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Turning a Negative into a Positive: What to do about Negative Externalities from Nitrogen Used in Farming?[1]

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Abstract

Much of the nitrogen fertiliser that farmers use to grow crops and pasture is not used by these plants but is lost to the environment, causing negative externalities such as nitrous oxide contributing to stocks of global greenhouse gases, and nitrate and ammonium polluting water and air. These externalities have large external costs. Much of the discussion of how to minimise these costs has focused on government policy actions such as quantitative regulations about use, and the implementation of taxes and subsidies, or cap and trade models. In this paper an alternative approach is outlined based on the theory of club goods and actions jointly with the private sector rather than solely by the public sector. A proposal for a public subsidy to fertiliser producers to cover the cost of precoating fertiliser products like urea, to reduce the cost of reduced-emission nitrogen fertiliser products, and to make treated nitrogen fertiliser products available to farmers at a similar cost to untreated nitrogen fertiliser products, is assessed against this approach.

***Keywords**:* nitrogen, negative externalities, external costs, policy options, club good solutions

Introduction

The nitrogen (N) fertiliser that farmers use to grow many of their crops and pastures enhances yields and outputs. Unfortunately, some of the N applied does not produce the agricultural products people need; instead, it pollutes the air and water that people need no less than their food, and which they need to be relatively free of contaminants. Further, people also need the atmosphere not to have too much carbon dioxide equivalents, so nitrous oxide pollution, which has considerable potential to warm the atmosphere, and ammonia, which causes health problems, are unwanted. These air, water and soil pollutants are termed 'negative externalities'.

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In market economies, when outputs fall short of people's expectations, and their well-being is less than it could be, governments can be justified in developing policies and intervening on behalf of the public.

The first policies to consider concerning N pollution in agriculture are existing policies that encourage farmers to use more N than would be economically sound under efficient, competitive market conditions. To reduce N pollution the first step is to desist from having agricultural policies that subsidise farmer incomes, distort commodity prices and input costs, and provide concessionary tax deductions, all of which encourage the intensification of the use of inputs such as N beyond the dictates of the competitive market. The irony of countries heavily subsidising agriculture and then battling environmental problems from over-intensive farming is profound. So the appropriate policy approach is to, first, stop encouraging N pollution; then, look at the policy measures available to tackle the remaining pollution and see which measure, or which combination of measures, best fits.

Regulatory approaches to environmental policies (restrictions on input use, for example) have been used often in Australia. The decline in the quality of water and coral within the Great Barrier Reef (GBR) region has been tackled by the Queensland Government and the Federal Government with the regulation and legislation of their Reef Plan. The goal is to reduce N and phosphorus (P) sediment pollution and pesticides from sugar cane and broad-area agricultural activities. Farmers in specific areas are legally bound to comply with regulated fertiliser, soil, and water management practices. Each State has a host of land-use and environmental regulations compelling farmers to behave in specific ways and not in others. Hitherto, though, there were few regulations about the use of N in agriculture.

The other broad set of policy options are those which provide incentives through the price mechanism to encourage good behaviour or to discourage bad behaviour. These policies include taxes and subsidies of inputs or outputs, tradable permits, etc. (see for example OECD (2013)).

The focus of this paper is on the pollution arising from N used in agriculture (which causes negative externalities such as nitrous oxide contributing to stocks of global greenhouse gases, and nitrate and ammonium polluting people's water and air) and what to do about this problem. The specific research question is what public policies might be best suited to tackle the problem of N pollution from nitrous oxide emissions? The discussion canvasses and distils information and results from a range of recent studies conducted by the authors for the ‘N Hub’ including Malcolm *et al*. (2022), Rathnayake *et al*. (2023), Tang *et al*. (2023), Wirtz *et al*. (2023a, 2023b), Tang *et al*. (2024) and Rached *et al*. (2024).

Characteristics of Using N in Crops that are Relevant to Policy Discussions

The first set of information required to answer a research question like this is related to the biophysical and economic relationships in the production system of the industries of interest. So, answers to the following questions about the characteristics of the use of N fertilisers to grow cotton, sugar cane and vegetables (the focus industries of the N Hub), which are of interest to policymakers, would include ideally:

- How much N is applied to the crops, and why this amount?
- How much N is used per hectare? Here we are referring to whether economic optima, both theoretical and practical, can be estimated.
- How much of the N that is applied becomes a pollutant of some form, and what is the negative externality cost to society caused by these pollutants?

- What are the characteristics of using N and the corresponding production functions of the grown crops? Here, we are referring to the position and shape of the N fertiliser production function.
- What are the characteristics that 'enhanced efficiency fertilisers' (EEFs) would need to have to make them a potential alternative source of N for use in agriculture? Here, we are referring to the position and shape of production functions of EEF fertilisers and costs relative to those of traditional N fertilisers.
- What are the characteristics of N fertilisers, and is their use in agriculture likely to make the 'first best' market methods of reducing pollution infeasible and the regulatory or subsidy methods costly and inefficient? Here, we are referring to N as an input to agriculture, having the characteristics of: highly inelastic demand by farmers; a high ratio of benefits to costs of using it to produce agricultural products; and the non-point characteristic of some of the forms of N pollution of water and air.

Following on from those questions are:

- What are the private and social benefits of the amount of N that is applied?
- What are the private and social costs of the amount of N that is applied?

