Capital Substitutability and Weak Sustainability Revisited: The Conditions for Capital Substitution in the Presence of Risk

FRANK FIGGE

Sustainability Research Institute
School of Earth and Environment
University of Leeds
Leeds LS2 9JT, UK
Email: figge@sustainablevalue.com

ABSTRACT

The capital approach is frequently used to model sustainability. A development is deemed to be sustainable when capital is not reduced. There are different definitions of sustainability, based on whether or not they allow that different forms of capital may be substituted for each other. A development that allows for the substitution of different forms of capital is called weakly sustainable. This article shows that in a risky world and a risk-averse society even under the assumptions of weak sustainability the circumstances under which different forms of capital may be substituted are limited. This is due to the risk-reducing effect of diversification. Using Modern Portfolio Theory this article shows under which conditions substitution of different forms of capital increases risk for future generations.

KEY WORDS

Weak and strong sustainability, risk, substitutability, capital approach

1. INTRODUCTION

Although the concept of Sustainable Development has been debated for quite some time there is no consensus on a generally accepted definition of Sustainable Development. Most definitions have in common that they favour some kind of intergenerational equity (e.g. Goodland 1995; Goodland and Daly 1996; Gundling 1990; Pearce et al. 1994). Decision makers in theory and practice need a concept that allows to assess if intergenerational equity is achieved. The

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capital approach lends itself to this task. We can distinguish between different forms of capital in this context. Human-made capital (e.g. machines, buildings) and natural capital (e.g. minerals, water) are among the most frequently cited examples in this context. Capital provides a future material or non-material flow of service (Neumayer 1999, p. 9). It is commonly assumed that the amount of capital a generation has at its disposal is decisive for its development. A development is called sustainable when it leaves the capital stock at least unchanged (e.g. Harte 1995; Pearce et al. 1990; Prugh et al. 1999, p. 49; Stern 1997; Victor 1991, analogously Dixit et al. 1980; Figge and Hahn 2004a; Hartwick 1977, 1978a, b; Solow 1986). Put differently, it is assumed that intergenerational equity is achieved when each following generation has at least as much capital at its disposal as the preceding generation. While the idea of leaving capital stock at least unchanged is widely accepted, differences arise concerning the question of whether one form of capital (e.g. natural capital) may be substituted by another form of capital (e.g. human-made capital). There are two positions in this debate.

Weak sustainability is based on the assumption that different forms of capital are basically substitutes. Reducing one form of capital is considered to be acceptable as long as another form of capital is augmented accordingly. The substitution of resources has been discussed for quite some time (e.g. Figge and Hahn 2004b; Fisher 1983; Gutés 1996; Hartwick 1978a, b; Stiglitz 1974). Critics point out that the assumption that one form of capital can substitute another form of capital is erroneous (Daly 1990; Klaassen and Opschoor 1991). From their point of view different forms of capital have a complementary relationship. This is sometimes explained using the example of fish stocks (natural capital) and fishing boats (human-made capital) (e.g. Daly 1995; Goodland 1995; Krautkraemer 1998). From the point of view of weak sustainability fish stocks and fishing boats are substitutes. If this were true diminishing fish stocks could be substituted by an increase in fishing boats. Obviously the value of fishing boats relies on the existence of fish stocks. Fishing boats and fish stocks are therefore complementary. For a sustainable development both natural and human-made capital must therefore be preserved. This is the point of view taken up by *strong sustainability*. Strong sustainability presupposes that different forms of capital are complements.

On a very general level this distinction between weak and strong sustainability is widely accepted. There are, however, a range of points at issue on a more detailed level. In the context of this article the substitution of different forms of natural capital are of particular interest.

