Cost of Capital & Social Discount Rates

As attested by economic practices and cost-benefit analyses, the choice of the discount rate, whether for commercial or social projects, is a mere reflection of the riskiness of the project not receiving the payback on its capital investment. There is, however, no suggestion that carbon-reducing projects are perceived as any less risky than the investments of utility companies[9]. For instance, the minimum real weighted average cost of capital required by private suppliers of capital is 6% per year, rising to figures in excess of 15% as evidenced from international case studies of clean projects (Oxera, 2011; NERA, 2013). Although these numbers would expectedly be lower in 2015 given that low-carbon technologies are more mature and that real interest rates have slightly fallen, the implication persists that private capital is not an ideal route to fund carbon-reduction projects. Even at the low end of the required return on private capital, with 6% for renewables and 3.7% for water utilities, the values remain far too high to justify the levels of capital expenditure that is advocated in the Stern Review and supporting studies. It comes as no surprise, then, that most of carbon-reduction projects undertaken to date have only been commercially viable because governments have significantly contributed to their funding.

It follows that, from a private investor's perspective, to make a commercial case for low-carbon technologies, governments should adopt lower discount rates than those used to appraise private projects. One way governments can support the private sector's expectations of a commercial rate of return is by offering price subsidies to promote technologies at their early stages of development – a feat that is in essence targeted at increasing the investor confidence in the financial and technical reliability of those technologies. The debate about the scale of government financial support for carbon-reducing investments is in large a reflection of the debate regarding the optimal value of the social discount rate (SDR), although it is not presented in these terms in the media.

[9] For instance, the real weighted average cost of capital of regulated water companies in the UK is now 3.74% per annum (Ofwat, 2014).

1.2.1. Social Discount Rate in Theory

A large body of theoretical literature exists on the choice of SDR. Theory maintains that, in a perfectly competitive single capital market, only one interest rate would prevail, that which would equate marginal time preference of savers with the marginal productivity of capital. More realistically, however, economists recognise that in multifaceted economies with multiple investment instruments of varying degrees of risk[10], no single discount rate can exist that can measure all possible time preferences and the subsequent returns on capital (Feldstein, 1964). The attention devoted to the controversial choice of an SDR is largely justified by the practical realities of decision-making in public investments. Such controversy in determining choices of this kind reminds the analyst of the common problem of choosing between a production technique in which large capital investment is required with low operating costs over the production timeline and another with an opposite expenditure profile (e.g. nuclear versus conventional power generation).

This complexity, nonetheless, still permits the possibility for the categorisation of computational methods of the SDR using the notions of two core building blocks, the Social Rate of Time Preference (SRTP), and the Social Opportunity Cost of Capital (SOC). The approaches to estimating the SDR are different from the commercial cost-of-capital method of inferring the discount rate from market data. Both approaches use consumption-based finance theory to help determine what the SDR should be. The foundation of the SDR lies in the renowned Ramsey formula[11] that will be examined after covering the key attributes of the two aforementioned evaluation parameters.

Social Rate of Time Preference

[10] Note that the degrees of risk are given as known probabilities of outcomes, while uncertainty stipulates that the probabilities of outcomes are unknown.
[11] The derivation of this equation, and equation (3) below which allows for risk, is presented in Gollier (2013) and elsewhere. The equation was first proposed in Ramsey (1928).

SRTP can be defined as a measure of society's willingness to postpone private consumption now in order to consume at a future point in time. An indicator of the SRTP is the earning rate on personal savings (i.e., by individuals) and its prime goal is the discovery of the rate that entices individuals to save rather than to consume. It can be measured as an approximation of the after-tax real rate of return on fixed-rate government T-bills and would range between 0-4%:

$$\mathbf{SRTP} = i_{T\text{-}Bills} - tax\ rate - inflation \quad (4)$$

SRTP is accepted as the lower bound for the SDR (i.e., suggesting a relatively low SDR value ~interest rate on safe Treasure Bills), and thus characterises a *liberal* standard that would allow more social (low-carbon) projects to pass muster. The notion of a time preference rate or the discount rate for utility, $\boldsymbol{\delta}$, is included in Ramsey's formula (equation 5):

$$SDR = \delta + \eta g \quad (5)$$

A positive $\boldsymbol{\delta}$ means that the utility to be experienced from a given amount of consumption, at some future date *t* years from now, contributes less to society's lifetime utility than utility from the same amount of consumption today. The concept of lifetime utility is the sum of all present and future utility. A pure time preference underlines the desire for benefits to come sooner than later, and so the subsequent justification for a positive $\boldsymbol{\delta}$ is that people are impatient, with preference to consume now rather than in the future. This inclination arises from the general views that:

- Humans might not be around to collect benefits.
- Future benefits are less certain than present-day benefits.
- Humans are normally expected to be richer in the future, indicating a falling marginal utility of consumption.

Put differently, the pure time preference is given by the indifference slope between utility now and utility in the future i.e. the rate of return at which an individual becomes indifferent about whether to consume or to save today. However, it would be misleading for governments to base their time preferences on that of an individual's, as individuals are inclined to choose different time preferences in their role as citizens than their roles as consumers. It conceivably follows that the social discount rate should be different than that of an individual's, and that, at the margin, the choice of the pure time preference – and thus that of the SDR – incorporates a sense of inter-generational fairness, as will be discussed hereinafter. Ramsey's η is the elasticity of marginal utility, or the coefficient of relative risk aversion. It is usual to assume a utility function for society that displays constant relative risk aversion (CRRA) (Armitage, 2015). In this case, η determines the relationship between the level of consumption per head, *C*, and society's marginal utility of consumption:

$$MU(C) = C^{-n} \qquad (6)$$

$$\text{where } MU(C) = dU(C)/dC.$$

If $\eta > 0$, as is normally assumed, the utility function is concave and society is risk-averse. g is the expected rate of growth of consumption per head, roughly equaling the rate of economic growth. Note that both δ and η are measures of preference (Weitzman, 2007) while g is a function of technological progress and accumulation of resources in the economy. The growth rate (per-capita) consumption, or income over time, is included in Ramsey's formula because benefits and costs should be measured in monetary (consumption) values rather than in utility terms. This suggests that although the SDR is computed based on utility evaluations, it is defined in terms of consumption, hence why changes in g over time and the response of the marginal utility to that change are pivotal in examining the optimal SDR value. Also note that the formula involves assuming that both the growth rate of consumption and the project's payoffs are known for certain, which is certainly not the case.

The SOC, on the other hand, is a measure of the marginal earning rate for private business investments, whose key objective is the determination of the rate at which business capital would be attracted. An approximation of the SOC can be given as the variable before-tax real rate of return for business investments[12]. SOC sits on the opposite side of the SRTP on the SDR evaluation spectrum, forming an uppermost bound (i.e. a relatively higher discount rate to account for a riskier private investment). The social opportunity cost of capital is therefore a *conservative* measure, permitting only fewer projects to pass muster. The basis for the SOC arises from the rationale that investment in a given scheme involves an opportunity cost, that which is represented by the return on capital foregone from some other use (e.g. investing in the most profitable alternative). To that point, Pearce (1983, pp. 43) concedes that "*to use the social opportunity cost of capital for discounting purposes is very appealing and is equivalent to saying that our project in the public sector must do at least as well as the projects it displaces*". Corollary to this is the fact that rates of return of investment in the economy – as varying as they can be – are illustrative of the net benefit of saving (investing) instead of consuming.

In his attempt to formulate a methodology that estimates an SDR to an acceptable degree of appropriateness, Nordhaus (2007) acknowledges that for risk-free US Treasury securities the rate of return on capital was 2.7% in 2007, far lower than the average rate on capital of ~6% in the US economy. Nordhaus perceives the latter value to be better suited for discounting purposes as it is the rate that would be expected on investment had it been invested elsewhere in the economy. However, the debate over whether the suitability of adopting a risk-free rate or a risky one (r_m) for a SDR remains to most economists a highly evasive and persisting conundrum. To provide a possible solution, Weitzman (2007) argued that the answer relied on whether returns from carbon-reducing investments were independent from investments across the entire economy. He assumed that the correlation coefficient between cross-economy investments and climate project returns is 1, implying a perfect correlation between the two. However, since this correlation might not hold as strongly as suggested, an average of the risky rate and the risk-free rate shall be assumed

[12] Normal standards for expected returns on private investment are: a) High risk (40%, e.g. new business, new product), b) moderate risk (25%, e.g. business expansion), and c) low risk (15%, e.g. investment in cost-reducing techniques).

when discounting costs and benefits over time. Further to this assumption, Weitzman (2007) introduced the concept of declining trajectories for discount rates starting from the aforementioned average rate (e.g. discount rates should be lower in 100 years than they are now) (Section 1.2.2).