Evidence about N Use and N Pollution in Cotton, Sugar Cane and Vegetable Production

Nitrous oxide emissions from nitrogen fertiliser used in agriculture go into the atmosphere. An average unit of nitrous oxide has a global warming potential of around 300 times that of carbon dioxide. Currently, depending on the jurisdiction around the world, the marginal cost of the negative externality of nitrous oxide as damage from global warming is $50-$200/t of emission of carbon dioxide equivalent. A market failure exists in the case of nitrous oxide, and the negative externality has a known current cost.

For cotton, sugar cane, and vegetables in Australia, some information about the above set of characteristics and measures has been generated. For example, information is available about the input-output response functions that apply under the most common growing conditions, viz., soil types, moisture availability, other nutrients, diseases, pests, climates, and management practices. Valid estimates also exist of the losses as nitrous oxides, often expressed as functions and not just average quantities of N2O emissions per input unit. The quantities of N2O emitted into the atmosphere convert into carbon dioxide equivalents, and the externality cost is estimated according to its global warming potential and valued using the social cost of carbon dioxide in the atmosphere, i.e., the market price of carbon. Further, at least for sugar cane grown in the GBR region of Queensland, the external cost of water pollution can be estimated for the N run-off in water that leaves blocks of cane and pollutes the waters of the GBR. It is possible to estimate the damage this N run-off causes to water quality, the corals of parts of the reef, and the value people put on more transparent GBR waters and less damage to (some of) the coral reefs.

Central to the question of appropriate policy to reduce nitrogen pollution is that the private and social benefits of using nitrogen, in most agricultural industries, are large relative to the private costs. In the case of growing cotton and vegetables, the private and social benefits of using nitrogen are considerable relative to the private cost and the negative externality cost of one of the sources of pollution, nitrous oxide pollution. Benefits exceed private costs and the external cost of nitrous oxide emissions by ratios of 8:1, at current product prices and growing costs and carbon dioxide emissions equivalents priced at a mean value of $80/t. Benefits also greatly exceed costs for the case where water pollution costs can be estimated: that of N pollution adversely affecting the quality of water around the GBR. Even with significant costs to the GBR from nitrate pollution of waters, benefits exceed costs by 3:1 at current prices, growing costs and emissions cost at $80/t Co2e (authors' estimate, unpublished).

Empirical evidence is that the N used as an input for growing agricultural and horticultural crops in Australia has a high ratio of benefits to costs (private and N2O externality), and the price elasticity of demand for N is highly inelastic. See Table 1 for data about N used for cotton, sugar cane, and vegetables, based on 'representative response functions' of nitrogen to output for economically optimum N rates.

As shown in Table 1, adding the external cost of nitrous oxide emissions to the marginal cost of the urea used changes only slightly the socially optimum quantity of N to use. The evidence is that, even if the costs of some of the pollution, such as the externality cost of N2O, are added to the cost of the input using the classic Pigouvian' tax the polluter' method, the demand for N fertiliser changes little. This also tells us that if the only cost was the N2O emissions and the Pigouvian tax captured all the externality cost, the right amount of N to use is similar to farmers' current N use levels.

Table 1. Rates of N use for representative response functions with and without N2O externality cost added to fertiliser prices for cotton, sugarcane and potato production

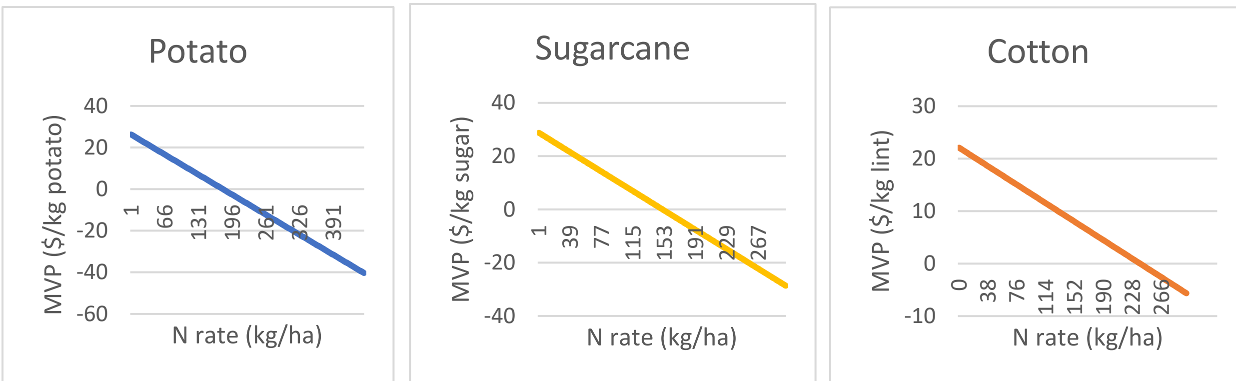
	Unit	Cotton	Sugarcane	Potato
The current price of nitrogen fertiliser	$/t	1,030	1,030	1,030
Current economic optimum N rate per ha*	kg N/ha	**228**	**146**	**172**
Total externality cost of N_2O emissions per ha at economic optimum kg N/ha when externality cost not included in the cost of N	$/ha	37	41	137
New economic optimum N rate with marginal externality cost added to the cost of each kg of N	kg N/ha	**222**	**145**	**171**
Total externality cost of N_2O emissions per ha at new economic optimum kg N/ha when externality cost $80/t Co2e is included in the cost of N	$/ha	34		
% Reduction in N use/ha		2.6		

Source: authors' calculations. *Note*: *Economic optimum here is the theoretical optimum where the marginal product equals the ratio of the price of input to the price of output. The actual optimum N use for growers includes further considerations such as 'insurance' and attitude to risk.

