



ECONOMICS OF ENERGY INNOVATION
AND SYSTEM TRANSITION

Deciding how to decide:
Risk-opportunity analysis as a generalisation
of cost-benefit analysis

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1. INTRODUCTION

Policymaking in the UK, the US and many other parts of the world relies heavily on cost-benefit analysis, applied within a market failure framework that rests on the theoretical foundation of welfare economicsⁱ. These techniques have their roots in the so-called ‘Marginal Revolution’ of the 1870s. As the UK government’s guide to policy appraisal (the ‘Green Book’) acknowledges (section 5.5)¹ these techniques are appropriate for informing policy in contexts of marginal change, but work less well outside those conditions.ⁱⁱ So, what should be done when the aim is to change big things quickly, or where opportunities for transformative change are available?

Concerns have been raised that applying marginal analysis techniques outside their appropriate realm may create a bias towards inaction.ⁱⁱⁱ But finance ministries may be equally concerned that if policymakers are given free rein to label their policies as ‘transformational’ in intent, and therefore exempt from cost benefit analysis, a bias for action may be hard to contain. The challenge, then, is to define an approach to informing policy in a broad set of conditions that has analytical rigour, demands a proportionate amount of effort, and avoids undue bias in either direction.

¹ “Social CBA and Social CEA are “marginal analysis” techniques. They are generally most appropriate where the broader environment (e.g. the price of goods and services in the economy) can be assumed to be unchanged by the intervention. These techniques work less well where there are potential non-marginal effects or changes in underlying relationships. This is due to the difficulties inherent in pricing such changes.” (Section 5.5)

2. DECIDING HOW TO DECIDE: THE THEORETICAL FOUNDATION

Social cost-benefit analyses of policy, such as the UK's guidelines contained in the HM Treasury Green Book (GB), are mostly applicable in situations where the assumptions on which the theory is based are reasonable ones to hold – i.e. the difference between those assumptions and reality is not so great as to significantly alter the conclusions of any analysis. Three important common assumptions are:

- i- **Marginality:** A policy intervention involves marginal change; it is not expected or intended to cause 'structural' change, i.e. change in the prices or existence of goods and services, the relationships between economic variables, the rules of economic behaviour, the existence of institutions and structures, or the values of macroeconomic variables (such as GDP growth or employment);²
- ii- **Homogeneity:** The heterogeneity of affected actors, of their interests, and of the dimensions of the intended and unintended outcomes of policy, is not sufficiently high, or important enough, to be significant factor in the choice of policy.³
- iii- **Certainty:** All parameters and possible outcomes are sufficiently well-known to be described accurately with quantified probabilities.⁴

Conversely, if a policy is expected or intended to lead to any of the non-marginal changes described above (which may not necessarily be large, but will always be structural), if the heterogeneity of actors and interests matters substantially to the policy objectives, and/or if possible outcomes cannot be confidently assigned probabilities, then the situation cannot be adequately analysed with social cost-benefit analysis as described in the GB. While branches of traditional welfare economics exist that address some deviations from these three key assumptions, they do not solve the core issues that we describe below. In such situations, the appropriate theoretical foundations are those that describe the behaviour of the economy in conditions of dynamic change and disequilibrium, incorporate a diversity of actors, interests and impacts, and acknowledge the existence of knowledge gaps and fundamental uncertainty. This alternative body of theory has been called 'complexity

² Notably, path-dependent economic dynamics are generally not considered, for instance long-term growth and productivity effects (sections 6.3-6.6).

³ While the GB provides comprehensive guidance to work with heterogeneity of distributional impacts and of domains (Annexes 2-3), it primarily focuses on applying weights to impacts on different socio-economic groups and domains, implicitly assuming impacts of similar nature but different magnitude.

