Trading Efficiency in Water Quality Trading Markets: An assessment of trade-offs

Hugh McDonald and Suzi Kerr

Motu Economic and Public Policy Research

17/6/2011

Author contact details
Hugh McDonald
Motu Economic and Public Policy Research
hugh.mcdonald@motu.org.nz

Suzi Kerr
Motu Economic and Public Policy Research
suzi.kerr@motu.org.nz

Motu Economic and Public Policy Research
PO Box 24390
Wellington
New Zealand

Email	info@motu.org.nz
Telephone	+64 4 9394250
Website	www.motu.org.nz

 ISSN 1176-2667 (Print), ISSN 1177-9047 (Online).

Abstract
A crucial factor in the success of any water quality trading market is its ability to cost-effectively reallocate nutrient allowances from initial holders to those users who find them most valuable; its trading efficiency. This paper theoretically investigates the extent to which regulators should pursue this 'trading efficiency', and discusses policies which will enable its achievement. We find that minimising transaction costs faced by participants at the time of trade has significant benefits for the operation of trading markets, but that its attainment can be costly, and requires the consideration of many trade-offs, including increased set-up costs and environmental uncertainty.

Keywords
Water quality markets, transaction costs, nutrient trading markets

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Comments welcome – hugh.mcdonald@motu.org.nz

1. Introduction[1]

Falling water quality as a result of increased nutrient pollution is a serious and growing concern both internationally and in New Zealand (Ministry for the Environment, 2007).[2] While these water pollution issues have traditionally been addressed with command-and-control type regulation, attempts to deal with the issue through market-based nutrient trading schemes are becoming more widespread (Selman et al, 2009).[3] For these water quality trading markets to efficiently and effectively achieve environmental goals, participants must be able to easily and cheaply trade allowances. This paper theoretically investigates the extent to which regulators should pursue this 'trading efficiency', and discusses policies which will enable them to achieve it.

Previous work in this area has approached the issue under the general umbrella of transaction costs in environmental markets. A useful survey by Krutilla and Krause (2011) presents a thorough overview of work and conclusions in this area. Stavins (1995) shows analytically that in the presence of transaction costs the cost effective equilibrium of equalised marginal control costs will not be reached in an environmental allowance market. Kerr and Maré (1998) provides evidence for this contention using evidence from the US Lead Phasedown Tradable Permit Market, while papers by Gangadharan (2000) and Fowlie and Perloff (2008) address this question using data from the Los Angeles Regional Clean Air Incentives Market (RECLAIM). Further work by Solomon (1999) and Falconer (2000) also emphasise the importance of considering transaction costs when designing environmental markets. Papers by Nguyen and Shortle (2006), Fang et al. (2005) and Schary and Fisher-Vanden (2004) and Prabodanie et al. (2010) extend this investigation into the specific context of water quality trading markets.[4]

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[1] This paper has been written as part of the Nutrient Trading and Water Quality research programme which is being led by Motu Economic and Public Policy Research in Wellington, New Zealand. The programme aims to design and simulate a prototype nutrient trading system for the Lake Rotorua catchment, in conjunction with a group of stakeholders and scientists with specialist knowledge of the region. An overview of the initial prototype design is published as Motu Working Paper 08-02 (Lock and Kerr, 2008b), with full information available at www.motu.org.nz/research/detail/nutrient_trading

[2] The most recent State of the Environment report released by New Zealand's Ministry for the Environment reported that more than a third of New Zealand's lakes have poor water quality, and that rivers throughout New Zealand have seen significant increases in nutrient levels over the past two decades.

[3] The recent overview paper by Selman et al. (2009) found 57 nutrient trading schemes worldwide (of which 26 were in active operation, 21 in development and 10 inactive) and that the prevalence of market regulation as a response to water quality issues was increasing. New Zealand currently has one operating nutrient trading scheme (Lake Taupo).

[4] The largely parallel literature on water allocation markets offers little further insight into trading efficiency. One of the few exceptions is found in two papers by Zhang (2007) and Zhang et al. (2009) which examine barriers to effective water allocation markets in the Heihe River basin of Northwest China. These papers also find that transactions costs and trading inefficiency decrease the effectiveness of trading markets in achieving an efficient allocation of allowances.

The exact definition of transaction costs has also seen significant discussion. McCann et al. (2005) and Krutilla and Krause (2011) both argue that shifting definitions of transaction costs within the environmental markets literature hamper its development. To avoid perpetuating this we explicitly follow Stavins (1995) and use a narrow definition of transaction costs that focuses solely on the costs that are faced by a trading participant as a result of deciding to trade in the market.[5] These time-of-trade transaction costs include the costs of gathering information, bargaining, decision making, any costs of trade approval borne by participants, and, in baseline and credit schemes the cost faced by participants in baseline setting and monitoring. We do not consider the behavioural or sociological barriers to trade efficiency that are considered in Breetz et al. (2005).[6] This definition also does not stretch to include costs faced by regulators such as set-up or administration costs. Both of these issues are important, and are considered and discussed in the discussion of trade-offs required to achieve low time-of-trade transaction costs, but we exclude them from our narrow transaction costs definition to better target the issue of trading efficiency. Trading efficiency is defined as an inverse of these time-of-trade transaction costs: trading efficiency is maximised by minimising time-of-trade transaction costs.

The initial conclusions of the literature are clear: transaction costs decrease the effectiveness and efficiency with which environmental markets can achieve environmental goals, and should be minimised. However, despite the importance placed on avoiding transaction costs in water quality trading markets, there has been little discussion in the literature of practical policies to decrease these transaction costs, or any real assessment of when it is and is not optimal to decrease transaction costs. This paper begins to address these issues.

We find that maximising trading efficiency by minimising transaction costs faced by participants at the time of trade has significant benefits for the operation of trading markets, but that its attainment can be costly, and requires careful consideration to ensure that trading efficiency and the benefits it brings are achieved at least cost. This paper sets out the exact nature of the trading efficiency maximisation decision, and also assesses the literature and examines existing schemes to recommend policies that will improve trading efficiency most cost effectively. We start by setting out the regulators decision explicitly.

[5] To avoid any confusion we refer specifically to 'time-of-trade transaction costs' for the rest of the paper.

1.1. The nature of the problem

The question of how and when to increase trading efficiency and decrease time-of-trade transaction costs for participants is a difficult one due to the nested nature of the problem, and the tradeoffs involved. We set out the problem facing the regulator below.

The overall goal of any regulator introducing a water quality trading market is generally to minimise the cost of achieving an environmental goal. This overall cost will be made up of costs from three major areas: mitigation costs, time-of-trade transaction costs, and administration costs. Mitigation costs are the actual costs of mitigating nutrient run-off, be this through the application of specific technologies or changes to production. Time-of-trade transaction costs refer to the costs faced by participants participating in the nutrient trading market, and are the result of low trading efficiency. Administration costs refer to the costs faced by the regulator establishing and running the trading scheme; these can be further split into set-up costs (the costs of designing and implementing a trading scheme), the effort and cost of reducing time of trade transaction costs, and the ongoing costs that regulators will face as participants trade.