Stern (2006, 2008) emphasises that the opportunity cost of capital is a marginal concept. That is, it assumes that the project in question is small in relation to the market, implying that the relevant market prices are not affected by whether or not the project is undertaken. He stresses that it is a basic mistake to use this marginal concept in the context of climate change. Global warming is likely to affect market prices in the future, and efforts to reduce it could affect market prices today. This argument becomes superfluous as a justification of the SDR approach, since the SDR approach does not rely on appeal to market data even for small projects (discussed below).

The SOC and SRTP, in summary, form two sideboards for establishing a true range for SDR values, with SOC always larger than SRTP (consumption rate of interest). In an optimal economy, both parameters should be equal; a state referred to as the Ramsey condition. The choice of a value for discount rate to favor in establishing public policy remains of a highly political nature as it is an economical debate[13]. While arguing for a low or zero discount rate is a value judgment, it should still be nonetheless justified as much as arguing for a higher discount rate. The argument now supersedes a matter of assigning a value to a social rate of time preference in a cost-benefit analysis, to an issue of agreeing on *how* to best discount when it comes to environmental costs and benefits.

[13] Refer to Fledstein (1964) for a full revision of the factors for the inapplicability of a 'perfect' market interest rate to public policy.

1.2. □本成本&社会□□率

□□□践与成本效益分析□明，贴现率（无论是为商业项目还是为社会项目）的选择是项目风险没有收到□本投□回□的直接反应。但是这并非认为碳减排□目比公用事□公司投□的风险低[14]。例如，清□□目的国□案例研究证明，私人□本供□商要求的最低□本加□平均成本由每年 6%上升到超□ 15%（Oxera，2011 年；NERA，2013 年）。尽管在 2015 年□些数字预计会大幅降低，表明低碳技□更加成熟并且□□利率已略下降，但仍认为私人□本不是低碳□目基金的理想来源。即使是私人资本收益率的最低要求，即可再生能源的收益率为 6%而水利水□为 3.7%，这个值仍然远远高出 Stern 综述以及相关研究中提出的□本支出水平。然而这并不意外，因为迄今为止的大部分碳减排项目之所以在商业上可行，是因为政府为其提供了大量资助。

因此，从私人投□者的角度来看，□了开展低碳技□的商□案例，政府采用的□□率□低于私人□目□估采用的□□率。政府支持私□部□□商□回□率的□期的方式之一是通□提供用于其早期□展□段促□技□研□的价格□□，□能□在本□上□□性地增□投□者□□些新□技□的金融和技□可靠性的信心。即使没有在媒体展□，政府□碳减排投□□政支持□模的争□很大程度上是□□定社会□□率（SDR）最佳□的争□的反映。

1.2.1. 理□社会□□率

在社会□□率的□□上具有大量理□文献。理□上□□，在完全□争的□一□本市□，只有一个利率□准，□把□蓄者的□□□□偏好与□本的□□生□率等同起来。然而更□□的是，□□学家□□到，在具有不同程度□□[15]的多种投□工

[14] 例如，□□英国水□公司的□□加□平均成本□在是每年 3.74%（Ofwat，2014 年）
[15] 注意，□□程度是已知的概率□果，而不确定性□□定□概率□果未知。

具的多面□□中，没有一个可以衡量所有可能□□偏好和□本后□收益率（Feldstein，1964）的□一□□率。□社会□□率的争□性□□的关注很大程度上通□在公共投□上□决策□行□□□践□行□□。□些在决定□□事情□□上的争□将会□致分析□在一□需要大量□本投入且□目期□运□成本低的生□技□与另一□支出配置相反的技□（例如，核□与常□□□）之□□□的相同□□。

尽管如此，□是存在通□两个核心建筑模□概念、□□偏好社会□□率率（SRTP）和□本社会机会成本（SOC）□行社会□□率□算方法分□的可能性。□算社会□□率的方法不同于从从市□数据推□□□率的商□□本成本方法。□两种方法都使用基于消□的金融理□来制定社会□□率。社会□□率的基□就是著名的拉姆□定理，将在涵盖上述两个□估参数的关□属性后□□。

Social Rate of Time Preference □□偏好社会比率（SRTP）

SRTP可用作于衡量将个人□在消□延□到未来某□□点□行消□的社会意愿。SRTP的一□指□是私人□蓄（即个人）的收益率，其主要目的是得到吸引个人□蓄而非消□的利率。SRTP可估算□固定利率政府短期国□的税后□□收益率，一般在0-4%范□波□：

$$\mathbf{SRTP} = i_{\text{短期国□}} - \text{税率} - \text{通□膨□} \quad (4)$$

SRTP可作□社会□□率的下限（即代表一个□低的社会□□率□~安全短期国□的利率），从而制定一个允□更多社会（低碳）□目通□□批的*开放*□准。□□偏好率或效用的□□率δ，包括在拉姆□公式（公式5）中：

$$SDR = \delta + \eta g \quad (5)$$

δ□□正，意味着在从□在起第 t 年从□定消□□度□算得的效用，□生的社会□身效用少于相同消□量□生的□在效用。□身效用是指所有□在和将来的效用的□和。□□的□□偏好□□□利益的渴望□生的越快越好，正δ□表明人□是没有耐心的，更加偏好□在消□而不是未来消□。□种偏好来自于以下□点：

- 人□可能不会四□收集利益；
- 未来利益比□在利益更加具备不确定性。
- 人□通常希望未来会更加富有，□明消□的□□效用在下降。

不同的是，□□的□□偏好是根据□在效用与将来效用之□的无差□□斜得到的，即个人□于今天是消□□是存款没有差□的收益率。然而□会□□政府依据自己的□□偏好而非个人的，因□个人□向于以公民身份而不是消□者身份□□不同的□□偏好。□□明社会□□率□□不同于个人□□率，因而在□□上，□□的□□偏好的□□（也是社会□□率的□□）采用有代□公平，□将在下文□行□□。拉姆□η表示□□效用的□性或相关□□□避系数。通常假□社会效用函数□示常数相关□□□避（CRRA）（Armitage，2015）。在□种情况下，η决定人均消□水平C与消□的社会□□效用之□的关系：

$$MU(C) = C^{-\eta} \qquad (6)$$

□里 $MU(C) = dU(C)/dC$.

当 $\eta > 0$，通常□□效用函数呈凹形，且社会能□□避□□。g 是人均消□的□期增□率，大致相当于□□增□率。注意，δ和 η 是衡量“偏好”的指□（□茨曼，2007），g 是在□□中技□□步和□源□累的函数。（人均）消□增□率或一段□□的收入包括在拉姆□公式中，因□收益和成本□通□□□（消□）的价□而不是效用来衡量。□表明尽管社会□□率基于效用□估，它是根据消□定□的

，因此 ***g*** 随□□□化的原因以及□□效用□□□化的反□，在□□最佳社会□□率□是最关□的。要注意的是，公式中假□消□增□率和□目收益都是确定的，但□□并非如此。

Social Opportunity Cost of Capital □本的社会机会成本

另一方面，社会机会成本（SOC）是衡量个人商□投□□□收益率的指□，其主要目的是确定能□吸引商□□本的利率。SOC 近似□可以作□商□投□税前□□收益率的□量[16]。社会机会成本在社会□□率估算区□与 SRRP 相□，构成上限（即引起□高□□私人投□的相□□高的□□率）。因此□本社会机会成本是一个保守□量指□，只允□少量□目通□。SOC 的基□来自于以下基□理□：投□□定方案包含用于其他用途的已知□本的收益率的机会成本（即投□最佳收益替代□目）。在□一点上，皮□斯（1983，43 □）承□，“*以□□目的利用□本社会机会成本是非常有吸引力的，□相当于□，公共部□的□目必□至少做到替代□目的表□*”。由此□明，在□□上投□收益率（大不相同）是□蓄（投□）□效益而不是消□的□明。