These findings are consistent with findings elsewhere about the relative price inelasticity of demand for N as an agricultural input (reviewed by Tang *et al*., 2024). For instance, Henseler and Dechow (2014) found in a study in Germany that a 150 per cent tax on N fertiliser prices reduced the use of N only by 12-13 per cent. Giraldez and Fox (1995) in Canada found a 55 per cent nitrogen tax could reduce the amount of N fertiliser used from 147kg/ha to 140kg/ha, a 4.7 per cent reduction. England (1987) in the United Kingdom found a 100 per cent tax on N resulted in a 10.6 to 13.9 per cent reduction in the amount of N fertiliser used on farms on four different crops. Bel *et al.* (2004), reviewing attempts to control non-point source nitrogen pollution in Europe over 20 years, found that N fertiliser prices in Europe had a weak impact on N fertiliser consumption trends over the past 20 years, and that high tax rates would be required to achieve significant decreases in use.

The demand for N by Australian cotton, sugarcane and potato growers is given by the marginal value product curve of N used for these purposes (Figure 1). The steepness of this curve indicates that the demand for the N input will be price inelastic along parts of it. If N2O were the only external cost from N

Figure 1. Marginal value product (demand) curves for nitrogen in potato, sugarcane and cotton production



Source: authors' calculations

used for cotton, sugar cane and potatoes, then taxing the producers to recoup the cost of this externality that results from their use of N would reduce the quantity of N used a little, while raising revenue to account for the external cost still being caused. However, this would not account for other costs that are difficult to measure and value but, in some cases, can be substantial, such as external costs to water and air quality caused by using N. Even when an estimate of the external cost of degrading water quality in the GBR region is added to the marginal cost of urea used to grow sugarcane, the benefit-cost ratio of the N input is 3:1, and the socially optimum amount of N to use changes slightly, from 143 to 136 kg N/ha.

If a tax on N2O emissions does not reflect all the external costs, requiring a more significant tax, and if N demand did not reduce a great deal, then this too would tell us that, because the benefits of N are great relative to the small private and external cost, the optimal amount of N demanded with all costs of the negative externality counted would be little different to current uses.

As mentioned above, the effectiveness of a tax on curbing use of an input depends on its price elasticity of demand. Up-to-date estimates of the price elasticity of demand of N in different agricultural uses and at different levels are not available for Australian agricultural production uses of N, although all indications are that this demand is inelastic. The results in Table 1 above, where the amount of N used changes little after the cost of N2O emissions are added in, come about from the levels of N used, the combination the nitrous oxide externality cost as a proportion of the cost of N and the size of the marginal value product of N compared to the cost of the N, at the levels of N use that are common.

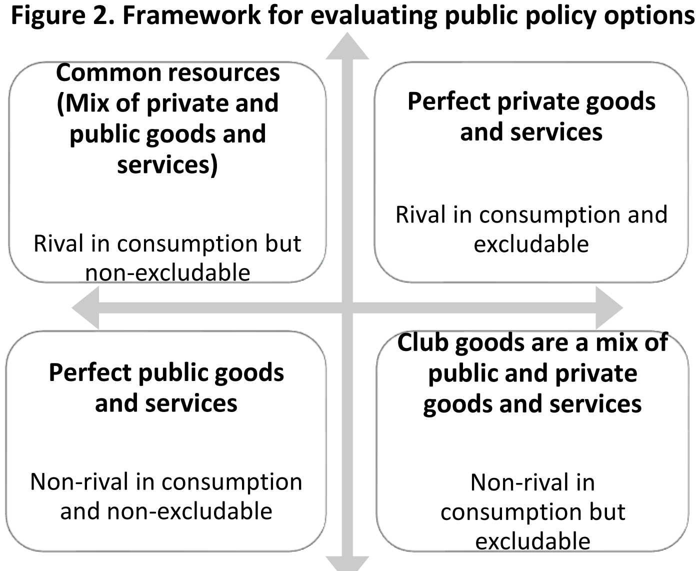
The implication of an inelastic demand for N as an input to agricultural and horticultural production is that for a tax, a cap-and-trade system, or a subsidy/credit policy to work in reducing N pollution, a large tax or subsidy would be needed to (i) match all the social costs and (ii) to reduce the use of N much. Furthermore, the perceived benefits of 'insurance' and the risk attitudes of farmers that influence farmer decisions about N use would likely make them even more reluctant to reduce their use of N to any significant degree. Perhaps the more important practical point is that the political likelihood of successfully introducing a fiscal measure such as a pollution tax on N use has to be rated as being extremely low. As Hicks *et al.* (2022) reported 'fiscal measures are politically sensitive and taxes on artificial N fertilisers proposed in other countries have been highly controversial and perceived as punitive and unfair by farmers' (p.155) – and they have responded accordingly! Overall, given the indication that the demand for N is inelastic, a tax or subsidy approach to reducing the externality costs of applying N fertiliser to agricultural production systems would have little prospect of success.

If public policy based on market/fiscal policy measures to reduce farmer use of N fertiliser are unlikely to be politically feasible and will not be economically effective because of the low-price elasticity of demand for N, alternative approaches warrant consideration. Examining the type and cause of the market failure underlying the creation of the negative externality is one such.