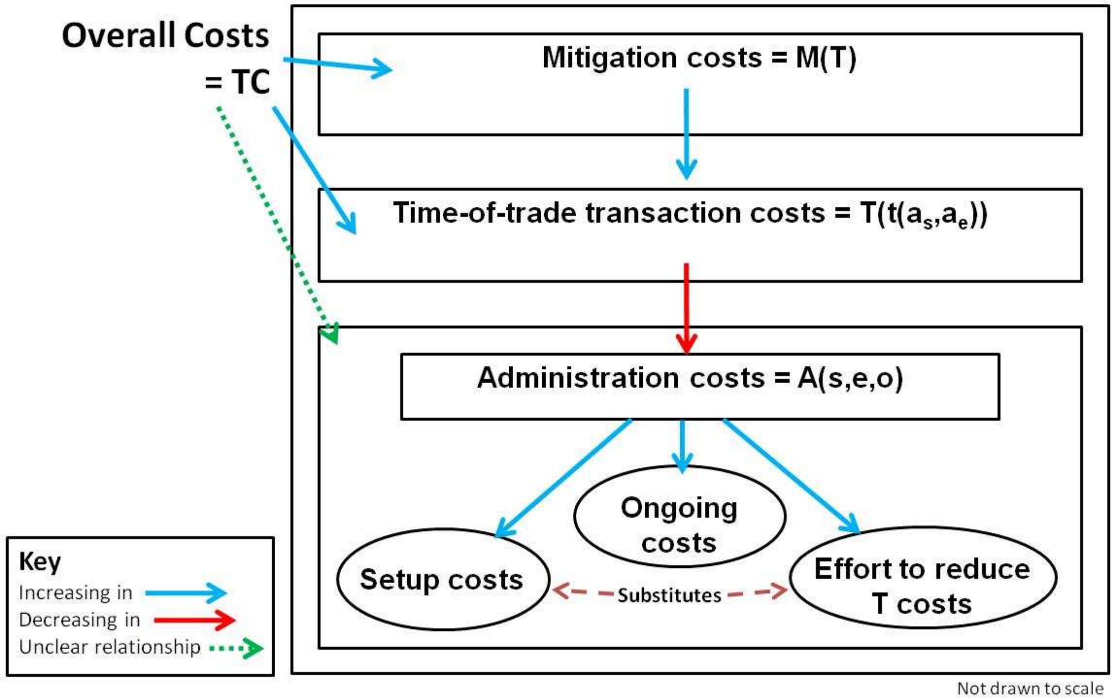
The regulators goal can be expressed as such (1):

$$min\, TC_A = A(s, e, o) + T(t(a_s, a_e)) + M(T) \qquad (1)$$

$$s.t.\ environmental\ goal$$

This states that the regulators goal is to minimise total costs (TC) by optimally setting administration expenditure (A), and optimally assigning administration expenditure between the three possible expenditures (s,e, and o), subject to meeting the environmental goal. Total costs are shown to depend on administration costs (A), time-of-trade transaction costs (T), and mitigation costs (M). Administration costs are shown to be made up of set-up costs (s), effort to reduce time of trade transaction costs (e) and ongoing costs (o). Time-of-trade transaction costs are shown to depend on the trading efficiency within the system (t), which in turn depends on the amount of money spent system set-up (a_s) and effort by the administrators to reduce time-of-trade transaction costs (a_e). A regulators aim is to minimise total costs (TC). The nature of the relationship between each of these individual costs is shown in Figure 1below.

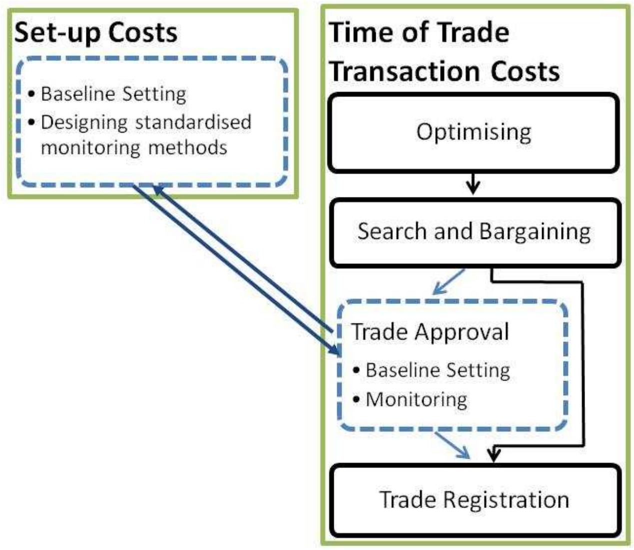
Figure 1: Relationship between costs



When set out as above, the first decision a regulator faces becomes clear: will the gains from increasing trading efficiency outweigh the costs of its achievement? Increasing expenditure on setup and expending effort to lower time-of-trade transaction costs is clearly only worthwhile if they bring about a decrease in the overall cost of the system. We find that this is most likely to occur in schemes with heterogeneous participants and large expected values and volumes of trading.

If a regulator concludes that increasing trading efficiency will decrease the overall cost of achieving the environmental goal, they then face a second question: should regulators increase trading efficiency by focussing on minimising the causes of time-of-trade transaction costs, or by shifting the timing of these costs to set-up? While the time-of-trade transaction costs of optimising, search and bargaining, and trade registration must always be faced by participants when they trade, the transaction cost of trade approval can be faced either at the time-of-trade or as a set-up cost. Trade approval costs occur as trades have to be monitored and baselines set so that every trade has no negative impact on the environmental goal. Instead of individually estimating and approving individual participants' discharges before every trade, regulators can design standardised monitoring systems as part of the set-up of the system. Also, instead of only setting baselines of participants if they choose to trade (as occurs in a baseline-credit system), baselines could be set for all participants at the time of the systems establishment. These time-of-trade transactions costs are set out in Figure 2 below, as is their potential for shift to set-up.

Figure 2: Participants' time-of-trade and set-up costs



We find that the trading inefficiency that results from optimising, search and bargaining, and trade registration costs can only be minimised. Many policies will decrease these barriers to trading efficiency: policies that improve information flows to participants, such as online trading systems, brokering systems, or computer based mitigation and discharge calculation systems; policies that improve participant certainty, such as clearly defined and well designed rules, general acceptance of policies by all stakeholders, and established methods for dealing with new scientific information; policies that increase liquidity, such as allowing the banking of allowances.

The issue of trading efficiency in environmental markets is also made more difficult by the trade-off between environmental certainty and low time-of-trade costs. While regulators may be tempted to restrict trading or increase measuring and monitoring requirements to increase the environmental certainty of a scheme's outcome, this will have negative effects on trading efficiency. We discuss examples of international schemes where a desire for environmental certainty has increased time-of-trade costs, and present a model that illustrates the possible approaches regulators can take to balance this trade-off.

The paper proceeds as follows: section two considers the characteristics of a scheme where the benefits of improving trading efficiency will outweigh the costs. Section three discusses policies that will improve trading efficiency by minimising the causes of time-of-trade transaction costs. Section four discusses the possibility of improving trading efficiency by shifting trade approval costs from time-of-trade to set-up. This section includes a discussion of cap and trade and baseline-credit schemes, and different monitoring systems, and how decisions on both of these aspects affect a scheme's trading efficiency. Section five discusses the trade-offs between environmental certainty and trading efficiency, and section six concludes.

2. Is increasing trading efficiency worthwhile?

As shown in Figure 1, the first (and ultimate) decision that a regulator must make when attempting to increase trading efficiency is whether the benefit of decreased mitigation costs will outweigh the effort of reducing time of trade costs. Any effort to improve the trading efficiency of a system will be worthwhile only if the improvements are expected to decrease the overall cost of achieving the environmental goal. The degree to which improved trading efficiency will decrease overall mitigation costs will differ scheme to scheme, and will be determined largely by the expected value of trading and the expected number of trades, which are in turn determined by the heterogeneity of participants, the efficiency of initial allocation and the distribution of the size of trades required to achieve gains. The choice of the type and coverage of sources to include – the scope of the scheme – will also impact this decision.

Trading efficiency improvements will be larger in schemes with a high expected value of trading: the larger the expected value of trading, the larger the nominal gains from improved trading efficiency. Trading efficiency gains will also be larger in schemes with a high number of expected trades: holding the total value of trades constant, gains from trading efficiency will be higher in a system with a high number of small value trades than in a system with a low number of high value trades. This is the case as the time-of-trade cost savings will be multiplied by the number of trades: the greater the volume of trades, the greater the gains from trading efficiency.

Schemes with high trading values and volumes are characterised by heterogeneous participants and inefficient initial allowance allocation. Newell and Stavins (2003) conclude that systems with highly heterogeneous participants (in terms of mitigation costs and baseline discharges) will have more gains from trading. This heterogeneity of participants depends not only on differences before any regulation, but also differences that remain after any free allocation of trading allowances: trading efficiency gains will be greatest in schemes with an inefficient initial allocation of allowances. This is most easily understood if the alternative, an efficient initial allocation, is considered. In this case the right to pollute will have been allocated to those who value it most and as a result we would expect no trading to occur. A highly inefficient initial allocation is most likely to occur if regulators have little knowledge of dischargers' mitigation costs.