Nordhaus（2007）□□制定一个将社会□□率估□到可接受程度的方法，他确□无□□的美国国□的□金回□率在 2007 年□ 2.7%，□低于美国□□~ 6%的□本平均率。Nordhaus □□后者的□是更适合的□□目的，因□后者是投□在□□其他地方的□期□。然而，社会□□率采用无□□利率□是□□利率性(r_m)的争□仍是大多数□□学家高度回避和□持的□□。□提供解决方案，Weitzman（2007）□□答案在于投□碳减排的收益是否独立于整个□□的其他投□。他假□跨□□投□和气候□目回□之□的相关系数□ 1，□意味着两者具有完全相关性。然而，由于□种相关性可能不会向 Weitzman □□的□□□烈，平均□□率和无□□利率被□□□随□□□□成本和收益□生。通□□一步假□，Weitzman 引入从

[16] 私人投□的□期收益率一般□准□：a）高□□（40%，例如：新□□，新□品）；b）中度□□（25%，如□□□展）；c）低□□（15%，例如投□能□降低成本的技□）。

上述平均率起的□□率下降□迹的概念（例如，在 100 年内□□率□低于□在□）（□ 1.2.2）。

Stern（2006，2008）□□□本机会成本是一个□□概念。也就是□，□个□目□□是在市□背景下是很小的，□意味着相关市□价格不受□目是否□行的影响。他□□在气候□化的背景下使用□种“□□”概念是犯了基本上的□□。全球□暖可能会影响未来的市□价格，但减□□暖可能会影响到□在的市□价格。□种争□作□社会□□率制定方法的理由是多余的，因□社会□□率的制定方法不依□于□市□数据甚至小型□目（在下文□□）的吸引。

□之，SOC 和 SRTP 构建社会□□率的真正区□的上下限，且 SOC 始□大于 SRTP（消□利率）。在理想□□条件下，□两个参数□□是相等的，□个□象被称□拉姆□条件。在制定公共政策□，因□□□率□的□□是□□争□，如何□□最□□□率□仍然具有高度政治性[17]。□然□□低/零折□率是否有价□仍被争□，它仍然是合理的，□□高折扣率的争□也是一□。□个争□将□□□成本效益分析的□□偏好社会率的□的□□，替代□在□境成本和效益上如何最□□□的□□。

[17] 关于不适用于公共政策下的“完美”市□利率的因素的全面修□，参考 fledstein（1964 年）。

1.2.2. Determination of the SDR

The choice of the SDR is one of the most controversial decisions in a CBA and is especially critical for projects incurring high net costs in their early years and high net benefits in the longer future. Recent publications (Burgess and Zerbe, 2011; Zerbe et al., 2010) and older ones (Harberger, 1972; Jenkins, 1973) advocate the usage of the social opportunity cost of capital in computing the real SDR. However, many economists, if not most, argue that the appropriate approach to discounting the impacts of public projects is to discount 'consumption equivalents' using a social discount rate based on the SRTP, as recommended in Eckstein (!958), Marglin (1963), Feldstein (1972), Bradford (1975) and Lind (1982). In fact, many governments have over the past decade switched from using a SOC-based approach to SRTP-based discount rate values (Moore et al., 2013). The UK has lowered its recommended discount rate from 6% to 3.5% for its projects in 2003; Germany in turn lowered its recommended rate from 4% to 3% in 2004 (European Commission, 2008), and in 2005, France reduced its recommended rate from 8% to 4%. Presented in Table 1 are discount rates as set by different countries for their social projects and public interventions.

It here becomes worthy of note as it is evident that the rates of time preference and elasticity of marginal consumption (as presented in Ramsey's) currently adopted by most governments of developed countries are still based explicitly on ethical judgment, as well as, in the case of the latter, empirical evidence[18]. Dasgupta (2008, p. 150), for instance, acknowledges that the SDR 'has to be derived from an overall conception of intergenerational well-being and the consumption forecast'. Evidence from attempts to infer δ and η 'from the choices people make as they go about their lives' (p. 147) is an input to the estimation of those parameters, but it is not the only consideration. If the SDR for a

[18] The judgment involves ethics in that it directly entails taking an explicit view about how much the welfare of people in the future matters compared with the welfare of people today. The commercial approach is to accept the 'view' about intergenerational welfare that is implicit in market data.

project as calculated by a public sector executive differs from an estimate of its cost of capital based on market data, the SDR takes priority.

Table 1. Social discount rates as set for public projects in different countries.

Country/Agency	Discount Rate	Comments
People's Republic of China	**8%**	Rate set for short and medium term projects; lower than 8% for long term ones.
Germany	**3%**	Set in 2004, down from 4% (1999)
United Kingdom	**3.5%**	Set in 2003, down from 8% (1967), 10% (1969), 5% (1978), and 6% (1989). Different rates lower than 3.5% apply for projects longer than 30 years.
France	**4%**	Set in 2005, down from 8% as set in 1985.
Canada	**10%**	
Australia	**8%**	Set in 1991 and is reviewed annually.
India	**12%**	
New Zealand (Treasury)	**10%**	Taken as a standard rate whenever there is no other agreed-upon sector discount rate.
Norway	**3.5%**	Set in 1998, down from 7% (1978)
Spain	**6%**	For Transport, 4% for water.
Pakistan	**12%**	
Philippines	**15%**	
Italy	**5%**	

The Ramsey Formula

As reflected earlier in the relationships that exist in Ramsey's equation (5), society is viewed as facing a choice between consuming resources today, or investing them for future reaping. Because greater investments today produce greater consumption in the future, the SDR becomes a measure of society's weighing of future utility of consumption as compared to the utility of consumption in the present. If both utilities were deemed equal, the SDR would be zero. However, as future utility of consumption is considered to be less than that of present consumption, SDR needs to be positive to maintain an indifferent behaviour for individuals between consuming and investing today (i.e. a further reduction in the marginal utility of future consumption implies a larger discount rate). This is explicitly materialised in a positive value for the time preference component of the formula, while the elasticity of marginal consumption, η, at the margin, delineates an inverse relationship between the consumption and the marginal utility that results from that consumption. Put differently, as consumption increases, the marginal utility from extra consumption declines faster, so as people become richer, they would derive less utility from each dollar they receive/spend.

A reflection of people's 'wealth' is given as the growth rate, g, so a higher value for the product of $\eta . g$ results in a higher social discount rate. However, the search for an estimate of the growth rate remains futile, as it is a function of a number of interdependent societal, technological and economic factors; let alone the fact that the expected real growth rate differs between countries, coined as the cross-sectional income inequality. In overcoming the latter dilemma, it would be intuitive (and fairer) to use a global estimate instead of a country-specific one for the growth rate[19], legitimised by the fact that payoffs of investments in alleviating global warming are received worldwide rather than country-specific. The figures which are commonly assumed for the components of the Ramsey formula are: δ = between 0.0% and 2.0%, η = between 1.0 and 4.0, and g = between 1% and 2%. SDRs chosen by governments in practice range from 3.5% (declining with time horizon) to 10.0% (Cropper et al, 2014; Spackman, 2008). Many authors support a value for δ very close to zero, though 1.0% is common in the finance literature and some authors suggest higher values. The key argument for $\delta \approx 0$ is that it is unethical to weight utility according to when the person is alive. The time a person is alive is, in itself, not a relevant consideration when it comes to weighting utility. The *Stern Review* (2006), for example, concludes that δ ought to exceed zero only to the extent that it reflects the possibility that humanity might not exist after some future date. The *Review* sets δ at 0.1% per year.

The parameter η provokes further questions. With the CRRA utility function, η measures both the rate at which the utility from marginal consumption declines as consumption grows over time, and aversion to uncertainty about consumption at a given date i.e. aversion to risk. In the first of these roles, a higher η implies a desire for less inequality in levels of consumption over time (as does a higher δ). Marginal consumption today provides high utility compared with marginal consumption in the future. A person with a high η chooses higher consumption now and in the near future, and slower growth of

[19] For example, China expects to have a higher growth rate than the world as a whole, at least for the next decade or two.

consumption, compared with a person with a low η. A lower η implies greater concern about future welfare, and subsequently a lower SDR. A consequence of lower η is less consumption today i.e. higher saving. Dasgupta (2008) and Nordhaus (2007) argue that a value of η of, say, 1.0, as in the *Stern Review*, implies that the proportion of income that would be saved is very high, 40% or more. This is uncomfortable because it is unrealistic that such high savings ratios will arise. This also suggests that the current generation should consume much less than it actually does, for the benefit of the future, even though people in the future are already forecasted to be substantially richer than are people today. Of course, not all the extra investment would be in low-carbon technologies; there are other projects that produce long-term benefits.