Some critics point out that the concept of strong sustainability could be used to justify that all forms of natural capital must be conserved and non-renewable resources will never be used (e.g. Beckerman 1994). This is based on the assumption that strong sustainability does not allow any substitution whatsoever. Daly (1995) has called this view absurdly strong sustainability. To justify the use of a non-renewable resource, substitution with a similar renewable resource, i.e. a resource that serves the same purpose, is usually allowed. A non-renewable energy source (e.g. oil) may, for example, be reduced to the same extent to which a renewable energy source (e.g. biofuel) is created. In contrast to weak sustainability the two resources must have similar characteristics, i.e. they must e.g. serve the same function. Weak sustainability would allow substitutes of a purely financial nature (Daly 1995), i.e. it is sufficient that the two forms of capital have the same value. Put differently, we can distinguish between different forms of weak and strong sustainability. Turner (1993), for example, distinguishes between four different forms of weak and strong sustainability that can be placed on a scale that ranges from complete substitutability to no substitutability. The distinction between weak and strong sustainability, as proposed in the existing literature, is therefore not clear-cut. However, all definitions are based on the distinction of whether a form of capital can be substituted by another form of capital.

As this article will show, in the presence of risk there are limits to the substitution of different forms of capital, even if the prerequisites of weak sustainability, however defined, are given. Put another way, even if one form of capital can be substituted by another form of capital intergenerational equity and therefore Sustainable Development might not be achieved. In the presence of risk weak sustainability is therefore not sufficient to allow capital substitution.

2. WEAK SUSTAINABILITY IN THE PRESENCE OF RISK

The future use of natural and human-made capital as well as the relationship between different forms of capital is usually subject to risk. In this article we speak of risk whenever a future outcome cannot be predicted with certainty. This is probably the broadest possible definition of risk.[1] Risk complicates sustainable decision-making. We must decide on the use or preservation of capital in a situation in which it is unclear if natural or human-made capital will provide benefit in the future, and if so how much. Risk can also encompass the question of whether different forms of capital can substitute each other or if they will have a complimentary relationship. This is the case, for example, when we don't know if we will need another form of capital (e.g. fishing boats) to use a given form of capital (fish stocks).

It is commonly assumed that human beings dislike risk, i.e. that they are risk-averse (e.g. Hardy 1923; Hawley 1893). This is also reflected in the way risks are dealt with in the discussion on natural capital. The two most prominent approaches in this context are the precautionary principle and safe minimum standards.

The precautionary principle, first used in Germany in the 1970s (Raffensperger and Tickner 1999, p. 4), states that in the presence of risk preference is given to prudence (e.g. Goodland 1995). More specifically it states that actions to protect the environment should be taken even before there is complete knowledge of the consequences of the loss of natural capital (e.g. Neumayer 1999, p. 115). The precautionary principle is used when (1) there is a threat, (2) there is uncertainty, (3) cause and effect are not proven and (4) there is a necessity to act (deFur and Kaszuba 2002, p. 157).

Safe minimum standards (Ciriacy-Wantrup 1968, p. 251) were originally developed for the preservation of species. Safe minimum standards advocate that a resource should only be used to a level that is considered to be safe. Safe minimum standards can be interpreted in both a context of certainty and a context of risk (Edwards-Jones et al. 2000, p. 213). When there is certainty safe minimum standards address the question of whether a resource should be used up to attain an economic benefit or be preserved. In the context of risk, safe minimum standards posit that resources should only be used to a level that ensures that the resource can regenerate. In the context of the preservation of species, this means that a species should only be reduced to a level that allows for its recovery. Safe minimum standards thus call for a sustainable yield.

The precautionary principle on the one hand provides a general rule on how to decide in the presence of risk and under the assumption of risk-aversion. Safe minimum standards on the other hand concentrate on individual resources or forms of capital. Society depends not on a single form of capital but on many different forms of natural and human-made capital. It is therefore safe to assume that society is not primarily interested in individual forms of capital but in the risk and return of the entire portfolio of different forms of capital it has at its disposal. As will be shown in the next section decisions must therefore consider systematically the impact on the entire portfolio of natural and human-made capital rather than relate to individual forms of capital. In contrast rules like the precautionary principle or safe minimum standards focus on individual forms of capital. As we shall see with the help of Modern Portfolio Theory, only decision tools that link individual risk to portfolio risk allow us to reduce risk on a portfolio level efficiently.