The distribution of mitigation costs that underlies participant heterogeneity is also important. Participants will trade with each other if the gains from trading outweigh the transaction costs of doing so. As a result, gains from improving trading efficiency will be greatest in schemes where a slight decrease in transaction costs results in the gains from trade subsequently outweighing the costs of trading, leading to significant efficiency gains from a small increase in trading efficiency. This situation is most likely to occur in schemes where a large number of participants have heterogeneous mitigation costs (which would require a number of small value trades to achieve equalized mitigation costs) than a scheme where only a few outlying participants have different mitigation costs (and only a few large trades would be needed to equalize these costs).

2.1. Scope

The choice of a scheme's scope – its comprehensiveness and the types of sources it covers – will also determine the heterogeneity of participants and, as a result, the benefits of improved trading efficiency. Regulators choose the scope of a scheme: they can choose to add participants if they expect the resulting cost of their inclusion will be outweighed by associated lower mitigation costs.

The scope of existing schemes differs considerably worldwide due to the different goals and approaches of regulators in different water catchments. The most obvious difference between schemes is whether they include only point sources of pollution, non-point sources or both. Point sources (PS) discharge pollution at a specific location, for example the outflow pipe at a water treatment plant. Non-point sources (NPS) pollute less directly, for example via diffuse run off from land.

Water quality regulation has traditionally set limits only for pollution from PSs. NPSs are more challenging to regulate because NPS nutrient loss is difficult to measure and is subject to seasonal and weather-related variation (Stephenson and Bosch, 2003). As a result the inclusion of NPSs is likely to increase uncertainty about actual environmental impacts; we discuss the trade-offs between environmental certainty and trading efficiency in section 5. Despite these issues, the incorporation of NPSs of nutrient discharge is often crucial to achieve environmental aims, as NPSs often cause the majority of discharges[7].

[7] Carpenter et al. (1998) report that 82% of nitrogen and 84% of phosphorus entering USA waterways comes from non-point sources. This is also true for our prototype New Zealand trading scheme; non-point sources are the primary origin of nutrients entering Lake Rotorua (Kerr and Rutherford, 2008).

There are advantages and disadvantages associated with schemes of different size and comprehensiveness - different scopes. Lock and Kerr (2008a) explore the impact of scope on liquidity and the risk of market power, and discuss the issues raised above in greater detail.

3. How do we increase trading efficiency?

If regulators decide that the gains from increasing trading efficiency are large and worth pursuing, what policies should they consider? Policies that minimise time-of-trade transaction costs faced by participants will maximise trading efficiency. These time-of-trade transaction costs are illustrated in the right hand panel of Figure 2, and include the costs of optimising operations, search and bargaining costs of finding trading partners, trade approval and trade registration.

The negative impact of these transaction costs can be reduced in two ways: regulators can focus on minimising the size of these transaction costs faced by participants, and they can shift the timing of costs away from the time-of-trade. Transaction costs can be minimised by ensuring that participants have easy access to full information, as much political and regulatory certainty as possible, and the ability to respond flexibly to the regulation. Ensuring that costs are not met at the time-of-trade can be achieved by shifting the occurrence of possible transactions costs, such as trade approval, so that they are faced as set-up costs. These costs can then be reduced by taking advantage of the economies of scale that are possible at set-up. The first approach is discussed below with examples of its application in existing schemes. The second approach, shifting the timing of these costs to set-up, is discussed in section four.

3.1.1. Information flows

Trading efficiency is supported through traders having ready access to high quality information. The transaction costs caused by optimising and search and bargaining costs can be minimised by proving good information to participants. Good market design can improve the types and quality of information available to those who require it.

Brokers and similar third parties make information gathering and decision making more efficient by accumulating knowledge of the trading framework and streamlining the trading process (Stavins, 1995). These organisations, in turn, require clear governing frameworks to ensure they are trusted and effective. Some markets have a single intermediary, known as a clearinghouse, which handles all allowance sales: an approach that negates all search and bargaining costs. The disadvantage of this approach is that there is no competition to encourage greater efficiency. Nevertheless, Selman et al (2007) lists as a success the implementation of a clearinghouse for the Great Miami River Water Quality Credit Trading Program in Ohio[8].

Online and automated trading facilities can also help to reduce optimising and search and bargaining transaction costs. Nutrient Net World Resources Institute, 2007 is a set of web-based tools to facilitate water quality trading. NutrientNet allows participants to connect with other possible traders, and to list credits for sale or bid on available credits. It also allows administrators and the public to access (confidentialised) trades and prices over time, and administrators to keep track of credits and compliance records, all at minimal cost. The system has been used for four trading programmes in the US (Selman et al, 2007), across five states.

NutrientNet's calculation tool, and a New Zealand counterpart, Overseer, also allow landowners to run relatively complicated nutrient models onsite and in their own time, which allows participants to more effectively and cheaply optimise their operations to changing market conditions. The New Zealand Overseer model has been built to compute nutrient budgets and to estimate nitrogen and phosphorus loss from pastoral land using data that can be reasonably easily obtained by farmers or consultants, whilst still giving thorough and dependable output.[9] The Lake Taupo Trading Program (and Motu's prototype trading system for the Lake Rotorua catchment) uses Overseer, in part for this reason (Selman et al, 2007).The information that such models provide to participants can greatly decrease optimisation costs and increase trading efficiency.

Information flows are also likely to change over time. A case study by Woodward (2003) investigating the first trade carried out in the Lake Dillon reservoir in Colorado, USA, suggests that over time participants have a better understanding of the system and also a greater knowledge of possible trading partners. Both of these factors work to reduce search and information costs and transaction costs as a whole, which increases the trading efficiency of a system over time.

3.1.2. Certainty

Certainty in the context of a nutrient trading system refers to certainty in the definition of an allowance and its properties, and to certainty in the regulatory, political and scientific

[8] The Miami River clearinghouse purchases allowances from agriculture using reverse auctions and allocates these to 'investor' companies (who require credits to meet environmental regulation) in proportion to their level of investment.

[9] For example, the Overseer pastoral farming model uses data on a farm and block level, and computes outputs based on farming region, animal shelters and feed pads, effluent management, animal species and their management and stocking rate, supplements, nitrogen inhibitors and wetland areas, topography, climate, soil and pasture type, irrigation along with soil analysis and fertiliser inputs AgResearch, 2009.

elements of the trading environment. Certainty is important as people are risk averse; as a result, any uncertainty will increase expected costs and lower expected net benefits. This will increase the cost of meeting environmental goals, and will manifest as defensive - and trade inefficient - trading behaviour. While an in-depth exploration of all of these uncertainties is beyond the scope of this paper, this section briefly outlines these uncertainties and how policy design can seek to avoid them.

Clearly defining an allowance and its properties is an important step for efficient trading. Measurements of nutrient discharges may need to consider soil type, slope, microclimate, heavy rainfall events, groundwater lag times, nutrient attenuation rates and residence times in the focal water body. It is not practical to directly assess these factors for every trade on every property. Authorities can instead develop standardised estimation methodologies. Both buyers and sellers (or their representatives) use these methodologies to determine with certainty the nutrient loss they are responsible for (the issue of monitoring and trade approval is discussed further in section 4.2). As discussed, online tools such as NutrientNet and Overseer can assist with this process. If participants can be certain in their knowledge of the definition of an allowance then they can begin to mitigate and manage their nutrient runoff. Any uncertainty in this definition will increase costs in optimising operations and negotiating trades with fellow participants.

Regulatory uncertainty also affects trading efficiency. If participants anticipate regulatory changes they may avoid trading until these changes occur or are ruled out. Clear advance notice of regulation changes and how these changes will be applied can reduce this effect. (Kerr and Lock, 2009).

Uncertainty at a political level can have similar effects.[10] Whether regulators, policy makers and politicians will remain committed to the nutrient trading system is a major concern for trading efficiency. Changes in political priorities could see politicians introducing new regulations or relaxing existing ones. Participants who anticipate these actions may choose to hoard or sell at a loss any allowances they hold. A stakeholder process can help to generate political support. Selman et al (2007) advocate both education and ongoing dialogue with stakeholders to ensure a system is implemented smoothly and with greater certainty.[11] Finally, the

[10] A recent paper by Karpas and Kerr (2011) illustrates the cost of political uncertainty in a trading market, the forestry component of New Zealand's emissions trading scheme. They find evidence that this uncertainty is a key reason for low levels of participation in the market.