Perhaps more troubling is a comparison with a different role for η, that of reflecting concern about cross-sectional income inequality at a given date. Lower η in this role implies less concern about the welfare of the poor, because the marginal utility from increasing income for the poor increases with η. We have the awkward conclusion that public sector executives concerned about current income inequality would apply a high η in their project appraisals, whereas a low η should be applied if they are concerned about the welfare of future generations. One answer is to use a utility function in which aversion to risk, and to income inequality at a given date, are separate from aversion to inequality of consumption over time. A number of papers explore such a utility function, including Gollier (2002).

Ethical Predicaments

Here salient arguments for low against high SDR values are summarised, before elaborating on ethical implications that accompany the governmental choice of the SDR.

Arguments favoring a low SDR:

- Lower discount rates favor investment in future generations.
- High discount rates violate our ethical intuition.
- A government has an infinite life, whereas individuals do not and hence are more impatient (i.e., government should have lower time preference).

Arguments for a higher SDR:

- Future generations inherit capital and knowledge from the present generations.
- Future generations are always better off economically & technologically than past generations.
- High discount rates avoid the possibility of present generations making unreasonable sacrifices.
- High discount rates cause the present generation to invest in high-yield projects that would best benefit the future.

As aforementioned, the approaches to determine a proper SDR vary from those methods used in inferring commercial rates of return from market data. One rationale for rejecting the usage of such data is that market interest rates do not exist beyond a horizon of 30 years (e.g. longest maturity of most government bonds), and even for those undated government bills that do exceed that time horizon, the market remains fairly illiquid[20]. The focus on treasury bills is a corollary of the view that funding for public projects is risk-free, but if this view is rejected, the expected rate of return on equity becomes potentially relevant market-based evidence for risky projects, as in Weitzman (2007).

Perhaps the most evident reason for explicit appeal to ethical judgment in the SDR is the view that market data, whether of bonds or equities, does not reflect enough concern for the welfare of future generations. Where the assumed aim of current governments is to maximise the societal utility, including those generations yet to be born (intergenerational utility), individuals contrarily act to maximise their own lifetime utility. However, Dietz, Hepburn, and Stern (2008) argue that while this might be the case, individuals alive today elect governments that act to benefit future generations at the expense of present ones, a view dubbed as the Government House Utilitarianism (Sen & Williams, 1982, pp.16). Since

[20] Discount rate values can be computer by using historic data over a succession of short-term T-bills, however, the result will be approximate and based on the assumption that the future will resemble the past.

market data is supposed to reveal the preference of utility of those individuals acting to maximise their lifetime utility, rather than intergenerational utility, market data are not to be trusted for the purpose of making decisions intended to maximise intergenerational utility[21]. In other words, people tend to ignore or undervalue externalities in their individual behaviour, and the effects of behaviour on future generations are externalities. One such externality is carbon emissions that result from a business-as-usual behavior. This negative externality can, and should in principle, be 'translated' and included in cash flow forecasts[22].

It can be hereby seen how dealing with discounted benefits and costs that stretch over to several generations would pose an ethical dilemma, and Schelling (1995) notes that by engaging in emissions reduction today, we would be incurring costs *today* so that future generations can reap the benefits. Although less appealing, we would still use a positive discount rate to benefit those closer in time more than those living farther away in the future. Schelling also argues that justifying discounting by the fact that future generations are richer and that the marginal utility of consumption would thereby decline might not hold for climate change policy, since the West, on the whole, is paying for abatement costs, and those who benefit in the future, are on the whole, the still poorer and thus higher-marginal-utility people in developing countries. One would then argue that if the West were sacrificing current consumption to benefit people in poor countries, it would be more logical to benefit them *now,* rather than invest them in the future. This stems from the fact that as incomes rise over time, the highest marginal utility of 'aid' for the poor is now, not in the future. This also implies that abatement schemes in the West and development projects should be compared to find out where the biggest returns on sacrificed current consumption occurs (i.e. benefiting the poor now, or the future poor).

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21 Although some lifetime utility could come from the anticipation of the individual's heirs, something reflected by the making of bequests – the lifetime utility of an individual might most likely outweigh the expected utility for future generations.

22 Dasgupta (2008) and others argue that, in the absence of 'market imperfections', society will maximise its lifetime utility and the social discount rate will be equal to the market rate of return on investment. His conception of market imperfections includes the existence of externalities which are not reflected in the rate of return on investment. There are more conventional types of market imperfections which might also make it difficult to infer from market data the revealed preferences of the current population regarding social decisions. These include taxes and poor information on the part of the population.

Broome (1994), for example, maintains that 'it is only the disenfranchisement of future generations that gives us the share of the world's resources that we have' (p. 152). He presents a thought experiment in which a trust fund is set up and would act in the interests of future generations. He regards it as self-evident that 'from the trust's point of view… future commodities would be much more valuable than they seem to us who are participating in the market now', and that the trust would transfer resources from the present to the future. But the trust's purchases of future commodities would not reduce market interest rates permanently, as he assumes that interest rates are determined by the productivity of the economy's technology[23]. So if we took proper account of the welfare of future generations, we would use a lower SDR than market interest rates.

There are also various special cases to consider, which invite a low discount rate, or other special treatment of investment decisions or regulation. Some 'commodities', such as fresh air, or more generally a reasonably healthy environment, could be considered especially important to maintain prospects for well-being. This could justify, for example, a very low discount rate for public projects designed to maintain a reasonably healthy environment. Some activities, such as lifesaving, discussed by Broome (1994), provide utility which does not diminish as society becomes richer. Some commodities might be seen as essential for future well-being, and so as not substitutable at all for other commodities, in which case they will be regarded as necessary to have at almost any cost. Some features of the world might be given a special status because once lost they cannot be replaced, such as a species of animal or an archaeological site.

A general question about the SDR approach is, how do we agree on values of δ and η, and hence set the SDR? Or if we are using a declining discount rate (below), how should the decline be determined? The values of δ and η are based partly on individual reflection under the SDR approach, so the values proposed will differ across SDR users. The published responses to the *Stern Review* show how much disagreement there is about the

[23] Assuming a constant return on investment (*ROI*). The trust would reduce the interest rate if there were diminishing returns on investment. With a constant *ROI*, $r_f = ROI$, otherwise the rate of saving would not be optimal. The growth rate in the Ramsey model is then $g = (ROI - \delta)/\eta$. The trust's activities imply a lower δ or η for society than would prevail without the trust, and a higher saving rate and growth rate.

SDR, as does the range of discount rates applied by different governments to public projects. Appeal to the evidence from clinical studies is rather inconclusive. Critical features about this evidence are as follows (Frederick, Lowenstein, and O'Donoghue, 2002). Measurement of the discount rates used by individuals is fraught with difficulties. The rates reported are highly heterogeneous across studies, and they are generally much larger than the rates of a few-per-cent used by governments for their SDRs. People apply high discount rates over short horizons, of up to about one year, and lower discount rates for longer future periods. With the important exception of this step reduction after one year, there is little clinical evidence that people apply declining discount rates.

The above discussion risks presenting use of the SDR-by-judgment approach as more firmly rooted than it actually is. The SDR was a rate based on market data in Lind (1982). Portney and Weyant (1999) summarised the deliberations of 20 leading public economists on the SDR in the context of climate change. There was agreement among them that a cost of capital based on market data should be used for projects with a life of up to 40 years, but that the SDR approach should be used for longer-term projects, because of 'discomfort' with the cost-of-capital approach for long-term projects. Weitzman (2007) believes that a distinct SDR approach is not that of mainstream economics.

Alternative Methods of Discounting: Declining Discount Rates

For far-in-the-future benefits, a small change in the discount rate has very big impacts on present values. Economists have recently advised that discount rates should *decline* as costs and benefits are appraised (for reference see Hepburn and Koundouri, 2007). There is evidence that people discount near-in-time benefits and costs at higher rates than further-away-in-time ones. There is also a high uncertainty associated with future value of the social discount rate as it is highly dependent on growth per capita consumption as discussed earlier, which in turn is very unpredictable over time. This uncertainty results in an uncertainty-adjusted discount rate which declines with time (on the one part for the desire for precautionary savings in the face of risky future). Then the equation becomes:

$$i = \rho + \eta g - \tfrac{1}{2}\eta P \mathrm{var}(g) \quad (7)$$

Where P is a measure of precautionary saving and var(g) is the variance of the growth rate of per capita consumption, resulting in a declining discount rate over time that is caused by people's attributes to risk in the future. The cost of capital in practice and in finance texts is always a flat rate. Conventional discounting, with a flat rate, is sometimes referred to as exponential discounting, and discounting with a declining rate as hyperbolic discounting.