Market Failure

Governments intervene in the market economy via public policies because they believe their intervention is more likely to meet people's needs and wants than leaving it to private agents acting in markets to do it. To this end, governments develop policies that establish rules designed to influence the behaviour of private and public agents in the economy to make people better off. The expected outcome is that the total benefits of the policy will outweigh the costs, resulting in a net gain in social welfare. Policy essentially is the development and implementation of a set of rules that establish incentives and penalties to influence the behaviour of producers, consumers, and public bodies. Whether or not policy responses to failures of markets are implemented, and where they are implemented in the economy, depends on the type of failure of the market to meet people's needs and wants and the benefits and costs of solving the problem that is the cause of the policy intervention. A common framework used for evaluating public policy options is shown in Figure 2[2].

Figure 2. Framework for evaluating public policy options



Source: based on Fleming et al. (2018)

The four categories of public and private goods shown in Figure 2 are the following:

[2] Non-rival means that when one consumer partakes of the benefits provided by the good or service, it does not diminish the benefits received by any other consumers. Non-excludable means that it is either impossible or very expensive to prevent anyone from consuming the good or service, even if they refuse to pay for it (see for example Katz and Rosen (1998, chapter 18)).

- Perfect or pure private goods and services, where the goods and services are rival and excludable in consumption;
- Perfect or pure public goods and services, where the goods and services are non-rival and non-excludable in consumption;
- Imperfect or impure public goods and services, known as common or shared resources, where the goods and services are rival in consumption but non-excludable; and
- Imperfect or impure public goods and services, known as club goods and services, where the goods and services are non-rival in consumption but excludable.

A ‘public good’ form of market failure that occurs within a value chain and prevents maximum net benefits being delivered by the value chain, falls into this category of ‘Club Good’. This is known as ‘Value Chain Failure ‘and is explained below (Griffith *et al*., 2015).

The schematic in Figure 2 is the framework for ascertaining whether government intervention in a market via public policy is warranted. Whether the economic problem at hand is one that can best be solved by the private sector of the economy alone, or warrants intervention by the public, alone or together with the private sector, depends in which of the quadrants of Figure 2 the market lodges that is providing too little of a good thing or too much of a bad thing (i.e., failing).

For example, the problem might be insufficient investment in food and agricultural product research, development and extension (agricultural RD&E). This happens because the 'product' – agricultural RD&E – has the characteristics of a classic public good. It is non-rival in consumption and non-excludable, which means that it is insufficiently supplied by the private sector operating in markets, i.e., too little of a good thing is supplied. The economic perspective is that agricultural RD&E often has a public good's non-rival and non-excludable characteristics. Farmers individually cannot justify investing in their own agricultural RD&E because, unless the outcome is patentable, they cannot capture enough of the benefits themselves and too many others will get the benefit of the research without contributing to the cost of it, to justify making the investment of doing so. There are other reasons too, such as the scale of such investment. Also, the benefits of agricultural RD&E include benefits that spill over into the wider community who have not paid for the research. This public good market failure is why Australia typically finances agricultural RD&E by a levy on farmers, and supplements that with taxpayers' funds on a 50:50 share basis through the Rural Research and Development Corporations.

Sometimes, a market failure arises because the good or service has the characteristics of being part public good, part private good. Such products are Common Resources (Quadrant 2 in Figure 2) or Club Goods (Quadrant 4 in Figure 2). Club Goods, which are non-rival in consumption but excludable, are the focus of this paper about policy options to restrict nitrogen pollution. A good or service being non-rival in consumption means there is a possibility that insufficient of it may be supplied, i.e., there is a disincentive for one of the economic agents in this club to invest in supplying something because it may not be possible to prevent others from obtaining access to it and benefiting, without contributing to the cost of providing it, as in the public good market failure (Quadrant 3 in Figure 2). The outcome is under-investment in supplying some form of good or service which, if supplied, would increase the total economic surplus delivered by the economic activity operating in the Club Good sector of the economy: in the case at hand, the nitrogen product value chain.

The club nature of the activity raises the possibility that, by acting together, the agents in the value chain (the members of the club) could jointly deliver the 'product' in question. Further, in a case where the product delivers a positive external benefit that is non-rival in consumption, such as reduced pollution, government intervention in the form of a public-private partnership in this economic sector could be warranted to deliver both public and private benefits.

The argument is that, just as the government is justified in intervening in the market failure of the perfect public good, a market failure of the Club Good type in an agricultural value chain caused by the 'non-rival in consumption' form of market failure can also be tackled by public policy to correct it. This intervention by the public to correct this form of ‘Value Chain Failure’ can often be justified in terms of economic theory, either singly or jointly with members of the ‘value chain club’. This 'non-rival in consumption' market failure component of Club Goods can also be tackled by the club members cooperating, without government intervention or involvement. Such a joint 'chain goods' solution of members in a value chain could be an application of the Coase Theorem, where private agents contract to solve a negative externality (Mounter *et al.,* 2019).

This preamble brings us to more detailed explanation of the concept of market failure in the value chain, called chain failure, and the characteristics of a problem that justify the public financing measures along an agricultural value chain to correct a failing of the market.

Club Goods and Chain Goods[3]

In recent decades, the traditional focus of agricultural RD&E on agricultural production has extended to the other components of the agricultural value chain. Also, increasing interest is shown in reducing agricultural production's negative externalities.

Related to the idea of public goods justifying public provision of them - the cases of public goods and club goods - is the related concept of market failure of the Club Goods type, in particular ‘Value Chain Goods’. These are goods and services which are not provided by firms in the agricultural value chain for the reasons of the market failure of a public good type; yet, if they were supplied, the total net benefits (economic surplus) from the activities of the value chain would be greater, to the benefit of producers, consumers and those agents who operate in between them. Mounter *et al*. (2019) argue:

> … The idea that agricultural value chain RD&E results in 'chain goods' is linked with Swann's idea of a 'club goods solution' to research funding, to argue that a 'chain goods solution' can be a viable means of funding research activity that relates to agricultural value chains. …Thus, value chain members need not rely solely on the government to fund value chain RD&E. They suggest criteria to determine who should fund RD&E activities in Australian agricultural value chains depending on the relative balance between expected private, chain and social benefits (p.45).