3. DIVERSITY OF CAPITAL – SUSTAINABLE PORTFOLIO THEORY

A society's different forms of capital will yield a future benefit. This yield can be interpreted as a return. The return is at the same time not certain, i.e. it is attended by risk. Return and risk are at the heart of Modern Portfolio Theory (Markowitz 1952, 1959). Portfolio theory and portfolio management make use of a phenomenon which is observed in the formation of stock portfolios: returns are additive, while risks partially cancel each other out (Markowitz 1952, 1959). This phenomenon allows portfolio managers to lower the risk of the complete portfolio without necessarily sacrificing return. From the point of view of the investor this leads to an improvement of portfolios, i.e. a higher value, since investors are generally regarded as averse to risk (e.g. Bodie et al. 1999, p. 148).

These relationships are explained below by taking the example of a portfolio containing two different forms of capital (for similar treatments of stock portfolios see Bodie et al. 1999; Elton and Gruber 1987). Portfolio theory can be usefully applied to this portfolio, if the elements provide a future return and if this return is subject to risk. This portfolio could for example consist of one form of human-made capital (e.g. fishing boats) and a form of natural capital (fish stock), two forms of human-made capital (fishing boats and tractors) or two forms of natural capital (stock of fish and game).

All different forms of natural capital as well as human-made capital have an expected return. It is for this reason, from an anthropocentric-utilitarian point of view, that they are valuable. In the case of fish stocks this return consists of the future fish haul and in the case of fishing boats or tractors of the future benefit that can be created with this equipment. The future return is usually uncertain, that it is to say attended by risk. For example, it is not known how much the exact future fish haul will be or how much value can be created with the equipment. The degree of risk is measured by the standard deviation of the expected yields (e.g. the standard deviation of the expected fish haul). The higher the standard deviation of the expected yields the higher the risk.

Society does not only use one form of natural and/or economic capital but a number of different forms of capital. Modern Portfolio Theory looks at the relation between return and risk of individual elements and return and risk of the entire portfolio, i.e. on the level of a group of elements. Applied to natural and human-made capital, Modern Portfolio Theory examines the link between risk and return of individual forms of capital, and risk and return of the entire portfolio of natural and human-made capital.

To explain the basics of the application of Modern Portfolio Theory we restrict ourselves to two elements for the time being. We choose one form of natural and one form of human-made capital. Three items of information are required in order to describe the portfolio (for financial portfolios compare, for example, Olson 1999, p. 83):

- What expected return and what expected risk does natural capital A have?
- What expected return and what expected risk does human-made capital B have?
- What relationship exists between the variation in return of the two types of capital?

The question of the variation in return is of particular interest here. Three typical variations in return can be distinguished. The elements may firstly vary in a *parallel* manner. Whenever natural capital A provides more benefit, human-made capital B provides more benefit, too. The elements may, secondly, vary in an *opposed* manner. If natural capital A provides less benefit, human-made capital B provides more benefit. The variation may also be *uncorrelated*, i.e. not show any relationship.

The relationship between the variation in return of the two elements is important, because it determines the risk of the complete portfolio. Elements whose variation in return is uncorrelated or even opposed are particularly interesting. In such cases the risks of the individual elements cancel each other out as a result of the decrease of the return of one element being offset by the increase of the return of the other element. Each element can be placed in a coordinate plane indicating its risk and return. Depending on the mix of the two elements the portfolio will have different risk–return characteristics. Line **a** in Figure 1 indicates risk and return of portfolios with a different mix of the two forms of capital where the two forms of capital are perfectly negatively correlated. The point where the portfolio is on line **a** depends on the weighting of the particular form of capital in the portfolio. The risk can even be completely diversified away (point C on line **a**) by a particular mix of the two forms of capital. In this case the decrease in return of the one form of capital is always offset by a corresponding increase in return of the other form of capital.