Probably the most influential argument for a declining discount rate is the following. If the discount rate for each future period is fixed but uncertain ex ante, there is a declining discount rate in the sense that, for a given collection of possible discount rates, the single, fixed discount rate that represents the range of possible rates declines as the number of future periods increases (Weitzman, 1998). This argument is easiest to understand by means of an example (Guo et al, 2006). Let the possible discount rates be 1%, 3% and 5% per year, each with equal probability. What Weitzman calls the certainty-equivalent discount rate for *t* years, $CEDR_t$, is the discount rate which results in the same PV as the average of the PVs which arise from using each of the possible discount rates. $CEDR_t$ is calculated from the certainty-equivalent discount factor, $CEDF_t$, which is the weighted average of the discount factors for the possible discount rates:

$$CEDF_t = 1/(1 + CEDR_t) = (1/3)[(1/1.01^t) + (1/1.03^t) + (1/1.05^t)] \quad (8)$$

For t = 10 years, $CEDF_t$ = 0.754 and $CEDR_t$ = 2.86%; for t = 100 years, $CEDF_t$ = 0.143 and $CEDR_t$ = 1.96%. The mechanism at work here is that, as the future horizon recedes, the lowest discount rate explains an increasing proportion of the PV. The argument only makes a difference if at least one of the possible discount rates is sufficiently low that PV is non-negligible. If the time horizon is 100 years or more, and the lowest of the possible discount rates is around 4%, PV is approximately zero even using the lowest possible rate.

Hepburn and Koundouri (2007) show how the certainty-equivalent discount rate (recommended for use in CBA) declines with time when there are two likely possible scenarios of equal probability (e.g. 2% and 6%, then 4% is taken as an average scenario that falls to 2.4% in 200 years). This stems from the theory that in an uncertain economy, the shocks on the growth rate of consumption (consumption-based approach) and of the shocks on short-term interest rates (in the production-based approach) determine the time path of the socially efficient discount rate, persistence of both types of shocks yields the Declining Discount Rate (DDR) (see Gollier et al., 2008).

The ideas thus far outlined are having an impact on practice; the UK, French, Danish and Norwegian governments now apply declining discount rates, and other governments have been prompted to do so (Cropper et al, 2014). The *Treasury's Green Book* in the UK also recommends the use of such an approach with discount rates falling from 3.5% for benefits and costs up to 30 years into the future, to 3% for years 31-75 and 2.5% for years 76-125. This plays the effect of increasing the present value of long-term benefits and costs. Using a certainty-equivalent discount rate reduces the risk associated with a policy. However, calculating this discount rate remains very difficult, as it involves obtaining information on all possible states of the world, on outcomes of each state, the probability of each state, and on the degree of risk aversion of everyone impacted by the project (along with their wealth levels). The alternative to using a certainty-equivalent discount rate is to use a risk-adjusted discount rate, as manifested in the Capital Asset Pricing Model.

1.2.2. 社会贴现率的确定

社会贴现率的确定是成本效益分析中最具争议性的一个因素，对于那些初期阶段净成本较高但长远净效益也很高的项目来说尤为重要。近期文献(Burgess and Zerbe, 2011; Zerbe et al., 2010)和早期研究(Harberger, 1972; Jenkins, 1973)都主张利用资本的社会机会成本来计算真正的社会贴现率。然而，正如 Eckstein (!958), Marglin (1963)、Feldstein (1972)、Bradford (1975) 和 Lind (1982)所建议的，许多经济学家认为，折现公共项目的影响的最恰当方式是利用基于社会时间偏好率的社会

贴现率来折算“消费等价物”。实际上，在过去十年多国政府都从利用基于资本的社会机会成本的方法转为应用基于社会时间偏好率的贴现率价值(Moore et al., 2013)。英国在 2003 年把推荐项目的折现率从 6%降到 3.5%；德国在 2004 年也将这一数值从 4%降到 3%(欧盟, 2008)；法国则在 2005 年从 8%降到 4%。表 1 中列出的是各国社会项目和公共干预的贴现率。

值得注意的是，目前大多数发达国家采用的时间偏好率和边际消费弹性（拉姆齐模型中所示）仍明显基于道德判断以及实际证据[24]。例如，达斯古普塔（2008, p. 150）认可社会贴现率“必须考虑两代人的福利和消费预期的总体概念”。推断“人们对他们的生活做出的选择”中 δ 和 η 的值(p. 147)的证据是预估这些参数的信息来源，但不是唯一的考虑因素。如果公共行业主管计算的项目社会贴现率与根据市场数据预计的资本成本不一致，则以社会贴现率为准。

国家/机构	贴现率	备注
中国	**8%**	中短期项目为 8%，长期项目低于 8%
德国	**3%**	2004 年确定，之前是 4%（从 1999 年开始）
英国	**3.5%**	2003 年确定，此前分别是 8%（1967 年），10%（1969 年），5%（1978 年），6%（1989 年）。对于 30 年以上的项目，折现率为 3.5%
法国	**4%**	2005 年确定，此前（从 1985 年开始）为 8%
加拿大	**10%**	
澳大利亚	**8%**	1991 年设定，此后每年进行评估
印度	**12%**	
新西兰（财政部）	**10%**	标准税率，没有其他商定的行业折现率
挪威	**3.5%**	1998 年确定，此前为 7%（1978 年开始）
西班牙	**6%**	适用于运输行业；水资源是 4%
巴基斯坦	**12%**	
菲律宾	**15%**	
意大利	**5%**	

表 1. 各国公共项目的社会贴现率

[24]判断涉及道德方面，必须要明确人们未来的福利与现在相比有多重要。商业化方法要接受市场数据中暗示的两代人的福利的“观点”。

拉姆齐模型

正如拉姆齐模型（5）中反映出的关系，整个社会面临着两个选择，消费资源或投资后在未来获取回报。由于当前的投资越多意味着未来的消费也会更多，社会贴现率是整个社会衡量未来消费效用和当前消费效用的工具。如果两种效用相等，则社会贴现率为零。但是，一般认为未来的消费效用小于现在的消费效用，社会贴现率需要积极保证个人平衡当前的消费和投资行为（也就是说，未来消费边际效用进一步降低，则贴现率变高）。这在公式中时间偏好率为正值时有明确体现，而边际消费弹性 $\boldsymbol{\eta}$ 反映出消费及其边际效用呈反比关系。换种说法，消费增加时，额外消费产生的边际效用迅速下降，因此当人们变得更加富裕时，他们获得或支出的钱的效用也会相应降低。

将反映人们“财富”变化的增长率设为 g，$\boldsymbol{\eta}.g$ 的值越大，社会贴现率就越高。然而，对增长率的预计仍然是无效的，因为这是互相依赖的社会、技术和经济多种因素共同作用的结果；更不用说各个国家因典型的收入不均而预计实际增长率存在差异。为了克服第二个困境，使用全球统一的预计增长率会更直观（也更公平）[25]，投资减缓全球变暖的事业回报的是全世界而不仅是某个国家这个事实就体现了这一点。拉姆齐模型中各参数的假定数值通常为：$\boldsymbol{\delta}$ = 0.0% - 2.0%，$\boldsymbol{\eta}$ = 1.0 - 4.0，g= 1% - 2%。政府实际选择的社会贴现率在 3.5%（随着投资期下降）到 10.0%(Cropper et al, 2014; Spackman, 2008)之间。尽管金融文献中 δ 的值通常为 1.0% 甚至更高，但很多作者认为 δ 的值无限接近零。$\boldsymbol{\delta} \approx 0$ 的主要论点是，通过人的寿命来衡量效用是不道德的。人的寿命本身与效用的衡量是不相关的。《斯特恩报告》（2006）就总结出 $\boldsymbol{\delta}$ 只有在未来人类可能不存在时才应大于零。该报告每年都将 $\boldsymbol{\delta}$ 定为 0.1%。