In efficient value chains, the economic surplus is maximised after accounting for positive and negative externalities from the whole chain. In this context, RD&E in agricultural value chains may take the form of (i) a private good (rival and excludable and done by the private firms), (ii) a public good (non-rival and non-excludable and done with involvement of the public); or (iii) a chain good (something in between private and public goods, partly rival in consumption, partly excludable and done by a 'club' of cooperating members of the value chain. Griffith *et al.* (2015, p. 12) and Fleming *et al.* (2018) defined the concept of 'chain goods' in a value chain as:

[3] Much of this discussion is based on Mounter *et al.* (2019).

> ...a form of club good, whereby people outside a value chain 'are excluded from sharing in any benefits [including spillovers] derived from collective action within the chain….' (p.49).

They continued:

> Agricultural value chain RD&E may be a value chain good in circumstances where the identification and adoption of improved tools and technologies by chain members result in benefits, some of which can be captured by other chain members. Examples of chain goods pertinent to producing and marketing food and agricultural products include grading and certification systems (p.49).

In contemplating policy action to correct a market failure, whether in the economy at large or within a value chain, such as where the benefits of a policy action (for example to reduce a negative externality) are expected to exceed the costs, the question becomes: Who should pay to fix the problem? The first-best rule is that the polluter pays. If this is not feasible, the following rule is that the problem should still be corrected because there is a net benefit to everyone. In this case (some of) the beneficiaries should pay: those who can be made to pay. As long as the benefits exceed the costs, net social welfare is potentially improved.

Mounter *et al.* (2019) embraced Swann's (2003) idea of a 'club goods solution' to research funding. The key to this approach is that all potential beneficiaries of an agricultural policy RD&E investment/policy action – private agents in the value chain, or these private agents and the public - combine to form a 'club' to fund the RD&E (or policy action). They pool resources to conduct the activity which is jointly beneficial. A significant implication of a market failure that is a value chain market failure is that value chain members need not rely solely on the government to fund agricultural RD&E in pursuing the chain good (Fleming *et al*., 2013). To these authors, a 'chain goods solution' is a subset of the broader' club goods solution' and is, therefore, 'an alternative collective approach to public funding for those members in the club' (p.49).

This category of cooperative research is additional to research justified by private entities for private goods and by the public for public good reasons.

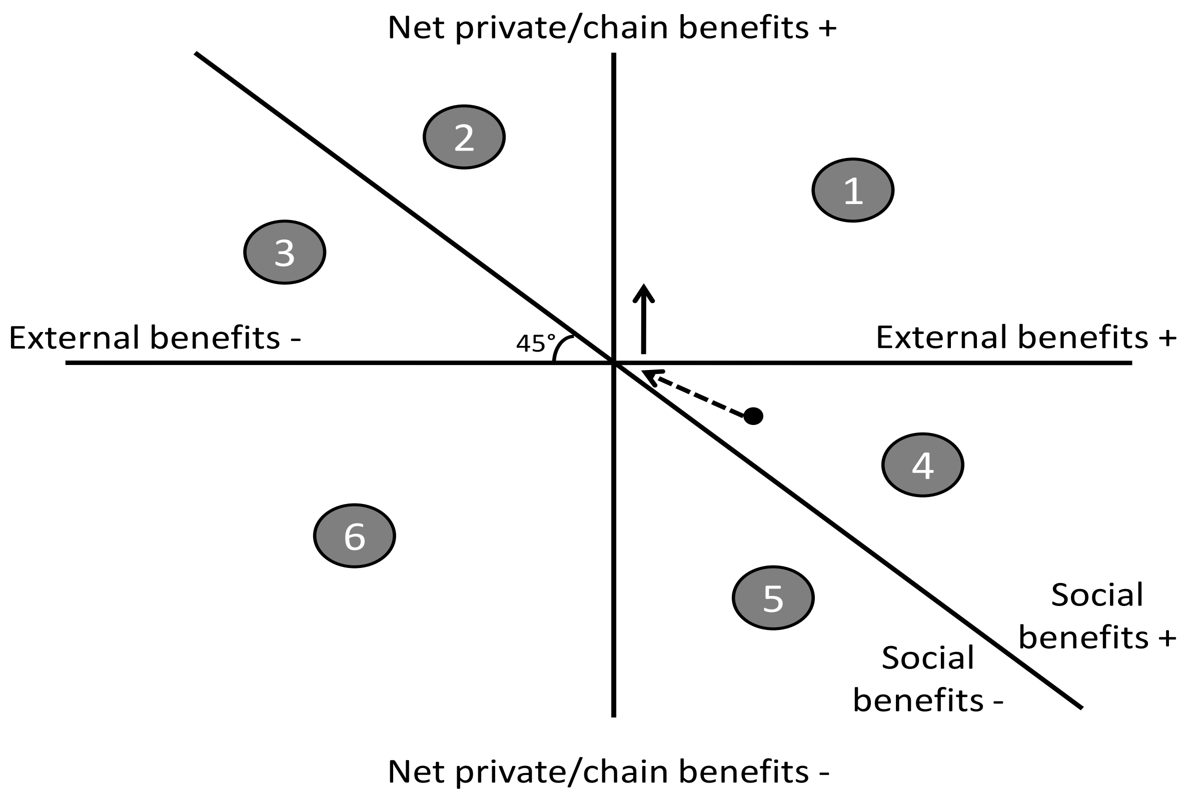
Drawing on the concepts described above, thinking about policy to reduce nitrogen pollution from N used in agriculture, and recalling the previous discussion about the expected ineffectiveness of price-based policies to reduce N use, and so N pollution, the critical relevant ideas are:

- The negative externality of nitrogen pollution in agriculture is a market failure of the public good, club good and chain failure types.
- If the benefits of reducing pollution from nitrogen exceed the cost, policy to reduce the negative externality is warranted and should be implemented one way or another.
- The next question is who should pay to reduce pollution: polluters, beneficiaries, both?
- To the extent that there is a chain good element in research and policy for solving the problem of N pollution from N used in agriculture, meaning that no individual firm supplying nitrogen or farmer using nitrogen has the incentive to act alone to reduce the negative externality they are adding that is reducing social welfare, there may be a value chain good solution to financing the RD&E and policy that is needed to solve the problem.

Funding public and joint private research and policy in ways that are fair and consistent with rules such as 'polluters' pay' and 'beneficiaries' pay' is always tricky. Trading and trade-offs are always part of the game.

Figure 1 from Swann (2003, p. 342) shows a framework for thinking about the relative shares in public, private, and jointly funded RD&E (or policy) activities in Australian agricultural value chains. First, where in the diagram is a particular project located? The funding decision for a particular agricultural RD&E project, such as one that reduced a negative externality from nitrogen pollution, rests on who is causing the problem and who benefits. This issue is discussed by Mounter *et al*. (2019, p. 51) using Figure 3.

Figure 3. Net internal and external benefits of an agricultural RD&E project



Source: Adapted from Swann (2003, p. 344), taken from Mounter *et al*. (2019, p. 51)

Mounter *et al*. (2019) explain the diagram as follows:

- The projects in Area 1 and Area 6 of Figure 3 are clear-cut. Activities in Area 1 have both positive private and positive external benefits (therefore, fund them), while activities in Area 6 have both negative private and negative external benefits (therefore, do not fund them). For projects in Area 1, the ratio of private to public benefits would provide guidance about who should fund the activities.
- Areas 2 and 5 are slightly more complicated. Projects in Area 2 should be funded (positive private benefits and negative external benefits but, on balance, positive social benefits), but activities in Area 5 should not be funded (positive external benefits and negative private benefits but, on balance, negative social benefits).
- Areas 3 and 4 are problematic. Activities in Area 4 should be funded on social benefit grounds but will not be privately funded by the chain or private members as private benefits are negative. Those activities in Area 3 should not be funded on social benefit grounds even though they will be privately profitable.

As an example, the research project marked by a dot in area 4 of Figure 3, is socially desirable (positive external benefits) but unprofitable to the entire chain (negative private benefits), even though it may be profitable to some individual participants in the chain (p. 50). Public participation in supplying these activities will improve net social welfare and should be done because overall social benefits are positive.

The position of an agricultural RD&E or policy project on the figure depends on the boundary between the private/internal and public/external dimensions. In the case of N fertilisers, the situation of RD&E or policy action into EEFs to reduce nitrogen pollution from N used in agricultural production is in the bottom right-hand quadrant of Figure 1 (area 4 or 5). In this quadrant, there are external benefits from solving the market failure causing the negative externality of pollution from nitrogen used in agriculture, but at the expense of higher private costs. As long as the external benefits exceed the private costs (area 4 rather than area 5), the problem should be tackled. Mounter *et al.* (2019, p. 59) summarise:

The initial step in deciding whether to fund an agricultural RD&E project is to establish which area of the diagram a particular project is located. Below are six principles, beginning with those projects where there is a clear interest for members of the chain to take private action and ending with those projects for which there is likely to be only public interest in funding:

1. Private goods solutions should be selected where there is a reasonable expectation that private net benefits from a research activity will be positive – whether for an individual firm or a group of firms acting collaboratively.
2. Coasian solutions to RD&E undertaken by value chain participants may assist, but participants often need prodding to take collaborative actions. A quasi-Coasian solution is selected in which a chain governor can negotiate with and nudge individual chain participants to collaborate in a research project.
3. Commercial fee-for-service arrangements should be implemented to provide research support services that mainly benefit chain members and entail forced riding by many chain members.
4. A pure chain goods solution is recommended, with a net chain benefit expected from a research activity. The transaction costs of governments engaging with the chain-governing agency are expected to outweigh extra-chain spillovers.
5. A hybrid public finance/chain goods solution should be adopted to fund RD&E activity within an agricultural value chain where a net chain benefit is expected, and extra-chain spillovers are expected to be significantly more significant than the transaction costs of governments engaging with the chain-governing agency.
6. A pure public finance solution is recommended where an RD&E activity is expected to result in a net social benefit but net chain loss, and (a) the ideal chain goods solution converges to the public finance solution but is costlier to implement and (b) transaction costs are high, and the only viable chain goods produce undesirable solutions. It may also be required where the RD&E is initially.

This framework could provide the theoretical basis for implementing least-cost private and public action to correct the negative externality of nitrous oxide pollution and other nitrogen pollution from using N fertiliser in agriculture. The approaches listed under principles 5 and 6 could justify such actions if the first best approaches of internalising the externality (polluter pays) via a tax or tradeable permit/cap and trade were not feasible (as expected if the demand for N is inelastic), or if regulation was feasible but likely to be highly inefficient and costly, or if the solution where taxpayers pay to reduce the negative externality such as with a subsidy/credit scheme was considered likely to be inefficient and a less effective and less equitable approach than one where both polluters and beneficiaries contribute some of their share of responsibility and of benefits to solving the problem.