⁴ While the GB recommends the analysis of risk, including optimism bias, and provides guidance to do so (Annex 5) it assumes that all possible outcomes of policy decisions can be exhaustively enumerated and that probabilities can be known or assumed. This leaves little space for the consideration of fundamental uncertainty, and risks encouraging undue reliance on unfounded assumptions.

economics', since it describes the economy as a complex, adaptive system.^{iv}

3. THE RATIONALE FOR POLICY

In situations of marginal change, it is assumed that no new economic resources are created. Consequently, the aim is to allocate the existing resources as efficiently as possible. A state of optimum allocation (Pareto efficiency) can be defined, from which deviations can be identified. 'Market failure' is then defined as a situation where the market mechanism alone cannot achieve this state of optimal static, allocative efficiency.^v Policy action can be justified if it would correct the failure, and restore the market to this optimal state.

In situations of non-marginal change – or over longer timescales in which non-marginal change is inevitable – the economy cannot be assumed to be in equilibrium. Without equilibrium, an optimal allocation of resources cannot be defined. Over such temporal or spatial scales, the creation of new economic resources and structures is a constant, ongoing process.^{vi} New possibilities are created more quickly than they can be explored, so the economy will only explore a comparatively small and ever-decreasing proportion of its possible future configurations.^{5, vii} Since knowing, enumerating and assessing all of these possible states is not possible, an 'optimum' course of action cannot reliably be identified. In such conditions, the primary concern of policy is *which* of the many possible ranges of new economic resources and structures might be created, and how can they be most effectively brought into being. In other words, the primary aim is not allocative efficiency, but dynamic effectiveness. For these situations, a 'market shaping' rationale^{viii} may be appropriate: policy action can be justified if it prepares for change that is likely, brings about change that is desirable, and/or avoids change that is undesirable. Policy action in these conditions is about 'steering' in an uncertain, changing environment, rather than about 'optimising' an outcome in a world of certainty.

4. THE ANALYSIS TO INFORM POLICY DECISIONS

In situations where the assumptions of marginality, homogeneity, and certainty are appropriate, cost benefit analysis can be a useful technique for informing policy decisions.

⁵ The economy is therefore non-ergodic: its average behaviour over time is not the same as the average of all its possible states.

Outside this domain, cost benefit analysis can be misleading. In such cases, policy analysis must deal appropriately with disequilibrium, diversity, and uncertainty. Here their implications are discussed in reverse order.

a) Uncertainty: from costs and benefits to risks and opportunities

In situations, or on timescales, of non-marginal change, there is fundamental uncertainty around the economic outcomes of policy decisions.^{ix} This arises from technological change, the actions and intentions of other economic actors, the interconnectedness of systems, the behaviour of the economy as a whole, and the possible emergence of windows of opportunity or unexpectedly disruptive events. Fundamental uncertainty means that the probabilities of some outcomes are not known. Often the full set of possible outcomes cannot even be identified or enumerated. In the presence of such uncertainty, sets of likely, worst and best case outcomes might be identified, but the expected value of these outcomes cannot be reliably calculated.⁶ When the analysis to inform a policy decision is limited to quantifiable costs and benefits, the danger is that these fundamentally uncertain outcomes, which in some cases may be important or even extreme outcomes, are excluded or guessed-at. This is unlikely to provide sufficient analytical rigour to guide policy action. A more appropriate course is to abandon the requirement for all outcome variables to be quantified with known probabilities and expected values, and instead broaden the analysis to consider all significant opportunities and risks – whether quantifiable or not.

b) Diversity: from one-dimensional to multi-dimensional assessment

In situations where the heterogeneity of actors, interests and policy outcomes is highly relevant to achieving the policy objectives, it is unlikely to be helpful to analyse policy options by aggregating all impacts into a single metric – as is done in cost benefit analysis. This is because there is no single method for objectively converting policy outcomes in different dimensions (industrial competitiveness, public health, environmental integrity) into the metric of money. There are many such methods that have been developed: stated preferences, revealed preferences, subjective wellbeing approaches, statistical value of a human life, the value of ecosystem services, etc. The choice of which method to use is subjective and to some degree arbitrary, and yet it unavoidably determines the relative weighting that the analysis gives to the different dimensions of interests and outcomes. Normative decisions are thereby made implicitly, by analysts, and subsequently presented as objective analysis. Where differences of interests are important to the policy choice, these normative decisions should be made explicitly, and by legitimate decision-makers as opposed to analysts. It is therefore more helpful for the decision-maker if an analysis is multi-dimensional, with options evaluated (with respective uncertainty) against a set of domain-specific metrics, each appropriate to its own dimension, rather than converting all outcomes into a single metric and aggregating these into a single valuation. The role of the analysis is