参数 $\boldsymbol{\eta}$ 带来了其他问题。在常相对风险规避系数效用函数中，不仅度量边际消费效用随着消费增长下降的比率，还计算在给定日期对消费不确定性的规避系数，

[25]例如，预计中国的增长率比全世界的总增长率高，而且至少在未来十年或二十年都将如此。

也就是风险规避系数。在第一种功能中，η 的值越大意味着人们希望随着时间的推移而减少消费水平的不平等（和 δ 的值变大一样）。与未来的边际消费相比，当前的边际消费带来的效用很大。η 的值较大时，人们目前及近期的消费就多，消费增长相较 η 值较小的人更慢。η 的值较小意味着人们更多的考虑未来的幸福，因此社会贴现率就会变低。η 值小就说明当前的消费少，也就是说储蓄更多。达斯古普塔（2008）和诺德豪斯（2007）认为，当 η 的值为 1.0（如《斯特恩报告》的假定）时，人们将收入储蓄起来的比例就很高，能达到 40%或更高。如此高比率的储蓄率在实际生活中并不常见。这也意味着，尽管已有预测表明未来人们的财富比现在要多很多，为未来考虑，当代人应极大地减少他们的实际消费。当然，不是所有的额外投资都将集中在低碳技术领域；其他一些项目也能带来长期的效益。

也许更大的问题是比较 η 的另一不同作用，即反映在给定日期明显的收入不均。η 的值越小，意味着更不关心贫穷人口的福利，因为穷人收入增加时的边际效用会随着 η 增加。这里得出了一个令人尴尬的结论，公共行业管理人员关心目前的收入不均，他们的项目评估中 η 的值就较高，但如果他们关心后代子孙的福利，η 的值就应该较小。为解决这个尴尬问题，需要应用一个效用函数，其中风险规避和对在给定日期收入不均的规避与对消费不均的规避是分开的。Gollier (2002)等大量论文作者对这种效用函数进行了研究。

伦理困境

在详细说明政府制定的社会贴现率暗含的伦理意义前，本部分对采用低社会贴现率的最主要论点做出总结。

采用低社会贴现率的论点：

- 社会贴现率低能增加对后代的投资。
- 社会贴现率高违背我们的伦理道德。

- 政府会一直存在，而人类个体不会，因而缺乏耐心（也就是说政府的时间偏好更低）。

采用高社会贴现率的论点：

- 未来后代会继承现代的资产和知识。
- 未来的经济和技术条件会更好。
- 高贴现率降低了现代人做出不合理牺牲的可能性。
- 高贴现率会引导现代人投资在最能造福子孙后代的高回报项目上。

正如前面所提到的，确定合适的社会贴现率的方法和根据市场数据得出商业回报率的方法有所差异。不使用这些数据的理由之一是，市场利率存在的时间不会超过 30 年（正如大多数政府债券的最长期限），即使那些未标明时间的政府债券超出了这一期限，市场也仍缺乏流动性[26]。Weitzman（2007）在他的研究中指出，认为投资公共项目不存在风险必然会导致对国债的关注，但如果这一观点不正确，预期资本回报率就成为高风险项目可能相关的市场证据。

明确呼吁在确定社会贴现率时考虑道德因素的最重要原因也许是，不管债券或股票相关及其它市场数据都没有反映出对后代福利的足够关心。假定当前政府的目标是将社会效用最大化，包括将后代的效用最大化，而相反，个人则是实现一生中效用的最大化。然而，Dietz、Hepburn 和 Stern (2008)认为，虽然这种情况有可能发生，但也存在政府功利主义（Sen& Williams, 1982, pp.16），即当今社会的个体会选举那些牺牲当代人利益来造福子孙后代的政府。由于市场数据会反应出那些希望实现一生效用最大化的个人的效用偏好，而不会反映出代际效用，因此无法作为将代际效用最大化决定的参考[27]。也就是说，人们往往忽视或低估了个人

[26]可以利用一系列短期国债的历史数据来计算贴现率，但这是基于未来与过去相似的假设，而且得出来的结果是近似值。

[27]虽然一些终生效用可能来自个人继承，反映在遗产中，个人的终生效用可能比后代的预期效用重要。

行为的外部效应，即对后代的影响。日常行为产生的碳排放就是其中之一。这个负面的外部效应原则上应反映在现金流预测中[28]。

在此可以看到处理延伸到几代人的贴现收益和成本是如何带来伦理困境的，Schelling (1995)指出，现代人参与减排*现在*会付出成本，但这样后代能受益。虽然这没什么吸引力，但我们仍然会采用积极的贴现率来造福近现代而不是遥远的未来。Schelling 还认为，我们不应以后代会更富裕且边际消费效用将因此下降的事实决定贴现率。这可能并不适用于气候政策，因为总体来说，西方国家都在为减排付出代价，而未来的受益主体将是更贫穷且因此边际效用更高的整个发展中国家。有人会提出疑问，如果西方国家牺牲目前的消费来让发展中国家在未来获益，那现在就帮助它们应该更合逻辑。因为未来收入会随着时间增加，“援助”发展中国家的边际效用会在现在达到最大，而不是在未来。这也意味着应通过比较西方国家的减排机制和发展项目，来找到牺牲目前消费效用产生最高回报的时间点（也就是让发展中国家在现在还是未来受益）。

例如，Broome (1994)认为，“只有剥夺后代公民的选举权，我们才能拥有现在这些资源（p.152）。他进行了一个思维实验，并在实验中设置一个信托基金，用以维护后代的利益。他认为，‘从信托的角度来看，未来的商品明显比参与当今市场的我们认为的价值更高’，信托会将资源从现代转移到未来。但由于他假定市场利率由技术的生产力决定，所以信托在未来购买的商品不会导致市场利率永久性下降[29]。因此，如果我们适当考虑子孙后代的福利，就应该选取比市场利率低的社会贴现率值。

[28] Dasgupta (2008)和其它一些学者认为，在没有“市场缺陷”时，社会将实现终生效用的最大化，社会贴现率将与市场投资回报率相等。他的市场缺陷概念包括承认外部性的存在，但这一外部性不会反映在投资回报率中。还有一些更传统的市场缺陷可能也会让从市场数据中总结现代人在社会决定上的偏好变得更难，其中包括税收和人口信息的缺乏。

[29]这里假定投资回报率（ROI））保持不变。如果投资回报减少，信托将降低利率。当投资回报率保持不变时，r_f =投资回报率，否则储蓄率将不能达到最优。拉姆齐模型中，增长率 $g = (ROI - \delta)/\eta$。信托基金的活动意味着 δ or η 相比没有信托基金时会降低，储蓄率和增长率都会上升。

还有一些特殊情况也需要考虑应用较低的社会贴现率，或特殊的投资决策或监管方式。新鲜空气或一个比较健康的环境等一些“大宗商品”对于维持幸福生活前景来说尤为重要。Broome (1994)认为，像保护生命等一些活动所产生的效用不会随着社会富裕程度增加而减少。一些商品可能和后代人的幸福同样重要，而且没有任何其他商品可以替代它们，这种情况下，无论花多大代价都必须得到这些商品。这个世界的一些特征应有特殊的地位，因为有些东西一旦失去就将无法替代，比如动物物种或考古遗迹。

社会贴现率方法存在的一个普遍问题是，如何在 δ 和 η 的取值上达成一致从而确定社会贴现率的值？或者，如果规定贴现率呈下降趋势，那么如何确定下降的幅度？在社会贴现率方法中，δ 和 η 的取值一部分取决于个人的反映，因此不同人取的值也不一样。已出版的回应《斯特恩报告》的文章显示出在社会贴现率取值上存在的分歧，各国政府采用的公共项目社会贴现率的范围也是如此。仅仅依赖案例研究中的证据是不恰当的，因为它没有给出一个清晰的结论。这个证据的关键特征包括以下几点(Frederick, Lowenstein, and O’Donoghue, 2002)。个人评估贴现率困难重重。各项研究中得出的贴现率数值非常不统一，通常比政府使用的仅几个百分点的社会贴现率要高得多。人们对于短期（最长为一年）项目使用的贴现率较高，而对于未来的长期项目则采用较低的贴现率。除了这种在一年之后分段降低贴现率的做法，很少有实践案例采用逐渐递减的贴现率。