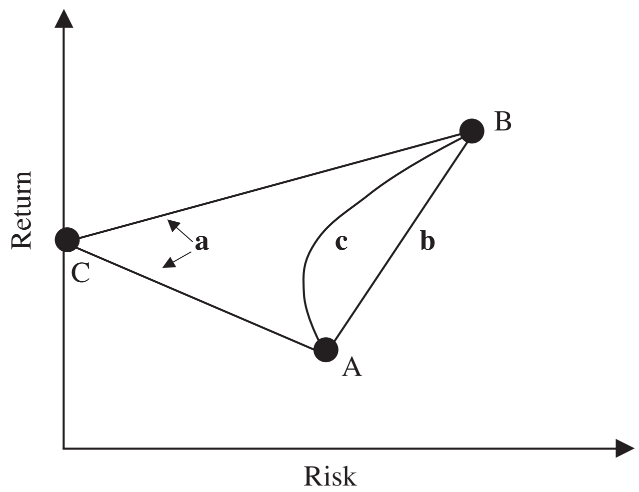

FIGURE 1. Relationship between return and risk for two forms of capital (similarly for stock portfolios compare, for example, Elton and Gruber 1987, p. 44)

This diversification effect does not come to bear, however, if the elements follow a completely parallel variation. The portfolio in this case, depending on the particular weighting, is on line **b**. If element A performs well, this is also true of element B. Risks will not cancel each other out and can thus not be reduced by combining the elements in a portfolio. The risk of the portfolio will correspond to the weighted average of the risks of the individual portfolio elements. Line **c** describes the case where both elements are uncorrelated.

Which of the three lines describes our portfolio best, depends therefore on the correlation between our two forms of capital. In the case of fishing boats (human-made capital) and fish stock (natural capital) we may expect a positive correlation. Fishing boats are, as proponents of strong sustainability point out, useless without the existence of fish in the sea. The benefit we can derive from fishing boats depends on the amount of fish in the sea. Line **b** in Figure 1 is therefore probably a good approximation for this portfolio. It is safe to assume that there is no significant correlation between the return of fishing boats and tractors or stocks of fish and game. Line **c** is in this case therefore a good approximation for these portfolios.

It is interesting to note that only in the case in which the two elements are perfectly positively correlated does the minimum-risk portfolio consist of only one element. Fishing boats and fish stocks are subject to the same risk. Therefore we must not expect any benefits due to diversification. In all other cases, i.e. when the positive correlation is not perfect, or they are uncorrelated or even negatively correlated, the minimum-risk portfolio will consist of both elements. This is the case of fishing boats and tractors or stocks of fish and game. The return of one form of capital (fishing boats/fish) has little predictive power for the other form of capital (tractors/game). Figure 2 demonstrates this case.

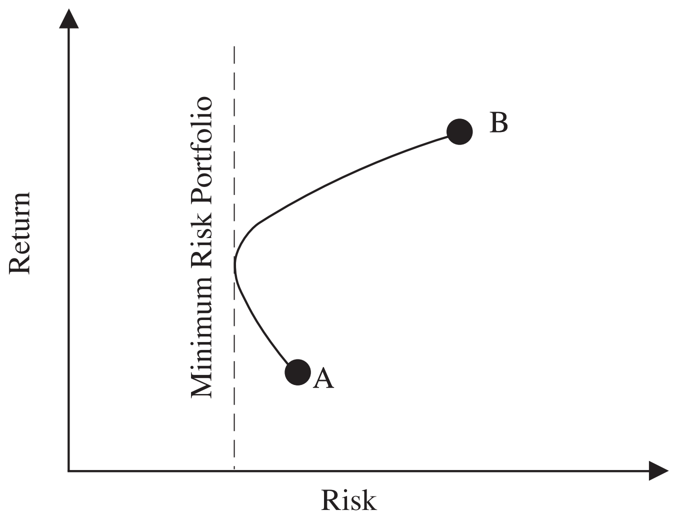

FIGURE 2.: Return–risk relationship of a portfolio of two forms of natural capital