[11] The appendix in Selman et al (2007) lists educational resources for communicating relevant information to a range of stakeholder groups. Breetz et al. (2005) draws on social embeddedness theory and concludes similarily: building trading market participants trust and understanding through education and the leveraging of existing social networks is crucial to ensure participation and the ongoing success of any nutrient trading scheme. As a practical resource, Motu's environmental trading game is designed to introduce the principles of nutrient trading to a non-technical audience (this can be found online at www.motu.org.nz/building-capacity/environmental_trading_game).

scientific information used to measure and address water pollution is subject to change, and provides another level of uncertainty for traders. New scientific information can be treated like any other potential change in regulation: uncertainty can be avoided through clear specification of which elements may be subject to change and a declared mechanism for transferring liability (or unexpected gains) to allowance holders.[12]

As a general rule, certainty in all of its dimensions can be maximised by the inclusion of well developed processes for managing any future change. It is highly unlikely that any trading scheme will continue unchanged indefinitely, so planning for the almost certain future change is the most effective method to promote certainty within a system.

3.1.3. Market liquidity

Ensuring that nutrient markets have adequate liquidity is essential to minimise search and bargaining costs, and to avoid any risk of market power. It should be relatively easy for a willing and able buyer to find allowances they can purchase, and vice versa.

To maximise this liquidity, designers of nutrient trading systems should examine how much flexibility a region's hydrology can handle. For example, the period for which participants are able to bank credits might be restricted to the mean residence time of a water body. In Miami River, Idaho, participants may purchase only allowances generated upstream from their point of discharge (King and Kuch, 2003). This is important to avoid 'hot spots', but limits liquidity as it means that buyers can trade only with a subset of potential sellers.

Liquidity can also be encouraged by holding regular auctions of allowances. Regular auctions enhance price discovery and increase transparency of the market, and ensure regular availability of allowances for participantsMatthes and Neuhoff, 2008. Using auctions rather than free allocation also encourages participants to actively participate in the market rather than simply comply using their free allocations, which will additionally encourage liquidity (Matthes and Neuhoff, 2007).

Allowing trading across more than one pollutant can also significantly increase allowance liquidity. Stephenson and Bosch (2003:11) draw on emissions trading literature as an example and state that "cross pollutant trading could be a practical alternative in many watersheds." This will only work if environmental impacts of the pollutants are similar. This trade-off between environmental certainty and trading efficiency is explored in section four.

[12] Guidelines for sharing costs as a system evolves are discussed in a paper by Kerr and Lock (2009).

In summary, the first decision that a regulator must consider is whether the mitigation cost and time-of-trade transaction cost savings will outweigh the costs of achieving greater trading efficiency. This is most likely to occur in schemes with heterogeneous participants and a high expected value and volume of trading. If regulators believe that bearing the costs required to attain increased trading efficiency will result in decreased overall mitigation costs, they immediately face a second question: what policies they should introduce to achieve this increased trading efficiency? As discussed above, trading efficiency can be improved by introducing policies that decrease time-of-trade costs by improving information flows, or increasing certainty and liquidity. However, these transaction costs can also be minimised by shifting their timing away from the time of trade and facing them instead as a set-up cost: it is this second approach that is considered in the next section.

4. Time-of-trade costs versus set-up costs

Trading efficiency may be able to be achieved at lower cost by shifting the timing of costs away from the time-of-trade. Participant's considering whether to trade will only consider those costs that they face as a result of trading; they will not consider any prior costs of scheme set-up. As a result, minimising costs faced at the time-of-trade by shifting costs to the establishment of a system will be an effective way to achieve trading efficiency. This approach may also result in additional overall savings due to the economies of scale that are possible at set-up, that cannot be taken of at time-of-trade. However, not all transaction costs faced by participants can be shifted away from the time-of-trade; optimising, search and bargaining and trade registration costs will be faced every time a trade is made, and can only be minimised. As shown in Figure 2 though, the costs of trade approval and baseline setting can be largely shifted away from the time-of-trade and dealt with as set-up costs.

While this shifting of cost timing will be an effective way to increase the trading efficiency of a scheme, it is not clear that it will be efficient. Decreasing costs at the time-of-trade (and increasing trading efficiency) requires an increase in the costs faced at set-up. This shift is only worthwhile if the mitigation and time-of-trade cost savings as a result of the improved trading efficiency are expected to outweigh the increased set-up costs; that is, the total cost of achieving the environmental target decreases.

Whether trade approval costs are faced at the time-of-trade or as set-up costs is largely determined by two fundamental policy design choices: the choice of a cap and trade or baseline-credit system, and the choice of an ex ante or ex-post monitoring system.

4.1. Cap and trade and baseline and credit systems

There are two basic types of nutrient trading markets: cap and trade, and baseline and credit (also known as offset systems). Cap and trade markets involve setting a comprehensive cap on the allowable discharge of a given nutrient over a catchment or watershed, and dividing this cap into individual, tradable allowances. These allowances are then distributed to market participants, and participants must obtain and remit an allowance for each unit of nutrients entering waterways from their property. Further trading rules can be written to ensure that the environmental goal is not compromised by trading.

In a baseline and credit (offset) market not all sources of nutrient discharge are regulated. Baseline and credit systems involve some regulated participants facing a cap (individually or as a group with allowances allocated to individuals) in the same way as in a cap and trade system, but also include a voluntary component. Voluntary sources outside the regulated group can opt into the system and participate by decreasing their nutrient discharges in exchange for credits. For sources to participate, a baseline level of nutrient losses must be set, generally by estimating nutrient leaching under best practice or business as usual. If this voluntary participant discharges less than its allotted baseline it can sell credits equivalent to its discharge decreases to the regulated cap and trade section of the system. When the system works as intended these voluntary reductions act as a substitute for nutrient reductions in the cap and trade segment of the scheme, and the environmental goal will still be met.

Differences in the trading efficiency levels of cap and trade and baseline-credit schemes stem largely from the timing of monitoring; whether it is ex ante or ex post (this is discussed in the next section). There are also other advantages and disadvantages of the two systems. Cap and trade schemes offer greater environmental certainty because of an explicit goal and compulsory participation. However, it can be politically difficult and costly to introduce a cap and trade scheme which includes all sources. Baseline and credit systems are more easily and cheaply established at a small scale than cap and trade schemes, and are also generally cheaper to establish, as they only cover a proportion of dischargers. The disadvantage of using baseline and credit schemes is that including fewer sources reduces market efficiency and raises the cost of achieving the environmental goal, as participants have fewer trading partners with consequently less variation in individual mitigation costs[13]. Not including all sources of nutrient discharge also introduces the risk of leakage, where decreases in pollution by regulated sources within the

[13] As a result, baseline and credit markets may be less likely to find that the gains from improving trading efficiency will be expected to outweigh the costs of its attainment – question one.

catchment are replaced by increases in discharges by unregulated sources. Also, baseline and credit schemes are liable to face a significant problem of adverse selection.

Adverse selection occurs as a result of the difficulties faced by regulators in accurately setting a business as usual baseline for participants, combined with the voluntary participation element of baseline and credit schemes. If baselines are estimated accurately for all potential participants, then any participants that opt in will do so because they can profit by reducing nutrient losses at a low cost and then selling the accrued credits on the nutrient market. However, if participants have better knowledge about their baseline discharges than regulators do (asymmetric information), and as a result baselines are estimated with error, then there can be a second reason for sources to opt in. If a source's baseline is estimated with error and they end up with an erroneously generous baseline, then this source can choose to participate and collect credits for apparent environmental savings without doing anything to reduce their runoff. The spurious credits that they accrue from this participation are not environmental substitutes for nutrient reductions by regulated sources, as no actual reductions have occurred. These credits unintentionally increase the level of the cap, and as a result, if this is not controlled for, they will result in violation of the environmental goal. There is no balancing out of these environmentally harmful credits; if a voluntary source is instead attributed an erroneously stringent baseline, then they will simply choose not to opt in. This too has a negative impact; efficiency will be lost if those who could offer some cheap mitigation do not because of an ungenerous baseline. This is adverse selection. This was a reported outcome of voluntary participation in the US Acid Rain Program (Montero, 1999).