⁶ It is for this reason that, for example, probabilities cannot be applied to any of the emissions scenarios of the Intergovernmental Panel on Climate Change.

then to provide the decision-makers with all the available information relevant to making an informed decision.

c) Disequilibrium: from static to dynamic assessment

In situations of non-marginal change and economic disequilibrium, a primary concern of policy – as discussed above – is dynamic effectiveness: how effectively new economic resources and structures are brought into being.^x A policy's dynamic effectiveness cannot be assessed by considering its potential outcomes at a moment in time, as is done by cost benefit analysis. It can only be assessed by considering its effect on *processes of change* in the economy. These may include innovation, diffusion, growth, contraction, reorganisation, or replacement of one set of economic resources, assets or structures with another. It is therefore processes – the likely direction, rate, and magnitude of change – that should be the focus of analysis.

In complex systems – such as the economy in situations of non-marginal change – change in behaviour at the system level cannot be extrapolated from change in behaviour of a single component. It is typically the relationships between components that determine system behaviour, more than the behaviour of individual components themselves. This means that the effect of a policy cannot be assessed in isolation; it can only be understood by assessing its interaction with other relevant components of the system of which it is a part.

Relationships between components of an economic system can be understood in terms of the feedbacks they create: reinforcing feedbacks, which accelerate change; and balancing feedbacks, which tend to preserve a steady state. Interactions between feedbacks cause non-linear behaviour, and disproportionate relationships between cause and effect. This creates the potential for tipping points, or sensitive intervention points, in socioeconomic and technological systems, where small policy inputs can achieve disproportionately large outcomes.^{xi} A rigorous approach to mapping feedbacks, and assessing how policy options may affect existing feedbacks or create new ones, can be an appropriate way to analyse the effect of policies on processes of change.^{xii}

The three approaches discussed above may be combined in a 'risk opportunity analysis', a more general form of cost benefit analysis appropriate for situations of non-marginal change, heterogeneous actors, and fundamental uncertainty. In this more general approach, much of the methodological guidance and many of the steps of analysis described in the GB can be maintained, while additional guidance can address the aspects of the situations to which the traditional approach does not apply. An overview of the steps involved in risk opportunity analysis, as compared to those of cost benefit analysis, is included at Annex A. Examples of problems of non-marginal change are given in Annex B. An illustrative example of how cost benefit analysis and risk opportunity analysis can arrive at different conclusions is given in Annex C.

5. THE MODEL TO INFORM ANALYSES

In situations where the standard, conventional assumptions of welfare economics and cost-benefit analysis are appropriate, the primary concern of policy is the optimal allocation of existing economic resources. Optimisation models can therefore be useful in informing analysis. If the heterogeneity of actors' interests is not relevant to policy objectives, models may appropriately use a single 'representative agent'. If only marginal change is expected or desired, models can assume conditions of equilibrium. If there is no fundamental uncertainty and all the important variables behave with quantifiable probabilities, the models that predict precise outcomes will be useful as an input to cost benefit analysis.

In situations where any of these conditions do not hold, the reverse is true. Models based on inappropriate assumptions will not provide helpful input to such an analysis. The models appropriate for informing policy in situations of non-marginal change are those that do not impose the existence of an economic equilibrium, that incorporate heterogeneous agents, and that represent system dynamics so as to simulate processes of change through time, rather than calculate outcomes at moments in time. Agent-based models, system dynamics models, and non-equilibrium macro-econometric models can fit this description, as can some qualitative models.