Portfolio theory can of course cover not only two but many different elements. If such a large portfolio with more than two elements is transferred to the risk–return representation chosen above, the picture illustrated in Figure 3 is obtained. The points in Figure 3 are placed according to the expected risk and return of the different forms of capital they represent. We can, for example, think of these elements as different crops (Figge 2004, 2002), or many different forms of human-made capital or natural capital, or a mix of many different forms of human-made and natural capital. The line that encompasses the portfolio elements represents the combination of portfolio elements that result in portfolios with the best risk-return characteristics. The portfolios that form this line are called efficient (Markowitz 1952, 1959). The line illustrates the most advantageous return-risk combinations, which can be achieved by combining and weighting the elements in a portfolio. In our example this corresponds to the combination of crops that are exposed to the lowest risk for a given return. There are no possible portfolios to the left of this line. If there were a portfolio to the left, it would be encompassed by the line. Portfolios to the right, i.e. within the area the line encompasses, are not efficient, since there are portfolios that offer more return for the same amount of risk.

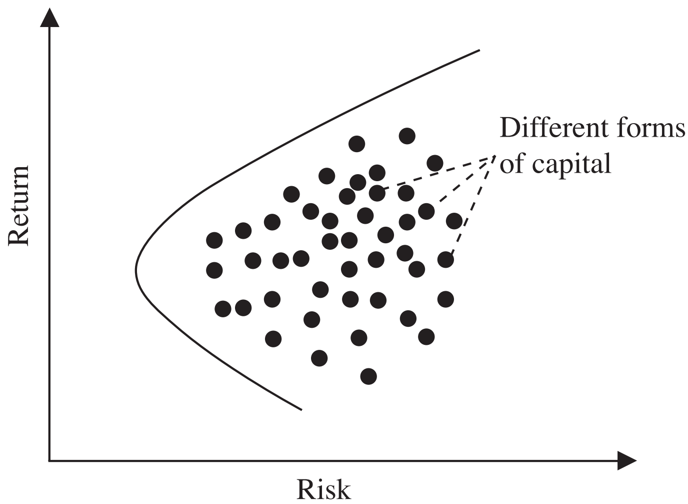

FIGURE 3. Return–risk relationship of a large portfolio of different forms of capital

The risk of a portfolio depends on the one hand on the number of elements and their weight in the portfolio and on the other hand on the relationship between the elements. More formally the portfolio variance can be expressed as follows (e.g. Brealey and Myers 2003, p. 160):

$$\text{Portfolio Variance} = \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j \sigma_{ij} = \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j \rho_{ij}\sigma_i\sigma_j$$

with: x_i = percentage of the portfolio invested in element i; σ_{ij} = covariance of elements i and j; ρ_{ij} = correlation coefficient between elements i and j; σ_i = standard deviation of element i; N = number of elements.

The diversification effect can be demonstrated using a simple numerical example. In this example we assume, firstly, that each form of natural capital has a variance of 10 if the absolute amount of capital is concentrated in that form of natural capital; secondly, that the overall natural capital can be spread equally over an arbitrary number of different forms of natural capital; and thirdly, that the yields of the different forms of natural capital are uncorrelated. Figure 4 shows how portfolio risk depends on the number of different forms of capital.