Clearly, the choice between a cap and trade scheme and baseline and credit has a large impact on the effectiveness and efficiency of the regulation. This choice also has significant flow on effects on other characteristics of the system. In particular it largely determines the type and level of monitoring and enforcement that is implemented; a characteristic which also has large implications for the trading efficiency of the system.

4.2. Monitoring and enforcement

Any regulation (with or without trading) must specify how and when emitters are monitored, and whether discharges are 'monitored' in advance (ex ante control) or once they have occurred (ex post monitoring). The method of determining emissions for regulatory compliance is critical for the environmental integrity of the system and also for the flexibility individual participants have in how they comply and their certainty about the effect of their actions on their compliance. Monitoring requirements can also have a large impact on the trading efficiency of any nutrient trading system.

Monitoring is considered ex ante when a scheme requires individual assessment of participants before any changes to their discharge levels or trades are approved. Ex ante monitoring is generally used to prevent non-compliance; unfortunately this approach also greatly increases transaction costs and decreases trading efficiency (Schary and Fisher-Vanden, 2004). Every time participants change discharge levels on their farms in order to trade they have to first submit to individual estimation and approval of any changes they plan to make. As a result, these ex ante monitored systems place the cost and uncertainty of this monitoring only on those who change their operations (all buyers and sellers of allowances). This decreases the net benefit of trading for all participants, and subsequently decreases the trading efficiency of the system.

Ex post monitoring systems instead require all participants to self-report their nutrient discharges and mitigation, and compliance is established after a change or trade has taken place. As a result, instead of requiring individual assessment of each trade, an ex post system allows participants to change management and trade freely according to pre-set rules, models and precedents. This approach to monitoring and measuring is expensive to set-up as it requires the establishment of models or systems that robustly estimate discharges using the supplied data. However, once established, this ex post monitoring system will be relatively cheap to carry out; participants can change operations with the only transactions cost being providing easily and cheaply collected verifiable data to regulators. This decreases costs at the time-of-trade, which will help to maximise trading efficiency. Also, if all participants are required to submit to periodic (generally annual) ex post monitoring, regardless of whether they have traded, this monitoring cost becomes independent of the trading decision. This will further decrease time-of-trade transaction costs.

Cap and trade systems can have either ex ante or ex post monitoring systems, and there are existing examples of each world-wide (Breetz et al, 2004). Cap and trade systems, both ex ante and ex post face some significant set up costs: baselines have to be set for all participants. These set up costs are larger still in ex post cap and trade schemes (such as our proposed Lake Rotorua nutrient trading scheme, see Lock and Kerr (2008b)) as a result of the significant costs involved in setting up the systems and models that ensure that the ex post monitoring system is robust. However, these additional set up costs have a positive trade-off: these ex post cap and trade systems have particularly low time-of-trade costs and high trading efficiency. Setting baselines and monitoring all sources of nutrient discharge has additional benefits: regulators will have better information on all discharging sources, and can use this to better predict environmental affects and policy impacts. The fact that all nutrient dischargers are treated alike also has some attractiveness in terms of equity. In comparison, ex ante cap and trade schemes (such as the Lake Taupo nutrient trading scheme, see (Environment Waikato, 2010)) face significant set up costs and also face large and uncertain time-of-trade costs (Environment Waikato, 2009).

Baseline and credit schemes generally employ ex ante monitoring systems[14]. Ex ante baseline and credit schemes are the most prevalent. These schemes have very low set up costs: baselines are set only for sources whose participation is compulsory (voluntary sources are not set baselines unless they decide to participate), and there is clearly no need to establish an ex post monitoring system. However, these ex ante baseline and credit schemes have high time-of-trade costs, and low levels of trading efficiency as a result. Participants in ex ante baseline-credit schemes only face any costs of participation in the system if they choose to trade and opt into the system: these costs are borne as transaction costs. If a discharge source in a baseline and credit system chooses not to trade then they will not have to adapt in any way to the market regulation – they can avoid learning the new system, the costs of optimising their operations, and obviously any baseline setting, measuring, monitoring and registering costs that they would have to face if they opted into the system and traded. These costs will greatly decrease the overall benefits of trading for optional participants in a baseline and credit scheme, possibly to the extent that they decide not to participate even if they can provide low cost mitigation.[15] The low number of trades reported in many nutrient trading schemes are evidence of this issue (King, 2005).

These dimensions are summarised in Table 1, where the arrow shows the direction of greater trading efficiency. Note that the timing of monitoring is largely a factor of whether the trading system is cap and trade or baseline and credit (offset).

Table 1: Comprehensiveness of Monitoring

Basis and timing of monitoring		Sources monitored if they trade	All sources always monitored

[14] They could theoretically use ex post schemes but the biggest attraction of an ex ante scheme - low set up costs - would be undermined by the costs involved with establishing standardised monitoring systems. Indeed, ex ante baseline and credit schemes are the most prevalent water quality trading schemes worldwide, particularly for those schemes that incorporate non-point sources (Selman et al, 2009).

[15] In contrast, participants in ex post and ex ante cap and trade systems face these costs of baseline setting as part of set-up, and face the ongoing optimising, monitoring and registration costs regardless of whether or not they trade (to ensure that they are in accordance with their allowed discharges). As a result these costs do not enter in their decision of whether to trade: transaction costs are lower and trading efficiency higher.

	Ex ante – prescribed plan or activities	Ex ante baseline and credit	Ex ante cap and trade
	Ex-post – nutrient losses modelled based on verifiable information	Ex-post baseline and credit (rare)	Ex-post cap and trade

Greater trading efficiency

The question of whether ex ante or ex-post monitoring will have a lower overall cost is less clear, and depends on the specific characteristics of trading schemes. These characteristics are largely similar to those discussed in section 2.1: the cost of setting up an ex post scheme is more likely to be offset by decreased mitigation costs in systems with high expected volumes and values of trade, whereas if little trade and participation from sources is expected then the lower set up costs of an ex ante system may make it the preferred option.

4.2.1. Innovation impacts

A final issue that should be considered when deciding on the monitoring system to use in a trading market is the impact that the approach will have on the innovation and development of new technologies and mitigation methods. An oft-cited benefit of environmental markets is that, unlike simple regulation, they can promote innovative responses to environmental problems (Jaffe et al, 2001)[16]. However, this will occur only if innovations in management or mitigation can be easily and cheaply incorporated into the nutrient trading scheme; if the cost of measuring the environmental impact of new mitigation methods is high then innovation will not be especially promoted. Streamlining this inclusion of new mitigation methods whilst minimising the cost of investigating potential mitigation methods requires careful consideration on the part of regulators, and decisions will need to feed into the choice of the monitoring process (Kerr and Rutherford, 2008).

Incorporating new innovations into a system with ex post monitoring will be more difficult and time consuming than in an ex ante system, but will provide greater certainty. To incorporate new mitigation methods in an ex ante system regulators can take an ad hoc approach where new methods and techniques can be recognised individually at the time of each trade approval. This is a relatively cheap and straightforward process for regulators, but may have negative impacts on the uptake of new innovations due to participant uncertainty: participants

[16] Tietenberg 2006 also discusses the relative strengths of this claim. The literature indicates that this claim is stronger under some circumstances and assumptions than under others; namely, if allowances are auctioned and marginal costs of production are increasing. In any case, decreasing the costs of incorporating new innovations into a system will increase innovation.

will have to go through the expense of a trade approval process before they know whether their innovative mitigation methods will be recognised. In comparison, in an ex post scheme new innovations would have to be tested and incorporated into the models and precedents that are used to estimate discharges for all participants before it can be used by participants. This method will be slower and more expensive, but is likely to offer more certainty for participants, who will know before applying any mitigation techniques the impact that this will have on their recognised discharges, and the savings that will be associated.

5. Trade-off: Environmental certainty and trading efficiency

The issue of trading efficiency in environmental markets is made more difficult by the trade-offs between environmental certainty and low time-of-trade costs. This trade-off and its implications are discussed and formalised in the following section. Examples of trading restrictions from existing systems are also explored.

As was discussed in section two, maximising trading efficiency and minimising transaction costs requires that trading is largely unrestricted and is made as flexible as possible. While this approach ensures that allowances can cost effectively move from initial holders to those who value them the most, if there is any difference in the relative impact of nutrient discharge cuts, then this free trade can also result in an uncertain net environmental outcome: environmental uncertainty.