Policies to Reduce Nitrogen Pollution

Summarising and synthesizing the above discussion, training in microeconomics raises the following questions to be answered about the appropriateness of potential policies to reduce pollution in market economies:

- Is there a market failure, with the existence of market failure being the justification for government intervention to fix the failure and its consequences? If so, of what type? Pollution is a negative externality where the private producer of agricultural products does not pay the actual cost. Is it point or non-point pollution?
- Does the counterfactual of the policy framework include the possibility of the pollution cost having to be paid, one way or another, if there is no policy to make this happen? Does the thinking behind the policy recognise the obligation to pay a worldwide social cost involved in N2O emissions? Other countries paying for their contribution to the social cost of global warming will ensure that countries from whom they obtain agricultural goods bear their rightful share of this cost.
- Is the market failure worth fixing? Would the benefits of reducing the negative externality exceed the cost of fixing it?
- Are the roles of related 'other' causes of the relevant negative externality considered? Some policies subsidise agriculture through various mechanisms that help to cause excessive nitrogen use[4]. That problem, too, needs fixing. Otherwise, we have a situation where public funds are being paid to encourage the excessive use of nitrogen and simultaneously pay to reduce the excessive use of nitrogen.
- What is the correct magnitude of the externality costs involved, and thus of the benefits of reducing these costs, be it for emissions of nitrous oxide, nitrates into water supplies, or ammonium into the air supply? What size of marginal abatement costs and marginal emissions costs are we dealing with here? Do they increase at an exponential rate?
- Are the problems caused of a generic nature, affecting whole environments and whole populations, or specific, affecting the environment and people on a localised, case-by-case basis?
- What are the policy choices, and what are likely to be the least-cost solutions to the pollution problems, and which would deliver solutions in the required time? Usual options here are regulations, market methods such as taxes on pollution to reflect the externality cost or a cap-and-trade system to do the same, subsidies, publicly provided RD&E, and information, or a chain failure-club good policy involving some form of public-private partnership, or as is standard, a mix of several of these policy approaches.
- What is the nature of farmers' demand for nitrogen input for their production system? Is demand for the input highly price inelastic, meaning they will still use similarly large amounts of nitrogen regardless? This means that if a tax is to be paid by farmers or a credit is to be paid to farmers to encourage less nitrogen pollution by using less nitrogen, such a tax or a credit would have to be significant.
- Do farmer decisions about using the input have a risk element as well as price and production components?
- What criteria to apply to the question of who should pay? 'First best' says 'the polluter should pay if it is possible to make them do so'. The second best says, 'If the expected benefits of fixing the problem exceed the expected costs, and even if the polluters do not pay all or any of the cost, still fix the problem,

[4] For example, this was the case for the European Union until recently. The 2023 reforms of the Common Agricultural Policy now state that agricultural policy must be in line with environmental and climate legislation as outlined under the 'Green Deal' (see https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27_en

and the public should bear the burden of financing the solution because there is a net social benefit from doing so'.

- Is the concept of the incidence of an added economic burden or a benefit throughout the economy to the fore in the thinking? Or are taxes and subsidies considered, as if once imposed, the imposed upon do not change their behaviors? Are the relevant supply and demand functions, and their elasticities, in domestic and export markets and whole-of-economy perspectives included in the suppositions about how the policy will work in practice?
- Regarding the cost burden, how will changes in the costs of agricultural production resulting from changes to reduce nitrogen pollution be distributed throughout the whole economy among all participants in agricultural production and consumption systems? Are there highly significant public finance implications of such a policy, let alone the 'pass-through' implications of changing financial conditions of production at the farm level for consumers – such as a publicly funded subsidy; or changing financial conditions at the consumer level for the farm level; or consumers paying both as consumers and as taxpayers when paying a tax.
- The extent to which consumers will share in the cost burden of reducing negative externalities depends on the price elasticity of demand for the output, which depends on whether it sells on domestic or export markets. If the export demand is highly price elastic, the burden will fall mainly on domestic producers.
- Will policy designed to reduce the negative externalities of nitrogen use in agriculture inadvertently create new and perverse incentives that will encourage unanticipated behaviours that undermine the aims of the policy (e.g., historically, policies to reduce populations of rats and cobra led promptly to rat and cobra breeding programs, and the fox ears bounty in Australia led to a flourishing trade in fox ears.) Will the policy add further unintended costs to the private and public sectors?
- Are critical decisions about production and consumption being made by people most integrally involved in production and consumption decisions, and who are likely to know what is best for them, or by, say, bureaucrats well distant from the actions of those involved parties most directly affected?
- Is it practically operational? Can the information requirements be met efficiently? Are affected parties given incentives to act outside the intent of the policy? Is it likely to be a least-cost means to achieve the policy goals?
- Are there alternative commercial products available, or are they being developed to have fewer polluting effects on the environment and still deliver the agricultural production objectives? Are these alternative products being developed rapidly enough to avoid the looming problems of N pollution?
- Is the situation of a 'Value chain failure' of a Club Good nature, with the possibility of public-private collaboration to generate a net benefit?