6. CONCLUSION: A DIFFERENT SET OF TOOLS

Situations involving non-marginal change are fundamentally different from those that do not. To inform policy, an appropriate set of economic concepts and tools needs to be employed. Table 1 summarises how the choice of theoretical foundation, rationale for policy, analysis, and models relates to the nature of the situation and the policy aim.

It may be seen from this comparison that the economic concepts and tools used for situations of non-marginal change are more generalised versions of those used for situations of marginal change:

- Market failure is a specific application of market shaping, where the aim is to restore a state of optimum allocative efficiency.
- Cost benefit analysis is a specific application of risk opportunity analysis, where there is high confidence in expected outcomes and their probabilities.
- Conventional welfare economic theory and models apply to the special case of equilibrium, which is one of the many possible states of dynamic systems that can be explained by complexity.

The ‘non-marginal’ set of economic tools and concepts thus does not contradict the ‘marginal’ set that is more widespread in use. Instead, it defines the scope of relevance of the ‘marginal’ set, and expands the range of policy situations for which economic analysis can provide a useful guide.

Table 1: choosing the appropriate set of economic concepts and tools

	the aim or expectation is marginal change	the aim or expectation is non-marginal change	Reason for difference (in non-marginal case)
Purpose of the policy intervention	Allocative / static efficiency	Dynamic effectiveness	Primary concern is not how efficiently resources are allocated (optimisation), but how effectively economic structures are changed or created (steering)
Rationale for policy	Market failure	Market shaping	Over period/scale of concern, the market is changing, optimal states cannot be reliably identified
Appropriate analysis	Cost benefit analysis	Risk opportunity analysis	Fundamental uncertainty makes precise costs and benefits unknowable
Appropriate models	Equilibrium / optimising	Disequilibrium / simulating	Need to assess effect of policy on processes of change, not just on end state
Theoretical basis	Equilibrium / welfare economics	Complexity economics	Need theory that can explain non-marginal change, not assume its absence

ANNEX A: STEPS IN RISK OPPORTUNITY ANALYSIS, AS COMPARED TO COST BENEFIT ANALYSIS

In situations of marginal change, cost benefit analysis (CBA) can be used to choose between policy options. The main steps in this process are:

- 1) The costs or benefits of options are valued and monetised where possible to provide a common metric [GB2.12]
- 2) Discounting is used to compare costs and benefits occurring over different periods of time – it converts costs and benefits into present values [GB2.17] Where risk and uncertainty exist, probabilities are assigned and expected values are used.
- 3) The preferred option is determined based on the difference between the discounted costs and benefits (net present value: NPV), or their ratio (benefit cost ratio: BCR), together with other considerations [GB2.19].

Risk opportunity analysis

In situations of non-marginal change, risk opportunity analysis (ROA) can be used to choose between policy options. The main steps in this process are:

- 1) System boundaries are delimited, and all relevant interactions and positive and negative feedbacks are identified; (suitable models, if required, are chosen or designed);
- 2) The potential effects (intended and unintended) of policy options in the economy are assessed (see below), and uncertainty ranges estimated;
- 3) The risks and opportunities of options (including most likely, best-case and worst-case outcomes) are compared along multiple relevant metrics and dimensions (where probabilities may be quantifiable or unquantifiable). This includes consideration of systemic risk (breakdown of an existing system), and systemic opportunity (where policy generates a whole new system, or set of opportunities);
- 4) The preferred option is determined by the decision-maker based on a qualitative judgment of the scale of the opportunities and risks, compared to the cost of the intervention. This will necessarily be a subjective judgment (since it incorporates a weighing of outcomes in different dimensions), informed by an objective assessment of likelihood and magnitude of possible outcomes in each of the relevant dimensions.
- 5) A clear statement of the reasoning behind the decision is recorded including the decision-making body's assessment of the risks and opportunities in their various dimensions. (This can be helpful for transparency and for learning from experience).