上述风险讨论显示出，靠判断来确定社会贴现率的方法比实际上更根深蒂固。Lind (1982)在他的研究中表示，社会贴现率根据市场数据得出。Portney and Weyant (1999)总结了 20 位领先公共经济学家对于气候变化背景下的社会贴现率的讨论。他们都一致认为，对于生命周期在 40 年以内的项目，应该利用基于市场数据的资本成本，对于更长期的项目则应采用社会贴现率的概念，因为资本成本的方法“不适用”于长期项目。Weitzman (2007)认为，区别于传统的社会贴现率方法不属于主流经济学。

折现的替代方法：逐渐递减的贴现率

为了未来长久的利益，细微的贴现率变化都会对现值产生重大影响。有经济学家提出，贴现率应随着成本和效益的上升而“逐渐下降”（参考 Hepburn and Koundouri, 2007）。有证据显示，人们对近期效益和成本的折现比率较长期的更高。未来社会贴现率的价值也存在很大的不确定性，严重依赖于人均消费增长，因此反过来会导致其价值难以预测。这些不确定性造成了随时间下降的贴现率调整的不确定性（一方面是由于人们面对充满风险的未来希望增加预防性储蓄）。那么该公式就变为：

$$\boldsymbol{i = \rho + \eta g - \tfrac{1}{2}\eta P \mathrm{var}(g)} \qquad (7)$$

其中 P 是预防性储蓄方法，var(g)是人均消费增长率的变量，由于人们在应对未来风险上进行投资，因此得出的是随时间递减的贴现率。实际的和金融文献中的资本成本总是统一费率。传统折现采用统一比率，也被称作指数折现法，而逐渐递减的贴现率是双曲线折现法。

或许递减贴现率最具影响力的论据是，如果未来每个时间段的贴现率是固定的，但在采取措施前是不确定的，在这个意义上存在一个递减的贴现率，在给定的可能贴现率的集合中，单一、固定的贴现率代表随着未来时间段的增加可能下降的比率范围(Weitzman, 1998)。理解这个论点最简单的方式是案例分析(Guo et al, 2006)。假设可能的贴现率有每年 1%，3%和 5%，并且它们出现的概率相等。Weitzman 将在第 t 年具有同等确定性的贴现率称为 $CEDR_t$，表示采用每个可能的贴现率产生的所有现值的平均值与 $CEDR_t$ 产生的现值相等。$CEDR_t$ 由具有同等确定性的贴现因子 $CEDF_t$ 计算得出，$CEDF_t$ 指可能贴现率的贴现因子的加权平均值：

$$CEDF_t = 1/(1 + CEDR_t) = (1/3)[(1/1.01^t) + (1/1.03^t) + (1/1.05^t)] \quad (8)$$

当 t =10 年时，$CEDF_t$ =0.754，$CEDR_t$ = 2.86%；而当 t = 100 年时，$CEDF_t$ = 0.143，$CEDR_t$ = 1.96%。这里起作用的机制是，随着我们深入未来，最低的贴现率反映出现值的比例不断上升。这个论据只有在至少有一个可能的贴现率低到现值不容忽视时才会产生影响。如果时间期限是 100 年甚至更远，可能的贴现率最低值大约是 4%，即使采用可能出现的最低贴现率，现值都几乎为零。

Hepburn 和 Koundouri (2007)的研究表明了存在两种可能的等概率情景时（例如 2%和 6%，那么取平均值就是 4%，200 年后将下降到 2.4%）同等确定性贴现率（建议用在成本效益分析中）随时间下降的方式。其理论来源是，在不确定的经济环境中，消费增长率的变化（消费分析法）和短期利率的变化（生产分析法）决定了最理想的社会贴现率的时间曲线，这两种变化的持续性决定了递减的贴现率（DDR）(Gollier et al., 2008)。

目前为止概述的这些观点都对实践产生了一些影响，英国、法国、丹麦和挪威政府现在都在应用递减的贴现率，其他一些国家紧随其后 (Cropper et al, 2014)。英国的《财政部绿皮书》也建议使用这种方法，将 30 年内收益和成本的贴现率定为从 3.5%逐渐递减，31 到 75 年为 3%，而 76 到 125 年为 2.5%。这就导致长期效益和成本的现值增加。运用同等确定性的贴现率能降低某种政策的风险。但是，由于计算这种贴现率需要从世界各洲获取每个洲的结果、概率和每个人受项目影响的风险厌恶程度（连同他们的财富水平）的数据，因此仍存在很大困难。应用同等确定性贴现率的替代方法是利用在资本资产定价模型中显示的风险调整贴现率。

1.2.3. The SDR and Risk

It has been 'commonly thought that the risk-free rate of return is appropriate for the appraisal of public projects due to the risk pooling available to governments (Groom et al, 2005, p.452; Arrow and Lind, 1970). This view has long been disputed, and, in principle, it is not correct to ignore risk. A public project with uncertain future payoffs should only be discounted at the risk-free rate if the payoffs are uncorrelated with consumption per head, as is in fact assumed by Arrow and Lind (1970), and as is re-iterated by Lind (1982, p. 69). Neither the *Stern Review* (2006) nor any reviews of *Stern* take the view that government investment to alleviate climate change should be treated as risk-free by virtue of being funded by the government.

Both portfolio theory and consumption-based theory show that risk-averse investors demand a risk premium for exposure to systematic risk; that is, risk which is not eliminated through diversification by means of holding a portfolio of assets or projects. Each public project has its own discount rate that depends on its systematic risk, as is the case for private projects, and taxpayers bear the risk of public projects. 'Investing' in public projects via paying taxes does not appear to offer greater elimination of risk than does investing in financial markets. Most unsystematic risk is eliminated by means of holding about 30 randomly selected shares, so a mature stock market provides more than enough opportunities for diversification. It is true that a government with a secure AAA credit rating can borrow at a lower cost of capital than the WACC of even the safest private-sector company. However, a sufficient reason for this is that a stable government can raise funds via taxation, which is a coercive method not available to a company. The coercive nature of taxation does not mean that the government has reduced project risk for the taxpayer.

While some governments have adopted a declining discount rate approach (1.2.2), the importance of risk as a determinant of private sector discount rates has not been fully accounted for by most governments that still apply a single discount rate to all their public projects (Spackman, 2008). The fact that a single rate is used by a given government for all projects constitutes an important difference from the commercial cost-of-capital approach. The commercial approach directs attention to differences in risk across companies and projects, which can result in large differences in the cost of capital, of several percentage points. Risk looms much less large for the SDR, for a cluster of reasons. One is the mistaken tradition, just mentioned, that government funding in itself implies that the discount rate for all public projects is low. Second, the weight given to the welfare of future people, rather than risk, is seen as the primary determinant of the SDR. Guided by the Ramsey formula, future payoffs are discounted because society will be richer, and, if δ is non-negligible, because utility in the future counts for less than utility today. The payoffs are not discounted because they are risky.

Public projects typically involve non-commercial objectives, and provide 'payoffs' that do not arise via cash flows. For example, what is the risk of investment to alleviate climate change? The cost of global warming is usually modelled as a fixed proportion of future output or consumption. In this case the size of the payoff, which is a reduction in that cost, is proportional to output, and the consumption beta is approximately one. A beta of one or more also arises in a model in which output before the impact of temperature increase has a linear positive effect on temperature, investment to reduce carbon emissions has a linear negative effect on temperature, and the marginal negative impact of temperature on output is increasing with temperature (Gollier, 2012). In this case the size of the benefit of investment to reduce carbon emissions is positively related to the underlying output, because the (non-marginal) relation between output and temperature is positive.

A final point about risk is that there is a very major difference between the SDR and the commercial cost of capital in the assumed size of the risk premium in the CAPM (equation 3). The empirical variance of annual global economic growth is approximately 0.0004 (or a standard deviation of 2%). There is debate about the value of η to assume, but with conventional values of between one and three or four, the maximum premium for risk is less than 0.2% per year in the standard consumption CAPM, which underpins the SDR. So allowing for risk in standard consumption-based theory makes little difference to the SDR. This potentially provides a justification for ignoring risk, though it is not a justification which has actually been used much in the SDR literature. In contrast, the risk premium assumed in the private sector is at least three per cent per year for a beta of one, and usually more. As a result, the cost of capital is highly sensitive to the estimate of beta.