This environmental uncertainty has the same impact whether the uncertain environmental outcome is due to true scientific unknowns or as a result of known and accepted variability. True (Knightian) uncertainty occurs if the actual impact of any nutrient discharges or reductions on the final environmental goal is not totally certain, for example, this is the case if regulators cannot be sure that a decrease in discharges by one participant will exactly offset an increase in discharges from another participant (as is often the case when including non-point sources in a trading scheme). Environmental uncertainty also results from known variability in environmental impacts. To establish a workable trading scheme an 'enabling myth' of homogeneity of impact may need to be assumed. Our analysis is unchanged whether this heterogeneity of impact is known or not.

This environmental uncertainty is likely to be a larger issue in a flexible trading scheme than in a command and control regime for a few additional reasons. Scientific understanding and modelling of nutrient discharges are based on status quo activity and discharge levels. Policies that result in large shifts away from status quo levels of activity will shift further away from accepted scientific understanding and will be associated with an increase in the uncertainty of the environmental outcome. Flexible trading schemes are more likely than command and control schemes to result in significant movement of discharges around a catchment and greater variation of discharge levels, with increases at some sources and decreases at others. As a result discharge intensities and locations will shift further from pre-regulation scientific knowledge which will increase environmental uncertainty.

This issue of environmental uncertainty is touched on in the literature on 'hot spots', which also outlines some regulatory attempts to decrease them (Tietenberg, 1995). Hot spots occur when unacceptably high levels of pollution occur in a localized area, within a wider trading market. While the literature has shown that the occurrence of hot spots has not been high (Swift, 2000), avoidance of these hot spots is another possible motivation to restrict trading.[17] Tietenberg (2006) provides a summary of possible policy responses to avoid hot spots. This tension between environmental certainty and low trading costs is not touched on in this literature.

5.1. Formal Depiction of Trade-off

We first set out the cost of environmental uncertainty. When faced with this environmental uncertainty, regulators have three options. Firstly, they can accept the environmental uncertainty and bear its cost. Secondly, regulators can attempt to decrease (the cost of) uncertainty, for example by introducing trading rules and increased monitoring and measuring at the time-of-trade. While this will decrease environmental uncertainty these regulations also act as transaction costs and decrease trading efficiency. Indeed, if regulators are especially risk averse and apply particularly stringent trading restrictions, then the high costs of trading could result in no trades at all occurring. Even small restrictions on trade will have a cost though. Thirdly, regulators can set a more ambitious environmental target that ensures that they will meet their original cap with certainty, but leave trading unrestricted as in the first option. This avoids the cost of uncertainty faced in option one, and the costs of trading efficiency in option two. However, nutrient dischargers will face additional costs to achieve this more ambitious goal.

5.1.1. Model set-up

Figure 3 shows the benefits and damages of mitigating discharges into a lake. The level of modelled mitigation is given by x. Society benefits from increased mitigation of nutrient

[17] A wish to ensure 'environmental justice' may be another related motivation to restrict trading. A recent paper by Fowlie et al. (2009) discusses this issue using evidence from the Southern California NOX program.

runoff (which decreases water pollution), but at a decreasing rate. The marginal benefit to society (MB^s) of increasing mitigation by one unit is shown by the downward sloping curve in Figure 3, and is given by equation two. Equation three gives the total social benefit of a given level of mitigation:

$$MB^S = a - bx \tag{2}$$

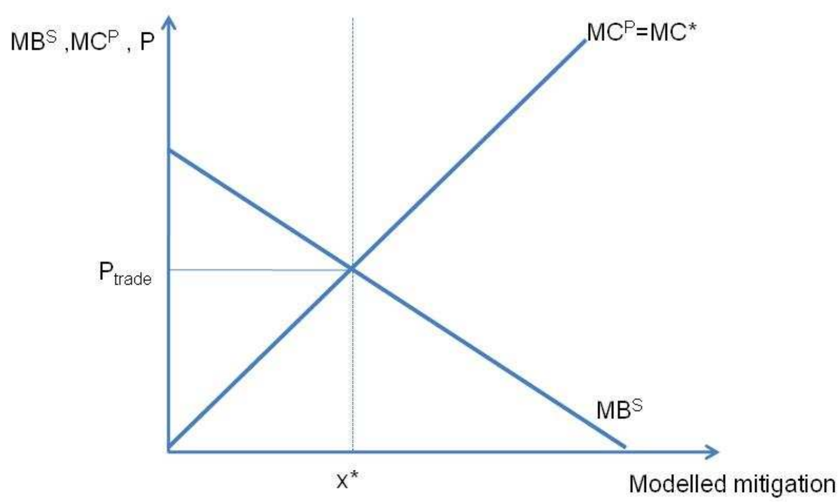
$$B^S(x) = \int_0^x (a - bx)dx = a(x) - \frac{b}{2}(x)^2 \tag{3}$$

The costs of mitigating are borne privately by the nutrient dischargers who do the mitigation and participate (or not) in the nutrient trading market. Their marginal costs of mitigation (MC^P) are assumed to be increasing as the mitigate more, and are given by the upward sloping curve in Figure 3 and by equation four. The total cost of mitigating (C^P) is given by equation five. This initial mitigation cost line illustrates the case where trading is unrestricted and monitoring requirements are not onerous, this results in mitigation being carried out by those who can most efficiently do so and at lowest overall cost (MC^P =MC*).

$$MC^P = c + dx \tag{4}$$

$$C^P(x) = \int_0^x (c + dx)dx = c(x) + \frac{d}{2}(x)^2 \tag{5}$$

Figure 3: Benefit and cost of mitigating



The optimal cap for our trading market (x^*) is given by the intersection of these two points, which is shown as the vertical dotted line in Figure 3. When the cap is set at x*, the price for the nutrient trading allowances is given by the intersection of this cap and the marginal cost line (P_{trade}).

5.1.2. Option one: Accepting uncertainty

Note that in Figure 3 above the horizontal axis is defined in terms of *modelled* mitigation. To achieve the high trading efficiency, low time-of trade transaction cost and efficient mitigation cost case described above, regulators model dischargers mitigation instead of exhaustively (and expensively) monitoring and measuring mitigation. As a result, we expect that there is some error between the modelled mitigation and the true level of mitigated nutrients arriving in the lake: environmental uncertainty. This does not affect the marginal costs of dischargers (they are required to remit allowances equal to their total modelled level of discharging, not actual). However, there is a real cost to environmental uncertainty. If, as we assume, the marginal benefit of mitigating nutrient runoff is decreasing with mitigation levels, then any increase in uncertainty results in a lower expected level of social utility. Conversely, if regulators can decrease environmental uncertainty at no cost, then social utility will increase. A related issue is the actual state of the relationship between environmental risk and trading efficiency. If the relationship between the two is non-linear, for example if variability grows increasingly as trading efficiency increases, then a lower level of trading efficiency will be preferable relative to a situation where a linear relationship exists between the two. It is unclear what the likely relationship will be.

We assume that the regulator sets the environmental target (cap) at x*, distributes the trading allowances to participants and allows trading which maximises trading efficiency by avoiding onerous monitoring and measuring, and allows free trading amongst participants. This is associated with low time-of-trade transaction costs, and will minimise the marginal cost of complying with the regulation for dischargers (MC^P=MC*). However, this is associated with environmental uncertainty: regulators will not be certain that the modelled mitigation (x) is equal to actual mitigation (x^A). We assume that the actual mitigation[18] is equal to the modelled mitigation plus or minus some error (φ), such that

$$x^T = x^* \pm \varphi$$

$$x_L = x^* - \varphi \qquad (6)$$

$$x_H = x^* + \varphi$$

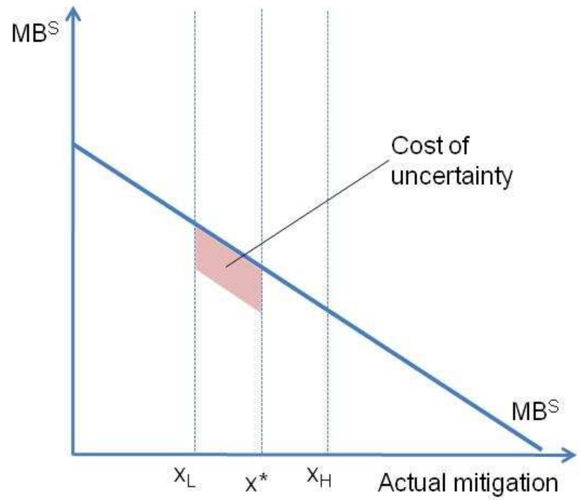
For illustration we assume that probability that the actual level of mitigation will be given by x_L or x_H is equal:

$$P(x_L) = P(x_H) = \frac{1}{2} \qquad (7)$$

[18] It is not clear whether the regulator may expect mitigation to be higher or lower than the cap at x, as it is not clear which way error in the modeling of mitigation will fall.