The potential effects of policy options on processes of change in the economy are assessed by:

- a) Mapping the relationships between components of the economic system of concern, in terms of reinforcing and balancing feedbacks⁷;
- b) Identifying the likely effect of policy interventions on system behaviour, based on changes to the structure of relationships between components (including relationships created by other policies that already exist or are under consideration). This may be extended to include the creation of a range of scenarios and storylines of cumulative causation that result from policy action, where longer-term effects are likely to be important to policy objectives;
- c) Comparing likely effects in terms of:
 - i. Direction of change (of any variables of policy interest)
 - ii. Magnitude of change (which may or may not be quantifiable)
 - iii. Pace of change
 - iv. Possible accumulation of risk and opportunity (option generation)
 - v. Confidence, or range of uncertainty, in each of i to iv above.

⁷ For the purposes of CBA, detailed guidance is given on how costs and benefits can be valued. Equivalent guidance for ROA would explain the use of systems thinking to map relationships between system components and understand the effect of interventions on system behaviour.

Table 2: Key differences between CBA and ROA

	Cost benefit analysis	Risk opportunity analysis	Reason for difference (in case of ROA)
Dimensions	Compare options based on a single metric	Compare options based on multiple metrics	Highly heterogeneous interests of actors
Scope (inputs)	Assess options individually	Assess options in combination	Emergence (interactions determine system behaviour)
Focus	Focus on expected outcomes at moments in time	Focus on expected processes that drive change over time (including nonlinear feedbacks)	Disequilibrium
Scope (outcomes)	Summary measures include only quantifiable costs and benefits* ⁸	Unquantifiable or long-tailed risks and opportunities (including systemic risk) central to consideration, so expected values are not used	Fundamental uncertainty
Directionality	Policy should apply minimum directionality (e.g. technology neutrality) to avoid distortion	Policy should aim for maximum leverage (ratio of outcome to input) in desired direction of change	Path dependence
Threshold of viability	Benefits should exceed costs (NPV>1) including opportunity costs, (or: action is justified until marginal costs = marginal benefits)	Intervention should be enough to generate self-reinforcing change in desired direction, or to achieve stated objective with acceptable likelihood	Disproportionality of cause and effect

⁸ Note: GB guidance on CBA is that it should include assessment of qualitative, unquantifiable costs and benefits [GB5.57]. But these are necessarily excluded from the calculation of a net present value or benefit cost ratio. In situations of non-marginal change, these unquantifiable factors are likely to be the most significant issues under consideration; therefore any summary measure that excludes them is likely to be not just incomplete, but either irrelevant or misleading in its comparison of policy options. [See also GB6.59: The focus of appraisal should be on benefits and costs important to the decision being considered.]

ANNEX B: EXAMPLES OF PROBLEMS OF NON-MARGINAL CHANGE

(1) Climate change mitigation and low-carbon innovation

Achieving the goals of the Paris Agreement on climate change in any country involves a deep transformation of many industries and economic systems, and a large-scale re-organisation of economic and industrial activity.

- i. This policy objective does not meet the criteria for marginal analysis:*
 - a. Diversity: Stakeholders and their needs and aspirations are heterogenous, over several dimensions and variables. Some workers and investors will gain from the creation of jobs in new low carbon industries, others will lose from the phase-out of high-carbon incumbents. Some citizens will benefit from cleaner air and better health, others may consider themselves inconvenienced by the installation of new energy infrastructure. Most are likely to benefit from reduced exposure to the dangers of climate change, but to different actual and perceived extents. Decision-making will benefit from analysis that allows each of these different interests to be considered explicitly.
 - b. Disequilibrium: Low-carbon innovation is a non-linear process, featuring strong positive feedbacks and sensitive intervention points. The diffusion of new technologies and their rapid improvement and cost reductions (through learning-by-doing, economies of scale) can be highly disruptive. Structural economic change is the primary goal of decarbonisation policy. Decision-making will therefore benefit from analysis that considers processes of change in contexts of disequilibrium.
 - c. Uncertainty: The impacts of climate change, as well as the outcomes of low-carbon innovation policy, are both characterised by fundamental as well as long-tailed uncertainty. Scientists do not know how quickly the disintegration of continental ice sheets will contribute to sea-level rise, and although they can make estimates, they cannot confidently assign probabilities to the full range of possible outcomes. Similarly, analysts do not know which of several possible low carbon technologies will achieve widespread adoption in sectors such as steel, chemicals, and shipping. Some assessment can be made of the likely effects of policies on private investment, industrial growth, job creation, and the evolution of systems such as the power sector or the construction sector, but outcomes in many of these dimensions – of central importance to policy – may not be reliably estimable with quantified probability. Decision-making will benefit from analyses that assess these potential outcomes using the best available evidence,