Let us take these last couple of dot points as points of departure to consider the proposition that the usual economic-based policies to reduce pollution are:

(i) not likely to be successful in reducing N pollution by reducing the use of N in agricultural production because N is much too profitable for the users for them to give much credence to the notion of them using much less of it. Using forms of N that pollutes less may be the way to go, and

(ii) there may be a legitimate role for public policy to help correct a value chain failure. That is, the possibility a private-public partnership, maybe pursuing a technical solution to the problem of nitrogen pollution, may have more chance of success than a market-based solution such as a tax, or subsidy or tradeable rights - a solution located in quadrant 4 of Figure 3 above. A public-private partnership could have a role in the situation where the costs to the private sector of reducing the pollution prevent it happening to the extent necessary, and the

> benefits to the public sector of reducing the pollution would outweigh these costs to the private sector. In such a case, a net benefit to society can result.

An example is the proposal by Eckard and Grace (2022), two eminent scientists in the field of nitrogen use in agriculture. In an appendix to the *White Paper* prepared by Fertilizer Australia they have put forward a 'Concept proposal for a pre-farm fertiliser treated aggregation payment'. The purpose was to set out 'the background and principles that guide a proposal for developing a treated fertiliser policy mechanism to encourage farmer use of nitrification inhibitor' (Norton *et al*., 2023).

They use Dimethylpyrazole phosphate (DMPP), a nitrification inhibitor, as an example because it is the technology with the most significant amount of Australian nitrous oxide (N2O) data, particularly in grains. They assert that if DMPP-coated urea was used instead of standard urea, a 59 per cent reduction of N2O emissions (1.13 Mt CO2e) per annum is possible across the agricultural sector.

Eckard and Grace (2022, p.67) state:

> Currently, urea fertiliser coated with a nitrification inhibitor is around 14 per cent more expensive per unit of N applied than conventional urea. While highly effective at reducing N2O emissions from N fertiliser application…, the actual N saved is typically less than 10 kg N per hectare per year. In many situations, this saving is not agronomically significant for farmers, and, not surprisingly, most of the research suggests no significant productivity benefit. If an offset method were developed to incentivise farmers to purchase this precoated fertiliser, the returns at an average grain farm would be less than $200 per farm per year. Therefore, farmer adoption would be almost impossible to achieve. We, therefore, see a public good outcome from the government addressing this market failure.

The focus by Eckard and Grace (2022) is on the benefit to the farmer from the amount of N that is saved. They argue that because the savings in N with the DMPP-coated urea would be minimal, and thus, with higher cost, little production benefit, and little savings in N used, adoption would not happen. However, there is a further benefit: reduced negative externality costs. Eckard and Grace (2022, p.67) go on, therefore, to suggest the following:

> It would be far more efficient and cost-effective for the government to engage in a pre-farm aggregation of N2O abatement, whereby a limited number of fertiliser manufacturers engage directly with the government to precoat fertiliser products like urea at an agreed price per tonne. This payment would then be passed on to growers at a reduced price for treated N fertiliser. Therefore, adoption by the farming community would be increased significantly, as the product would be sold at a similar unit cost as standard urea, depending on the value of the N2O abatement payment. We also understand from Fertilizer Australia that their members are not looking for a profitability outcome from this mechanism, just the credential of supplying a more benign form of fertiliser (reduced N2O emissions associated with the end use of fertiliser) but at no loss of profitability to their core business.

In essence, Eckard and Grace (2022) are arguing for the public purchase of N2O emission reduction. Payments would be made to fertiliser manufacturers to cover the cost of precoating fertiliser products like urea, to make treated nitrogen fertiliser products available to farmers at a similar cost to untreated nitrogen fertiliser products. The proposal would enable an immediate reduction in N2O emissions. These researchers see this as a relatively straightforward system that would be effective.

Improved N fertilisers that pollute less already exist and have the required characteristics of being private goods. Under what circumstances could a case be made for the public working with the private sector to contribute to the RD&E and policy to help develop less polluting N products? Necessary conditions for this case include:

- Value chain failure exists in the N fertiliser value chain, which has Club Good characteristics with part private and public good components.
- The nitrogen users in agriculture do not pay the external cost of their nitrous oxide emissions.
- The suppliers of enhanced efficiency fertilisers cannot produce these products at the same cost as the usual urea, but the benefit to the public of reducing the N pollution would be greater than the difference in the cost of the usual urea and the cost of the EEF.

Those conditions hold. Such a joint private levy and public investment in a public-private partnership could lower the private and external costs of fertiliser N more rapidly than otherwise. Such an additional RD&E and policy arrangement of a 'Club Goods' nature would sit alongside and work with the existing Rural Research and Development Corporation system that is justified based on solving the pure public goods market failure problem that much agricultural RD&E represents. That policy has long had public support.

Conclusion

Much of the nitrogen fertiliser that farmers use to grow crops and pasture is not used by these plants but is lost to the environment, causing negative externalities such as nitrous oxide contributing to stocks of global greenhouse gases, and nitrate and ammonium polluting water and air. These externalities have large external costs. Much of the discussion of how to minimise these costs has been about government policy actions such as quantitative regulations about use, and the implementation of taxes and subsidies, or cap and trade models. In this paper an alternative approach is outlined based on the theory of club goods and actions jointly with the private sector rather than solely by the public sector. The nitrogen policy idea canvassed here is a mixed market approach to reducing N emissions from farming, the costs of which the polluters and the beneficiaries would bear, i.e., the producers and consumers of N and the products produced.

Ideas are relatively easy and cheap. The complex policy work is to do a comprehensive and detailed economic welfare analysis of the imagined futures under the operation of such arrangements, which makes the case, and then to convince the interested parties that the approach warrants their support.

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