This cost of this environmental uncertainty is illustrated in Figure 4, and calculated below.

Figure 4: Accepting uncertainty



The value of social benefit under certainty is given by equation eight (from equation three):

$$B^S(x^*) = a(x^*) - \frac{b}{2}(x^*)^2 \tag{8}$$

The expected value of social benefit under uncertainty is given by plugging equations six and seven into three.

$$E(B^S) = \frac{1}{2}\left(a(x^* - \varphi) - \frac{b}{2}(x^* - \varphi)^2\right) + \frac{1}{2}\left(a(x^* + \varphi) - \frac{b}{2}(x^* + \varphi)^2\right) \tag{9}$$

Expanding and simplifying equation nine:

$$E(B^S) = \frac{1}{2}\left(2ax^* - \frac{b}{2}\left(2x^{*2} + 2\varphi^2\right)\right)$$

$$E(B^S) = a(x^*) - \frac{b}{2}(x^*)^2 - \frac{b}{2}\varphi^2$$

$$E(B^S) = B^S - \frac{b}{2}\varphi^2 \tag{10}$$

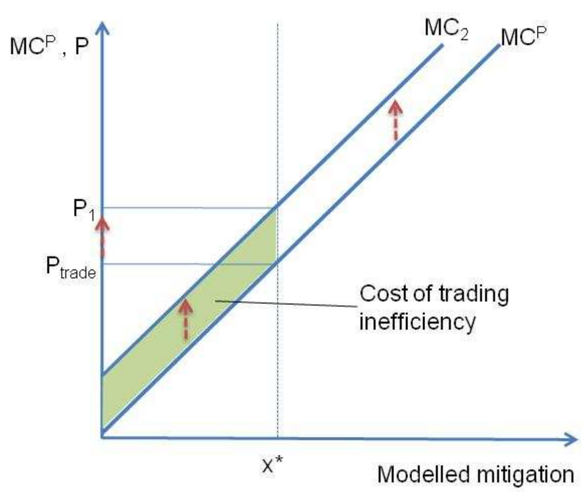
Equation ten clearly shows that, given the assumptions, under uncertainty the expected value of social benefit is lower than the social benefit under certainty by $\frac{b}{2}\varphi^2$. This is shown as the red shaded area of Figure 4 [19].

[19] This area is given by subtracting the economic cost if nutrient discharge levels were higher than expected, and fell at the high end of the uncertainty band, from the surplus that if nutrient discharges were lower than expected, and fell at the low end of the uncertainty band.

5.1.3. Option two: Limiting uncertainty

This second approach is illustrated in Figure 5. To avoid the environmental uncertainty, regulators restrict trading in some way, for example by limiting who can participate or by requiring extra monitoring and measuring. This will have two effects, both of which are shown in the right hand diagram of Figure 5. The first effect will be an increase in environmental certainty, which is shown as the disappearance of the uncertainty band around the cap goal level of discharge, x*, which results in the disappearance of the cost of uncertainty. However, restricting trade in this way will also decrease the trading efficiency of the scheme. This makes the achievement of any environmental goal more expensive. This is shown by a shift upwards of the marginal cost line from MC^P to MC_1: this MC line is no longer equal to efficient marginal cost as the trading restrictions mean that the cost of mitigation are augmented by time-of-trade mitigation costs, and that as a result mitigation may no longer be being carried out only by those who can most cheaply mitigate. The cost of this is shown by the increase in the price of the final unit of mitigation rising from P_{trade} to P_1, and also by the shaded area which represents the cost of trading efficiency losses.

Figure 5: Limiting uncertainty



Mathematically, the total cost of achieving the environmental goal under MC^P=MC* is given by equation eleven:

$$C^*(x^*) = cx^* + \frac{d}{2}x^{*2} \tag{11}$$

The marginal and total cost of achieving the environmental goal with the additional costs that are faced as a result of trading inefficiency (m) are given by equations twelve and thirteen.

$$MC_1 = c + dx^* + m \tag{12}$$

$$C^1(x^*) = \int_0^{x^*} (c + dx^* + m)dx = cx^* + \frac{d}{2}x^{*2} + mx^* \tag{13}$$

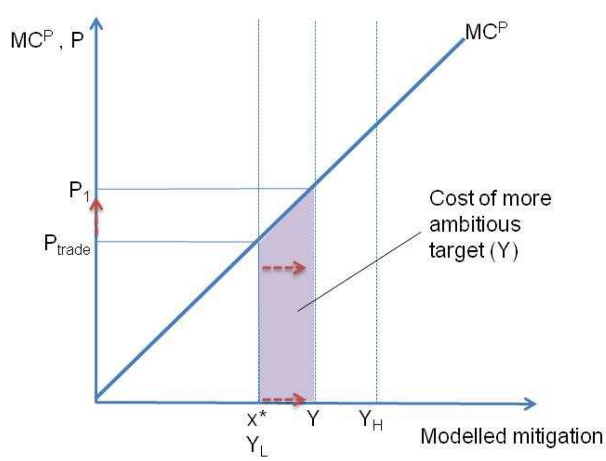
$$C^1(x^*) = C^*(x^*) + mx^* \tag{14}$$

Equation fourteen clearly shows that the cost of decreasing environmental uncertainty is equal to mx*.

5.1.4. Option three: Ambitious environmental goal

The third approach, of aiming for a more ambitious environmental goal but placing no restrictions on trading, is illustrated in Figure 6. Here, instead of introducing expensive monitoring and measuring requirements (as in option two above) regulators could set a more ambitious environmental goal (Y), such that the worst outcome (Y_L) is more than or equal to original socially optimal cap (x*). This new environmental cap will ensure that the environmental goal (x*) is met with certainty (while regulators won't know exactly what the environmental outcome will be, they know that mitigation will be at least x*), and thus avoids the cost of environmental uncertainty in option one. The cost of this approach is shown by the increase in the price of the final unit of mitigation rising from P_{trade} to P_1, and indicated by the purple shaded area of Figure 6).

Figure 6: Ambitious environmental goal



This cost can also be expressed mathematically. Equation 15 gives the new cap:

$$Y = x^* + \tau \tag{15}$$ [20]

Plugging (15) into (5) gives the cost of meeting this new cap

[20]In figure four we have implicitly assumed that τ=φ.

$$C^*(x^* + \tau) = c(x^* + \tau) + \frac{d}{2}(x^* + \tau)^2$$

$$C^*(Y) = c(x^*) + c(\tau) + \frac{d}{2}(x^{*2} + 2x^*\tau + \tau^2)$$

$$C^*(Y) = c(x^*) + \frac{d}{2}(x^*)^2 + \frac{d}{2}(2x^*\tau + \tau^2) + c(\tau)$$

$$C^*(Y) = C^*(x^*) + \frac{d}{2}(2x^*\tau + \tau^2) + c(\tau) \tag{16}$$

Where (16) clearly shows the cost of achieving the new cap is equal to more than the cost of achieving efficient cap proposed in the model set-up. This additional cost is shown to be increasing in the slope of the MC curve, increasing in the optimal cap (x^*), increasing in the additional ambition of the new cap (τ), and increasing in the size of the cost of the first unit of mitigation (the vertical intercept, c).

The formal expression of this decision makes the regulators decision clear; regulators can choose to either; one, cheaply achieve the environmental goal, but face a cost of environmental uncertainty (as shown in Figure 4): two, face a higher cost of achieving the environmental goal but with no environmental uncertainty costs (as shown in Figure 5); or three, face the additional cost of a more ambitious environmental goal (as shown in Figure 6). There are clear costs to each approach. The relative benefit of following one approach over the others is the decision that a regulator must face.

