**ANNEX I: Including employment effects using shadow wages in CBA**

**Step I:** The first assumption of our analysis is that the total investment costs (IC) of any project can be comprised of both capital costs () and labour costs (), such that:

**Equation 1:**

In our study, we assumed a ratio of 60 percent capital costs to 40 percent labour costs. There is no fixed formula for estimating the ratio of capital vs. labour costs of infrastructure investments. Generally speaking, the total cost of labour would depend on factors such as the type of construction, location, materials, and project scope. Depending on these factors, the percentage of construction labour costs can typically range anywhere between 20% and 40% of total investment costs (CLMA 2014). In our case, we assumed a higher estimate for labour costs based on the fact that the investment is a large infrastructure project, with a long construction period, situated in the centre of a metropolitan city. Based on this assumption, the capital costs of the project can be expressed as:

**Equation 2:**

And, the labour costs of the project can be expressed as:

**Equation 3:**

**Step II:** While the capital costs of the project remain fixed, we can apply a conversion factor (CF) to labour costs in order to adjust for labour market conditions in the region. The conversion factor represents the ratio between the shadow and market wage. The shadow wage (*w\**) can generally be expressed as:

**Equation 4:**

Where, represents the welfare weight of a social welfare function, is the opportunity cost of labour in terms of production in its former use, and , the manufacturing market wage, is the prevailing wage rate for workers hired in the new investment project. Depending on region-specific labour characteristics, the value of varies according to which category the workers displaced by the project come from (Del Bo, Fiorio, and Florio 2011).

Using the estimated conversion factor, we can adjust labour costs in order to reflect more context specific labour market conditions in the region. Because the shadow wage rate is especially sensitive to unemployment, we can assume that higher rates of unemployment will result in lower CFs and that lower rates of unemployment will result in higher CFs (i.e. the CF needs to do less to adjust for differences in job alternatives). The adjusted labour costs of the project can thus be denoted as:

**Equation 5:**

Whereby, , and therefore, . Adjusting for labour costs in this way, particularly in cases of high regional unemployment, can reduce the total investment costs of the project, such that:

**Equation 6:**

The assumption here is that the benefits of generating employment offset the additional costs needed to incentivise workers to switch between labour alternatives.

**Step III:** The adjusted costs accounting for employment effects can then be re-integrated within CBA using the standard NPV formula, such that:

**Equation 7:**

**ANNEX II: Including equity using distributional weights in CBA**

**Step I:** Distributional weights for different neighbourhoods (with different income bands) can be calculated based on the following social welfare (*W*) function (Atkinson 1970):

**Equation 1:**

Where *Yi* represents the income of individual *i,* is the elasticity of social marginal utility of income or inequality aversion parameter, and *A* is constant.

If the social marginal utility of income is defined as:

**Equation 2:**

Then taking per capita national income, , as numeraire, we can set the marginal welfare at that level of income as equal to one:

**Equation 3:**



Therefore, the expected distributional weight for each region , can be denoted as:

**Equation 4:**

Values forderived from government social policies have been proposed, with typical rates ranging between 1 and 2 (Atkinson 1970; Gouveia and Strauss 1994; Lambert, Millimet, and Slottje 2003; Stern 1977; Young 1990). This inequality aversion parameter measures the responsiveness of demand for a particular good or service with respect to changes in income and tells us whether a particular good represents a necessity or a luxury. Due to decreasing marginal returns, the evidence suggests that on the whole, the social marginal utility of one additional Euro for someone earning €1000 is worth double that of someone earning €2000 (H. M. Treasury 2003). In general, higher elasticities will do more to adjust for differences in the social marginal utility of income.

If we assume a population with an average income of €20,000, for example, we can derive distributional weights for different income bands and different elasticities of income (see Table 5 for an example).

|  |
| --- |
| **Table 5:** Relationship between income level, elasticity and distributional weight  |
| **Income (EUR)** | **Distributional weights** |
| **= 1** |  **= 2** |
| 5,000 | 4 | 16 |
| 10,000 | 2 | 4 |
| 20,000 | 1 | 1 |
| 50,000 | 0.4 | 0.16 |
| 100,000 | 0.2 | 0.04 |

**Step II:** Next, we calculate a conversion factor based on the ratio between the expected weighted benefits and the expected unweighted benefits . The expected unweighted benefit for each affected neighbourhood can be expressed as:

**Equation 5:**

Where, , is the affected population of neighbourhood *i, N* represents the population of the entire affected area, and re.

And where, the expected weighted benefits for region can be denoted as the distributional weight for region multiplied by its unweighted benefit:

**Equation 6:**

Thus, the total expected weighted benefits would be:

**Equation 7:**

And the conversion factor (CF) would be the ratio between the expected weighted benefits and the expected unweighted benefits:

**Equation 8:**

**Step IV:** This conversion factor can then be used to adjust each annual benefit value in order to account for distributional effects. Such that, the overall benefits (*B*) can be denoted as:

**ANNEX III: Including risk aversion using certainty equivalents in CBA**

The added-value of adaptation for a risk-averse society can be accounted for by estimating the value of a “certainty effect”, that is, the added benefit of reducing external (environmental) uncertainty (for risk-averse individuals) by investing in protection. By estimating this certainty effect, we can generate a risk-ratio for each year that compares the expected cost of a flood event for an individual in a risk-averse versus a risk-neutral society. Assuming that the probability of a flood occurring in any given year *t*, is , and the probability of it not occurring is then the expected utility (*EU*) for each affected individual *i* can be denoted as:

**Equation 1:**

That is, the probability of a flood event not occurring for that year () multiplied by the average income per person plus the probability of a flood event occurring that year () multiplied by average income minus the estimated loss per person (*EAD*). The estimated loss per person is calculated as the damage from flood event in year *t* divided by the affected population (*N*).

If the certainty equivalent, denoted as *Y\**, is:

**Equation 2:**

Then the true loss, including loss due to risk, is given by:

**Equation 3:**

If society is risk-averse, then we assume a concave utility function such as for example when gives us the following:

**Equation 4:**

This allows us to calculate *Y\** as:

**Equation 5:**

This is a special case of concave utility functions of the form:

**Equation 6:**



These functions exhibit what is called constant relative risk aversion, given by the value of . When  is set equal to 1, then the function reduces by L’Hôpital’s Rule to:

**Equation 7:**



Once, *Y\** is known, the risk-adjusted cost in year *t* accounting for the certainty effect can then be calculated as:

**Equation 8:**

That is, the expected loss per person (*EL*) – estimated as real income minus expected income – plus the expected utility *(EU)*, minus *Y\*.* The risk conversion factor (CF) in year *t,* would then be:

**Equation 9:**

This ratio is calculated for each year, and can then be applied within CBA to adjust benefits accounting for risk aversion, such that:

**Equation 10:**

Adjusting benefits in this way, demonstrates how the willingness of households to pay to avoid an event, including the WTP of risk averse individuals to reduce or avoid the risk completely, might change when risk aversion is included in the analysis. When constant relative risk aversion is not assumed, then the extent of risk aversion can by adjusted by altering (Equation 6), wherein the higher the value of the more risk averse individuals are assumed to be.