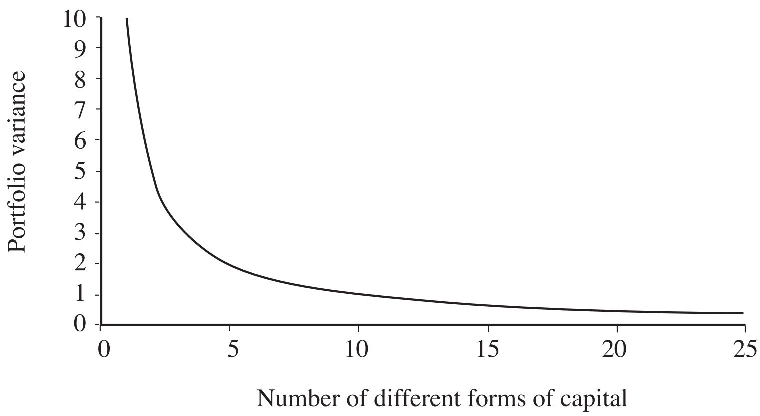

FIGURE 4. Risk reduction through diversification

As can be seen, most of the portfolio risk can be diversified by spreading the total amount of capital over many different forms of capital. This diversification effect holds true even if the different forms of capital are positively correlated. In that case the risk cannot be diversified entirely. Portfolio variance will asymptotically approach a non-diversifiable level of systematic risk.

Calculating or even estimating all covariances is impossible in practice. If we assume that there are only 100 different forms of capital, 4,950 covariances must be considered (compare analogously Sharpe 1970, p. 118). Financial management faces a similar problem when calculating portfolio risk. To reduce the complexity of this task a model has been developed that relates the risk of each element to a common index (e.g. a market index representing all securities) rather than to all other elements (Sharpe 1963). We can learn from this model that it is satisfactory for decision-making purposes to consider the correlation between each element and the portfolio of all elements rather than the correlation between all elements.

4. CONSEQUENCES FOR CAPITAL SUBSTITUTION

Weak sustainability stipulates that one form of capital can be substituted by another form of capital as long as the overall capital stock remains unchanged. The underlying assumption is that different forms of capital are essentially substitutes. If different forms of capital are complements, compensating for the reduction of one form of capital by raising another form of capital is not possible. Strong sustainability describes this point of view.

What is usually overlooked is that the conditions for weak sustainability only hold true in the case of certainty. Decisions on the use of natural and/or human-made capital, however, are subject to risk. The future benefit society derives from capital cannot be predicted with certainty.

Society draws its future benefit from an entire portfolio of different forms of human-made and natural capital. Modern Portfolio Theory (Markowitz 1952, 1959) shows that the risks of the individual elements of a portfolio add up to the risk of the entire portfolio only in the exceptional case that the different elements are perfectly positively correlated. Whenever the correlation between the different elements is not perfect or elements are even negatively correlated the portfolio is less risky than its elements. This is due to the risk-reducing effect of diversification.

Diversification will be observed when the following two assumptions are given. Firstly, society draws its benefits from an entire portfolio of different forms of natural and human-made capital rather than from a single form of capital. Secondly, the different forms of capital are not perfectly positively correlated. If these assumptions are given, any decision on the use or transformation of a society's capital must be based on the risk–return characteristics of the entire portfolio rather than the individual capital under investigation.

A number of important consequences result from this.

Decisions on individual forms of capital must take into account how much this form of capital contributes to the risk and return of the entire portfolio. For example, if the expected return of a form of capital is not correlated with other forms of capital and there are many different forms of capital then this form of capital will not contribute to the riskiness of the portfolio. From a portfolio view this form of capital can thus be considered to be risk-free. This implies e.g. that, if discounting is used to determine the value of the capital stock, the risk free rate can be used to discount the expected benefits even if those expected benefits cannot be predicted with certainty on the level of the individual form of capital (compare analogously Pearce et al. 1994, p. 460). This can be the case of a portfolio of many different forms of natural capital (e.g. many different crops) when the overall yield of the natural capital (i.e. the overall yield of the portfolio of all crops) can be predicted with great certainty. The risk-free rate will usually be lower than a discount rate that reflects risk. The value of the form of capital in question (an individual crop in our example) will therefore be higher when the risk free rate is applied. This enhances the incentive to preserve this form of capital. In a well-diversified portfolio, when one form of capital is positively correlated with other forms of capital, only the degree to which it covaries with the other forms of capital determines its riskiness from a societal point of view.