5.2. International examples of trading limits

Examples of trading limits and restrictions that target this trade off between environmental certainty and trading in existing schemes worldwide are plentiful. Some of these limits and restrictions successfully target the trade-off between environmental certainty and trading, others are less successful in their aim of reducing environmental uncertainty. In either case, these restrictions can be a significant source of transaction costs and trading inefficiency. We present a number of international examples of trading restrictions below and discuss their implications on environmental certainty and trading efficiency.

Trading systems are usually set-up under the assumption that the scheme alone will ensure that nutrient mitigation in one area is a perfect substitute for mitigation in another area. However, if regulators are not confident that this is the case, then additional rules or pre-approval of trades may be a sensible method to decrease any risk to the environment. Rules that restrict trading to between like sources are an example of rules that aim to restrict trading to increase environmental uncertainty. 'Like sources' can be defined in a few ways. The Pennsylvania Water Quality Trading Program looks to ensure that trading is restricted to 'like sources' where like is defined by location within the same watershed.[21] 'Like' can also be defined by the same arrival time in the focal body of water; in the prototype Lake Rotorua nutrient trading scheme discharges must be matched by allowances appropriate to the year that nutrients arrive in the lake (a 'vintage' system) (Lock and Kerr, 2008c). However, the most common appearances of these environmentally motivated trading restrictions are as uncertainty ratios.

Uncertainty trading ratios can be found in many schemes internationally as a method to decrease the uncertainty about the actual environmental impact of trading, particularly in schemes which include NPSs. NPS discharge reductions are generally thought of as less certain and more variable than PS reductions, as their effectiveness depends on things such as the weather and storms (Selman et al, 2009). Uncertainty ratios are set such that for a NPS to get a credit equivalent to a one unit PS discharge reduction, the NPS would have to decrease their discharges by more than one unit. This approach is meant to work as a safety margin that ensures that even if NPS discharge reductions don't work as expected, water quality will not be negatively affected. While the use of uncertainty ratios may have some environmental benefit by ensuring that water quality is protected, they also impose clear costs on trading efficiency. The use of these uncertainty ratios decreases incentives for NPSs to participate in any trading system: any discharge reductions they make are worth significantly less than PS discharge reductions. This will work as a significant barrier to getting discharge allowances from the low cost abaters (presumed to be NPSs) to those who face high costs of abatement (presumed to be PSs), which by definition will negatively affect trading efficiency. However, if this is balanced by a significant decrease in the uncertainty of the environmental impact, then this may be justified.

International trading schemes offer many examples of these uncertainty ratios. In the Lake Dillon scheme in Colorado, USA, two units of discharge reduction by NPSs are required for any one unit increases in discharge by PSs (Woodward, 2003). The Pennsylvania Water Quality Trading Program places a 10% 'insurance' ratio on all trades to cover any mitigation that fails due to reasons outside of the credit sellers control (Pennsylvania Department of Environmental Protection, 2006). Uncertainty ratios are also present or proposed in many other schemes such as the Lower Boise River Effluent Trading Demonstration Project and the Minnesota River Basin trading program Greenhalgh and Selman, 2008. The use of uncertainty ratios is also encouraged as good policy by the United States Environmental Protection Agency US Environmental Protection Agency, 2007.

[21] The Pennsylvania scheme controls nutrient discharges across two watersheds, the Susquehanna and the Potomac.

Despite their impact on trading efficiency, the use of uncertainty ratios may be preferable to other less certain mechanisms that are used to address this environmental uncertainty issue. Complicated and uncertain compliance systems may achieve environmental certainty but are associated with high levels of uncertainty for participants. An example of such a system is present in New Zealand's Lake Taupo Trading Program: in this scheme both the buyer and the seller have to have any changes to their emissions individually assessed and approved before a trade can be carried out. This mechanism provides very little certainty for participants to plan ahead, is costly, and as a result significantly decreases trading efficiency. Under such uncertain approaches participants may choose to mitigate more than is efficient and over-comply (buy additional allowances or not sell) to reduce risk (Shimshack and Ward, 2008). This over-compliance comes with a cost; if the goal of environmental certainty was pursued through a method which gave participants more certainty over their costs and obligations, such as the uncertainty ratios described above, it could be achieved at higher levels of production.

There are also many examples of trading rules and restrictions that limit trading but do not offer any related environmental certainty gains. In the Pennsylvania Water Quality Trading Scheme landowners can accrue nutrient credits for decreasing nutrient discharges through almost any nutrient mitigation method, but they cannot receive credits for land use change.[22] In the Connecticut Long Island Sound Nitrogen Credit Exchange Program trades are only allowed between PS participants and the central exchange board. The board also sets the price of credits based on an assumed average mitigation cost. This approach results in no market clearing, and trading inefficiencies as a result. The restriction of participation to point sources is another trading rule which deceases trading efficiency, this limitation is present in at least 13 of the 57 existing, proposed or inactive trading schemes worldwide (Selman et al. 2009).

Trading systems should also give participants the choice of whether or not to trade. While trading is expected to lower the cost of mitigation, in some cases nutrient discharges may be most cost effectively cut through onsite methods. Fang et al (2005) criticise the Minnesota system because it requires point sources to purchase allowances from non-point sources to comply – point sources are unable to meet their target through in-plant control methods. This restriction potentially forgoes more efficient nutrient reductions. It also retains a high level of control for regulators, negating the 'command but not control' philosophy of market-based instruments (Shabman and Stephenson, 2007).

[22] There was political concern in the lead up to the nutrient trading scheme that its introduction would result in farms stopping operations and selling or shifting to alternative land uses. As a result a clause was written into the law to ensure that farmers would not get credits by shifting land out of farming, even if this was the most cost efficient method of nutrient reduction.

Local circumstances and political processes can also lead to inefficient trading rules. An example is the interaction between existing or parallel command-and-control regulations and any trading scheme. If the scheme is not carefully aligned with any existing regulation, trading efficiency can be significantly hindered. King (2005)argues that this is a cause of inefficiencies in the Chesapeake Bay, Maryland trading scheme.

There are clearly many examples worldwide where regulators have attempted to address this trade-off between environmental certainty and trading efficiency, generally in favour of environmental uncertainty. There are also clearly instances where trading restrictions and limits have been introduced that decrease trading efficiency with no obvious gains in environmental certainty. While regulators may have other good reasons for introducing such regulations, it is important that the negative impacts of restricting and limiting trade are recognised. The negative impacts of restricting trading efficiency in this way can be large, and must be considered when designing policy.

6. Conclusion

In this paper, we examine existing water quality trading markets worldwide and assess the growing literature on transaction costs in environmental markets to address two key questions. Firstly, under what circumstances should regulators try to reduce time-of-trade transaction costs in a water quality trading market? Secondly, what policies will successfully decrease these time-of-trade transaction costs and increase trading efficiency in these markets?

Our discussion indicates that maximising trading efficiency should be a key consideration when designing a nutrient trading market, but that maximising trading efficiency can be costly, and involves the careful consideration of a number of issues. Regulators must first consider whether increased expenditure on improving trading efficiency will be more than offset by decreased time-of-trade transaction and mitigation costs. Expending effort to improve trading efficiency is only worthwhile if it results in a lower overall cost of achieving the environmental goal. Regulators must also consider the most effective way to improve trading efficiency, and whether this is by focussing effort on minimising the causes of time-of-trade transaction costs, or by increasing the time and effort spent setting up the water quality market. The trade-off between trading efficiency and environmental certainty is also significant; all options to deal with it must be considered by regulators.

We also offer a selection of policies that will effectively increase trading efficiency, post consideration of these issues. A key insight of the discussion is the importance of designing schemes with trading efficiency in mind; high levels can be achieved, but only if the goal of trading efficiency is considered from the design stages. Improving the information made available for participants and maximising certainty (in all its spheres) for participants, and shifting the timing of costs to set-up will all decrease time-of-trade transaction costs and improve trading efficiency.

A final insight comes in our discussion of the trade-off between trading efficiency and environmental certainty. While regulators may be tempted to restrict trading or increase measuring and monitoring requirements to increase the environmental certainty of a schemes outcome, this will have negative effects on trading efficiency, and comes with a significant cost. Regulators and the public must consider the option of accepting some degree of environmental uncertainty, and the possibility of compensating for this uncertainty with a more ambitious environmental target.

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