None of the above points mean that it is correct to assume that all projects are risk-free, or that they all have the same risk. At the same time, the measurement of the risk of real investment projects is a serious challenge for both public and private sector agents. A good deal of judgment is involved, and, for the commercial cost of capital, the judgment made regarding choice of beta has a major impact on the discount rate. Although SDRs used in practice are not explicitly adjusted for risk, evidence from market data is likely to affect one's view of the SDR that is chosen. If a public sector executive chooses a low SDR, of around 1% to 2%, someone used to the private sector approach, in which risk matters, would see this SDR as implying a belief that public projects are close to risk-free. If the executive chooses a high SDR, of 5% or more, this would imply a belief that public projects have a risk similar to investment in the stock market.

1.2.3. 社会贴现率与风险

一般认为，“由于公共项目的风险由政府分担，因此评估这类项目适合采用无风险的回报率(Groom et al, 2005, p.452; Arrow and Lind, 1970)。这一观点长期以来都存在争议，而且原则上来说，忽视风险的做法并不恰当。Arrow 和 Lind (1970)首先提出，Lind (1982, p. 69)后来也重申，如果一个公共项目的未来收益不确定，那么只有在其收益与人均消费不相关时才应采用无风险的贴现率。《斯特恩报告》（2006）及斯特恩其它的评论都认为，政府对缓解气候变化的投资都不能由于政府资助的优势就被认为是不存在风险的。

最佳证券投资理论和消费理论都显示，规避风险的投资者要求对不可避免的（即通过持有资产或项目多样化也不能消除的）风险暴露做风险溢价。正如私人项目，不可避免的风险决定了每个公共项目的不同贴现率，而公共项目的风险由纳税人承担。与投资金融市场相比，通过纳税“投资”公共项目的风险似乎并不会变低。同时持有 30 种随机股票能消除大部分非系统性风险，所以成熟的股票市场提供了丰富的多样化的机会。实际上，拥有 AAA 信用评级的政府可以借的资本成本比最安全的私人企业的加权平均资金成本还要低。但是，只有在政府稳定、能通过税收筹集资金的前提下才有充分的理由这样做，这是企业无法做到的一种强制性政策。税收的强制性也并不意味着政府能帮助纳税人降低项目风险。

虽然一些国家的政府采用了递减的贴现率方法（1.2.2.），但大多数仍对所有公共项目应用单一固定贴现率的政府都没有充分考虑对于私营行业贴现率具有决定性作用的风险因素(Spackman, 2008)。政府对所有项目应用统一贴现率与商业资本成本方法存在很大差异。商业方法聚焦于不同企业和项目存在的风险差异，这能导致它们的资本成本相差几个百分点。社会贴现率存在的风险小得多，其中的原因有很多。首先是上文中提到的一直以来的误解，认为政府对自身投资意味着所有公共项目的贴现率都很低。其次，我们认为社会贴现率的主要决定因素是对后代福利的重视程度。根据拉姆齐模型，随着未来社会富裕程度提高，而且如果 δ 不可忽略，未来效用没有现在的效用重要，因此未来收益会打折。

通常，公共项目不涉及商业化性质目标，而且“收益”不涉及现金流。例如，投资缓解气候变化项目的风险是什么？一般认为，全球变暖的成本在未来产出或消费中占固定比例。在这种情况下，能减少成本的收益的多少与产出成正比，消费贝塔约为 1。在消费贝塔为 1 或更大的模型中，温度上升的影响扩大前，产出对温度具有线性积极影响碳减排投资对温度有线性消极影响，温度对产出的边际消极影响随着温度上升而增加(Gollier, 2012)。而这种情况下，由于产出和温度呈（非边际）正比关系，碳减排投资回报的规模与潜在产出呈正相关。

最后，社会贴现率和资本资产定价模型（公式 3）中假定规模的风险溢价中商业资本成本有着本质区别。每年全球经济增长实际方差约为 0.0004（或标准偏差为 2%）。对于 η 的假定值也存在争议，传统观念认为在 1 到 3 或 4 之间，在支撑社会贴现率的标准消费资本资产定价模型中，最高的风险溢价小于 0.2%/年。因此，在标准消费理论中考虑风险对社会贴现率的影响甚微。这可能给出了一个忽视风险的理由，但社会贴现率相关文献中很少把这当成一个理由。相反，在消费贝塔为 1 或更大时，私营行业的风险溢价至少在 3%/年。所以，资本成本对于贝塔的预计高度敏感。

以上所有观点都认为假定所有项目都不存在风险或风险程度都一样是不恰当。同时，对于公私行业机构来说，评估实际投资项目的风险都是个极大的挑战。其中都涉及到大量的判断，而且就商业资本成本方面，根据贝塔的选择做出的判断对贴现率有很大的影响。虽然社会贴现率在实际应用中没有很明确地根据风险进行调整，但市场数据有可能影响人们对于社会贴现率选择的看法。如果公共行业的官员选择了较低的社会贴现率，即 1%到 2%，习惯于利用私营行业方法的人就会觉得这个数值暗示了公共项目几乎是零风险的。如果选择高达 5%或以上的社会贴现率，就暗示公共项目与投资股票市场的风险差不多。

1.2.4. Conclusion

Government-sourced investment in emission reduction is an application of the SDR that has become increasingly important in recent years, and is set to remain so. To justify substantial investment in low-carbon technologies, governments have to apply discount rates which are lower than the rates which would apply were the same investment to be undertaken by the private sector. But the case for very low discount rates, of 2% per year or below, remains highly contested. No matter what 'adjustments' are incorporated into measuring the discount rate for benefits and costs of a certain environmental policy, the future still raises considerable unease. Dependent on market behaviour and people's choices, making decisions over the discount rate remains highly debatable, and a tradeoff between ethical and efficiency criteria plays off. It is hard to be "fair to the future" as it is impossible to know what future generations will "want" or "need", and so it is hard to conceptualise the rights of imagined individuals who are not around today.

In summary, deciding on a single, *correct* rate of social discount is challenging, since many factors influence this decision, including time preferences, the social opportunity of cost of capital, time itself, risk and uncertainty. This chapter has reviewed the main features of the SDR approach to discounting, explained why an SDR can be set that is below the commercial cost of capital, and discussed the main reasons for controversy. What is recommended, then, and is further applied in the CCUS and offshore wind case studies to follow in this report, is to include a sensitivity analysis which demonstrates how the NPV of a project or a policy changes as the discount rate varies.

1.2.4. Conclusion □□

近年来社会□□率□得越来越重要并将□□保持□种□□，而政府方面在减排上的投□即是□社会□□率的□用。□了保□□低碳技□的大□投□，各国政府采用的□□率□当低于私人企□开展的相同投□的□□率。但□于制定超低□□率（每年等于或低于 2%）的情况仍存在争□。无□□某个□境政策的收益和成本□□率的制定采用哪种“□整”，未来仍会引起很大担□。根据市□表□和人□的□□，□□率的制定仍然非常具有争□性，需要在道德□准和效率□准之□□衡。因□无法得知未来后代“想要”或“需要”什么，很□做到“跟未来一□公平”，也因此很□定□□在不存在的想象中的个人的□利。

□而言之，制定一个□一准确的社会□□率很有挑□性，□多因素如□□偏好、□本社会机会成本、□目□□、□□和不确定性都会影响社会□□率的制定。本章□述了采用社会□□率方法□行□□主要特征，解□了□何社会□□率要制定的低于□本商□成本，并□□了□生争□的主要原因。□本□告中 CCUS 技□和海上□□的案例研究作出的建□及其□一步□用，包括了演示□□率波□如何引起□目或政策□化的敏感性分析。

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Appendix I

Benefit-Cost Ratio (BCR) represents the ratio of total discounted benefits derived from a project, divided by its total discounted costs as in equation (9):

$$\mathbf{BCR} = \sum_{t=0}^{T} \frac{\frac{Bt}{(1+r)^t}}{\frac{Ct}{(1+r)^t}} \qquad (9)$$

The project leads to an increase in real wealth when the BCR is greater than 1. It is also important to mention than when comparing projects of different scales, the use of the BCR better reflects the generation of real wealth. For instance, although a project with total benefits of $1 million might lead to a greater increase in real wealth than a project with benefits of $100, the BCR might still not be as high due to high costs incurred.

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Address 地址: Floor 2, Zone D, 1 Tianfeng Road, Luogang, Guangzhou, Guangdong, China 中国广东省广州市科学城天丰路 1 号 D 区 2 楼

Tel 电话: **020 3211 7500**

Email 邮件: **information@gdccus.org**

Web 网站: **www.gdccus.org**

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