Two factors have an impact on the degree to which risks of individual forms of capital can be diversified away. Firstly, the less the total amount of capital is concentrated on few forms of capital, the better risks can be diversified. A high degree of concentration of capital can be due to the fact that there are only a few forms of capital and/or that most of the total capital is distributed unevenly across the existing forms of capital. Monocultures are an example of a concentration of natural capital. Secondly, risks can be diversified the more effectively the lower the correlations between the different forms of capital. As pointed out before, it is not necessary to consider the correlations between all forms of capital, but we can restrict ourselves to the correlation between each form of capital and the portfolio of all forms of capital.

Substitution of capital can lead to more or less concentration of capital. A country that relies mostly on one form of non-renewable energy and develops a form of renewable energy to compensate for the decline of the former will reduce at the same time its capital concentration. If the country has currently a well-balanced energy mix and concentrates increasingly on one form of energy it will increase its capital concentration. From a portfolio theory point of view, adding a new form of capital is preferred to removing a form of capital, and spreading total capital more evenly over the existing forms of capital is preferred to concentrating it on few forms of capital.

The correlation of the substituting vs. the substituted form of capital with all other forms of capital is the second impact on diversification. The substituting form of capital might correlate more or less with the portfolio than the substituted form of capital. Diversification will be hampered whenever the substituting form of capital correlates more with the portfolio of all other forms of capital than the substituted form of capital. This is the case if the value of the substituting form of capital has a stronger tendency to follow the value of other forms of capital than the substituted form of capital. Diversification will be enhanced whenever the substituting form of capital has a less pronounced correlation with all other forms of capital than the substituted form of capital.

Both effects, i.e. the effect on concentration of the total capital and the correlation between the different forms of capital, can mutually support or cancel each other out. As Figure 5 shows we can distinguish between nine possibilities in this context.

		Correlation of substituting form of capital vs. substituted form of capital		
		Lower correlation	**Same correlation**	**Higher correlation**
Change to capital concentration	**Contributes to higher concentration**	Trade-off	Reduced diversification	Reduced diversification
	Concentration remains unchanged	Enhanced diversification	No effect	Reduced diversification
	Contributes to lower concentration	Enhanced diversification	Enhanced diversification	Trade-off

FIGURE 5. Diversification through capital substitution

Diversification is enhanced when the correlation of the substituting form of capital is lower than the correlation of the substituted form of capital and capital concentration is reduced. Both effects contribute to diversification. Diversification will also be enhanced when either concentration remains unchanged or when the substituting and the substituted form of capital have the same correlation with the portfolio of all forms of capital.

Diversification will be reduced when the opposite holds true. This is the case when capital substitution results in a higher concentration and the correlation of the substituting form of capital exceeds the correlation of the substituted form of capital. Diversification will still be reduced when substitution results either in a higher concentration or the correlation of the substituting form of capital exceeds the correlation of the substituted form of capital.

There are two cases where there are trade-offs, i.e. where the overall effect is unclear. On the one hand, this is the case where substitution results in less concentration but the correlation of the substituting form of capital exceeds the correlation of substituted form of capital. On the other hand, this can be due to a higher concentration but a lower correlation of the substituting form of capital in comparison to the substituted form of capital.

When there is no change in capital concentration and both the substituting and the substituted form of capital have the same correlation there will be no impact on diversification.

A higher degree of diversification will result in less risk. As mentioned before it is usually assumed that human beings dislike risk. A higher risk will therefore devaluate future benefits and therefore the value of the underlying natural and/or human-made capital. To ensure that a risk-averse society is as well off as before, the reduction of diversity of the capital base must therefore be matched with a disproportionate increase in another form of capital. This will become the more difficult the less different forms of capital there are left in the portfolio. This is the case, for example, with different forms of energy. Our society makes use both of renewable as well as non-renewable sources of energy. One could now assume that the amount of renewable energies needs to be increased by the same amount by which the non-renewable energies decline in order to leave society as well off as before. What is usually overlooked is that by reducing the number of different energy sources diversity is lost and risk increases. If we assume that future generations can be compensated for a risk increase through an increase in capital (i.e. they will accept more risk provided they may expect more return, similar to the way investors will assume an additional risk when offered a higher expected return), renewable energies would have to be developed disproportionally to the amount of non-renewable energies lost. Otherwise intergenerational equity and thus Sustainable Development is not achieved.