considering significant risks and opportunities even when they cannot be quantified.

(2) Policy for preparing for and responding to a pandemic

The COVID-19 pandemic, and governments' responses to it, have highlighted the difficulty of policymaking to prepare for and respond to pandemics. Challenges include determining the level of preparedness that society should continuously maintain, the nature of the health system response, the form of the economic response and the structure of any economic stimulus package post-crisis.

i. Preparedness and response to pandemics do not meet marginal analysis criteria:

- a. **Uncertainty:** The likelihood and frequency of pandemics is not a well-known distribution. It has a heavy tail that is not well characterised. The probability of a pandemic of a given seriousness is therefore not well defined, and neither is the expected economic value of any preventative or preparatory measures. Decision-making will benefit from consideration of worst-case scenarios, even if their probabilities cannot be reliably estimated.
- b. **Disequilibrium:** The propagation of diseases is highly non-linear, such that delays in acting can result in disproportionate impacts, damages, and loss of life. The effect of protective measures (e.g. wearing a face mask) may be qualitatively different at the level of an individual economic actor and at the level of a society. The effect of a pandemic can include the economy falling far below full-employment equilibrium. Decision-making will therefore benefit from analysis that considers disequilibrium dynamics, including emergent effects of policies at the societal level.
- c. **Diversity:** There are trade-offs between the different dimensions of policy outcomes, including public health, GDP, employment in different sectors, and disruption to normal lifestyles. There are also significant differences between the interests of different stakeholders: for example, between schoolchildren and highly vulnerable older citizens. Decision-making will benefit from analysis that makes these trade-offs explicit, so that the implications of policy options are more clearly understood.

(3) Regional development and 'levelling up'

Regional development is highly path-dependent, as local industrial, innovation, and development capabilities build on existing capabilities. Success breeds success: regional development allows the creation of ever higher-wage occupations and living standards, which attract highly-skilled labour, which helps fuel development further. Wages typically follow steep gradients between highly developed and less developed regions both across and within countries. Assessing regional development policies based on comparisons of local

productivity, wages, and prices can inadvertently strengthen the typical winner-takes-all positive feedback that already exists.

- i. Regional development policy does not meet the criteria for marginal analysis:*
 - a. Disequilibrium: The aim of regional development policy is generally some form of structural economic change, including the creation or growth of new jobs and industries. Reinforcing feedbacks between the level of development of a region, and its ability to attract resources necessary for further development, can help meet this objective. Similarly, the objective can be undermined by the reinforcing feedback that exists when a slowdown in regional development drives highly skilled labour away, leading to intensified economic decline. Decision-making will benefit from analysis that considers the effect of policy options on these processes of change, since they are of central importance to policy objectives.
 - a. Uncertainty: Regional development policy and infrastructure investment can affect wages and attract new workers to a region, changing its economic structure in a path-dependent way. It will often be difficult to reliably quantify any of these changes, or to reliably assign probabilities to their different possible outcomes. Since these changes are central to the objectives of policy, decision-making will benefit from analysis that includes the best available evidence on possible outcomes, even if this is qualitative. Exclusion of these unquantifiable factors would be likely to make the analysis irrelevant to the decision.
 - b. Diversity: Stakeholders in this situation are heterogeneous and many dimensions of economic outcomes are involved, potentially including wealth, health, quality of life, and inequality. The differences in interests between people living and working in one region and those in another region is, by definition, of central concern to policy. Decision-making will therefore benefit from analysis that makes these differences in interest explicit, rather than aggregating them into a single estimate of value.