Another interesting conclusion is that the reverse will also hold true. A society that currently only has a single form of non-renewable energy and builds up a new form of renewable energy to compensate for the decline of the former will create diversity. This can result in less risk. We can assume that future generations prefer less risk to more risk, i.e. future generations are also risk-averse. Future generations might therefore prefer less capital to more capital if risk is reduced at the same time. It could therefore be acceptable to develop less renewable energies than the non-renewable energies that are used up. A society that moves over time from a single source of non-renewable energies to a single source of renewable energies might therefore have to build up less renewable energies in the beginning while diversity increases and more renewable energies when diversity decreases again.

Weak sustainability posits that different forms of capital can be substituted by each other. We can learn from Modern Portfolio Theory that there is a limit to substitution of different forms of capital in the presence of risk. To what extent one form of capital can be substituted by another form of capital will also depend on society's degree of risk friendliness. If society is risk neutral one form of capital can be substituted by another form of capital even if diversity is reduced and risk increases. In that case the only limit is the degree to which the two forms of capital are really substitutes as weak sustainability presupposes. If society is risk averse and if we assume that diversity is reduced by substitution of one form of capital by another form of capital, then the degree to which one form of capital can be substituted by another form of capital is limited. How difficult it is to substitute one form of capital by another form of capital will depend on the degree of risk aversion. The stronger risk aversion, the more difficult to substitute one form of capital by another form of capital. If we assume that the substitution of one form of capital by another form of capital increases diversity, the relationship between risk aversion and substitutability is reversed. In that case it will become easier to substitute one form of capital by another form of capital the more risk averse society is.

A last possibility is that society is risk friendly, i.e. society prefers more risk to less risk. In this case less diversity of capital will be preferred to more diversity. It would thus become easier to substitute one form of capital by another form of capital if this results in a decline of diversity. If substitution adds to diversity, then the degree of risk friendliness will hamper capital substitution.

Figure 6 summarises the relationship between substitution of different forms of capital and risk aversion.

		Substitution of one form of capital by another form of capital leads to…	
		reduced diversification	**enhanced diversification**
Society is…	**risk averse**	Substitution limited by degree of risk aversion and degree of substitutability	Substitution favoured by degree of risk aversion and limited by degree of substitutability
	risk neutral	Substitution limited by degree of substitutability	
	risk friendly	Substitution favoured by degree of risk friendliness and limited by degree of substitutability	Substitution limited by degree of risk friendliness and degree of substitutability

FIGURE 6. Substitution and risk aversion

5. CONCLUSION

The question of whether one form of capital can be substituted by another form of capital is at the heart of the distinction between weak and strong sustainability. Up to this point it has been commonly assumed that, if the conditions of weak sustainability are given, one form of capital can be substituted by any other form of capital. If capital is left constant over time, intergenerational equity and thus Sustainable Development is achieved. As this article shows this only holds true if there is certainty or if society is risk neutral. Both assumptions are usually not given. If society is risk averse diversity of natural and human-made capital must be preserved to achieve Sustainable Development even if the different forms of capital are substitutes.

NOTES

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[1] A common subdivision of risk is into risk, uncertainty and ignorance. The division between risk and uncertainty can be attributed to Knight (1921). Risk in the narrower sense describes a situation in which the probabilities of possible future pay-offs are known objectively. In the case of uncertainty the probabilities of future pay-offs are not known objectively but there are (subjective) beliefs about the future pay-offs. Ignorance (e.g. Shubik 1954) describes a situation in which there are not even subjective beliefs about future pay-offs. Risk in this article encompasses risk (in the narrower sense), uncertainty and ignorance. The findings of this article can be applied analogously to a narrower definition of risk.

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