ANNEX C: AN ILLUSTRATIVE EXAMPLE HOW COST BENEFIT ANALYSIS AND RISK OPPORTUNITY ANALYSIS CAN ARRIVE AT DIFFERENT CONCLUSIONS

In recent years, many governments have made policy decisions about whether to subsidise low carbon energy technologies in the power sector, and if so, which of those technologies to support.

Cost benefit analysis (CBA) has often been used to inform these decisions. An example is provided by Frank (2014)^{xiii}. This study compares the policy options of replacing coal power (the most carbon intensive technology) with wind, solar, nuclear, hydroelectric, and gas power. For each technology, the benefits of avoided emissions are measured using a consistently applied value in dollars per tonne of carbon, multiplied by the tonnes of carbon emissions avoided over the course of a year by using this alternative technology, instead of coal. The net cost of deploying each technology as a replacement for coal is estimated by comparing its capital costs and operating costs to those of coal, taking into account differences in capacity factors (the proportion of time that the technology is used to generate power), and differences in their ability to generate power at times when demand is high. The emissions benefits and deployment costs are then added together to produce a single net cost/benefit value for each of the five options. Based on a comparison of these values, the conclusion is reached that the most cost-effective approach to reducing power sector emissions would be to replace coal with gas. Hydroelectric and nuclear power are assessed to be the next best options, far ahead of wind, with solar power being the least cost-effective option of all.

A risk opportunity analysis would have compared these policy options differently.

- i) Assessing the potential effects of policy options on processes of change in the economy

In the CBA example described above, policy options are compared on expected outcomes at a moment in time. A risk opportunity analysis (ROA) would instead compare the effect of policy options on processes of change in the economy.

The processes that lead to changes in relative costs between different technologies would be one component of the analysis. It is well documented that new technologies benefit from reinforcing feedbacks that lead to persistent improvements in performance and reduction in cost over time. These include learning-by-doing, economies of scale, and the development of complementary technologies.^{xiv} Observations show that the cost of wind power has fallen by 15%, and that of solar power by 28%, with the doubling of their respective global deployment^{xv}, and that such trends are in fact, predictable^{xvi}. In contrast, no strong trend is visible over time in the costs of coal or gas resources.^{xvii}

The processes that lead to structural change in the power sector would be another object of analysis. An ROA would consider not only the emissions reductions immediately achieved by each of the policy options (marginal changes), but also the extent to which they create opportunities for further, non-marginal changes. Replacing coal with gas power provides limited opportunity for structural change relevant to the policy objective of reducing emissions. A power system comprised wholly of gas plants would still emit carbon, albeit less than one of coal. If the future policy goal was to continue emissions reductions, then these gas plants would eventually have to be replaced, incurring additional costs. In contrast, the diffusion of zero emission technologies such as solar and wind power, together with

complementary technologies such as batteries, increases the likelihood of structural change in the direction of developing a zero-emission power system.

An ROA might conclude that deployment subsidies would be likely to strengthen the reinforcing feedbacks driving cost reduction in wind and solar, but unlikely to lead to the same effect in the case of gas. It could also anticipate those very cost reductions dynamically and assess the likelihood of solar eventually becoming less costly than gas overall. It might assess support for solar and wind as being more likely than support for gas to generate options for structural change relevant to the policy objective of reducing emissions. And it might assess support for solar as being likely to lead to a faster pace of change than support for wind, given the difference in observed rates of cost reduction.

ii) Comparing the risks and opportunities of policy options

An ROA would compare the policy options along several different dimensions of interest to policy. These might include:

- **Cost of electricity:** This would consider how each of the options might affect the cost of electricity not just immediately, but also over time, as described above.
- **System reliability:** a rapid transition towards intermittent renewables has system stability implications that are not monetizable that would be assessed, while committing the grid to a gas lock-in also incurs risks that may become challenging to manage at a later stage, which can also be assessed.
- **Air quality:** The burning of fossil fuels, including gas, contributes to air pollution that has damaging effects on public health. Solar and wind power do not have this effect, although local pollution can be caused by the mining of materials used in their technologies.
- **Industrial opportunity and jobs:** As solar and wind power take a growing share of the global market for new power capacity additions, jobs in the industries manufacturing, installing, and maintaining these technologies are growing. The same industrial growth is not apparent in the global market for gas power technologies.
- **International influence:** The risk of climate change depends on global emissions, not national emissions. The policy of one country may influence the choices of another, particularly if it is perceived as either notably successful or unsuccessful in meeting its objectives. A government considering support for either renewables or gas may wish to consider how its choice might influence that of other high-emitting economic powers.
- **Energy security:** For countries that are highly dependent on imported fossil fuels, the opportunity to generate power from domestic renewables instead of imported gas might be an important consideration.

- **Social preference:** Some communities may strongly support renewables over gas for the perceived climate change benefits; others may oppose wind turbines on the basis that they spoil the view.

It is up to the decision-maker to determine which of these dimensions are relevant to their policy objectives. For those that are relevant, the task of the analyst is to provide the best available information on the potential effects of policy options.

An ROA would not seek to aggregate the risks and opportunities in each of these dimensions by converting them into a single metric. Such a conversion would necessarily make implicit decisions about the relative importance of outcomes in each of these dimensions. Instead, an ROA would make separate assessments in each of these dimensions, expressing each in its own metric (e.g. dollars per megawatt hour of electricity; number of early deaths from air pollution; number of new jobs created; proportion of energy imported; etc). The decision on the relative importance of these diverse interests would then be kept explicit and left in the hands of the decision-maker.

Several of these outcomes are likely to be subject to fundamental uncertainty. For example, the cost trajectory of solar panels may be relatively predictable, but the cost of electricity from a power sector entirely reconfigured around renewables and flexibility technologies is much less certain. The growth of global markets for solar and wind technology may be foreseeable, but the likelihood of a given country succeeding in taking a given share of this market is impossible to reliably quantify. The extent to which one country's actions will influence another country is deeply uncertain. If the decision-maker determined such outcomes to be relevant to policy objectives, an ROA would not exclude the unquantifiable from consideration; instead, it would provide the best available information on each potential outcome, whether quantifiable or not.

- iii) Judgment of the scale of opportunities and risks compared to cost of the intervention

The CBA example cited above reaches a firm conclusion: 'the net benefits of new nuclear, hydro, and natural gas combined cycle plants far outweigh the net benefits of new wind or solar plants.' Renewable incentives that favour wind and solar are concluded to be 'a very expensive and inefficient way to reduce carbon dioxide emissions'.^{xviii}

An ROA might be more qualified in its conclusions, as it would recognise the inherent subjectivity in the relative weighting given to each potential outcome in their different dimensions. However, it is not difficult to see how an ROA could come to a different conclusion to that of the CBA in this case. On the dimension of electricity costs alone, the ROA might conclude that support for solar power was the most cost-effective option; wind the second, and gas the least. This conclusion might be strengthened when the other dimensions were taken into account, given the potential benefits of renewables in terms of air quality, energy supply security, and industrial opportunity.

The purpose of this example is not to argue that the CBA conclusion was wrong, and our hypothetical ROA was right. Instead, the purpose is twofold: first, to illustrate how a CBA and an ROA could plausibly reach different conclusions when applied to the same policy decision; and second, to support the contention that the ROA would provide more helpful analysis to the decision-maker in this case. If the decision-maker's interests are limited to short-term marginal change in the power sector, then the CBA may be sufficient. If they encompass non-marginal change in the power sector, as well as outcomes in related policy dimensions, such as industrial opportunity and the effectiveness of the global response to climate change, then the ROA will provide a better quality of analysis.

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