Levy-funded research choices by producers and society*

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Commodity levies are used increasingly to fund producer collective goods such as research and promotion. In the present paper we examine theoretical relationships between producer and national benefits from levy-funded research, and consider the implications for the appropriate rates of matching government grants, applied with a view to achieving a closer match between producer and national interests. In many cases the producer and national optima coincide. First, regardless of the form of the supply shift, when product demand is perfectly elastic, or all the product is exported, domestic benefits and costs of levy-funded research all go to producers and they have appropriate incentives. Second, if research causes a parallel supply shift, the producer share of research benefits is the same as their share of costs of a levy, and their incentives are compatible with national interests. In such cases, a matching grant would cause an over-investment in research from a national perspective. However, if demand is less than perfectly elastic, and research causes a pivotal supply shift, the producer share of benefits is smaller than their share of costs of the levy, and they will under-invest in research from a national point of view. A matching grant can be justified in such cases, however the magnitude of the optimal grant is sensitive to market conditions.

1. Introduction

Commodity levies and matching government subsidies have come to play a central role in the funding of applied agricultural research in Australia (Industry Commission 1994), and levy-based funding is emerging as a more important funding mechanism in other countries. In the present paper we

develop a stylised model of a levy-based research funding institution. This model captures the essentials of the Australian Research and Development Corporation (RDC) framework, but is meant to be representative of a more general class of such institutions as may be implemented in other countries or at different times in Australia.[1] We derive and compare the levy rate (and research expenditure) that a producer group – which for simplicity and concreteness we refer to as an 'RDC' – would choose to maximise producer welfare and the levy rate that would maximise aggregate national welfare. Among other questions, this assessment provides a basis for evaluating the appropriate rate of matching government grant to supplement levy funds, for example the present common practice of a dollar for dollar, or the lower 25 cents per dollar proposed by the Industry Commission (1994), or something else.[2]

We use a partial equilibrium, competitive market model in a comparative static format, building on models described by Duncan and Tisdell (1971), Lindner and Jarrett (1978) and many others, as surveyed by Alston *et al.* (1995). Previous studies have specified predetermined values for the rate of levy, the amount of research, or, more commonly, the supply shift, and then assessed the consequent changes in prices and quantities, and the effects on consumer, producer and total economic surpluses. In contrast, the present paper establishes explicit linkages between changes in the levy rate, total research spending, and the size of the research-induced shift in the supply curve, and consequent changes in market prices and quantities. We solve an optimisation problem for the levy rate (and research expenditure) that would maximise national economic surplus and show how that rate compares with

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[1] RDCs have been used in Australia, particularly since the mid-1980s, as a government legislated institutional structure to internalise spillovers of R&D among the many producers within a particular primary industry. Industry organisations negotiate with the Commonwealth government to set the levy rate, usually specified per unit of physical output but sometimes in *ad valorem* form. The Commonwealth government provides matching grants, in most cases on a dollar per dollar basis with an upper limit of 0.5 per cent of farm gate gross value of production, but there are options to vary the subsidy. Agriculture, Fisheries and Forestry Australia (AFFA, 2002) provides more detail on the RDCs as presently structured. The Commonwealth and State governments also directly fund applied and especially basic research through the Commonwealth Scientific and Industrial Research Organisation (CSIRO), universities and government departments and agencies. Government subsidies for applied research by the corporate sector, including agribusiness, are provided by tax concessions.

[2] The compulsory levies are collected by the Commonwealth. In 2001–02 the government distributed over $A400 million (levy receipts of $A209 million supplemented with the Commonwealth contribution of $A196 million) to the RDCs, who are responsible for the allocation and administration of the funds among research projects (Troeth 2003). The balance of funds reflects the fact that some RDCs set levies in excess of the 0.5 per cent upper limit such that their overall rate of matching grant is less than 1:1, and some RDCs do not have a levy base and are entirely funded by the Commonwealth.

the levy rate (and research expenditure) that would be chosen by a producer group to maximise producer surplus. To make this analysis tractable, we adopt and maintain the conventional assumptions of undistorted markets – the absence of market power of firms, government price policies, and external benefits and costs in production – and we assume that the benefits from the R&D funded by the levy are reaped by consumers and producers of the product on which the levy is collected. In the penultimate section of the present paper, we discuss the implications of relaxing these and other modelling assumptions.

In the analysis, particular attention is given to the effects of the nature of the research-induced supply shift (i.e., parallel versus pivotal shifts), combined with the elasticities of demand and supply, on the choices of optimal levy rates and research quantities that would maximise benefits for producers and society.[3] We show that, in the case of a parallel supply curve shift, the distribution of the benefits from research between producers and consumers of the commodity is identical to the distribution of the costs of a levy used to finance the research. Consequently, for parallel supply curve shifts, the producers' optimal levy choice is the same as that for society, and there is no need for a government subsidy. This result generalises to traded commodities, even when some of the benefits and costs may accrue to foreigners.[4] However, with a multiplicative or pivotal supply curve shift, unless demand is perfectly elastic, producers bear a greater share of the incidence of the levy than their share of research benefits and, from a national perspective, they will opt for too little research in the absence of matching government support. As we show below, the appropriate government matching grant for the producer levy depends on relative elasticities of supply and demand and the trade status of the commodity, along with other factors that influence the incidence of benefits and costs.

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[3] There has been much discussion in the published literature but as yet no consensus has been reached about how to determine the nature of the research-induced shift of the supply curve, whether it is parallel, pivotal, divergent or convergent – for example, Lindner and Jarrett (1978, 1980), Rose (1980) and Wise and Fell (1980). One set of approaches uses a representative firm model with the supply curve derived from a production, cost or profit function. R&D that augments factor inputs or enters the production function as a separate input results in a pivotal supply curve shift, but Martin and Alston (1997) show that a parallel shift is obtained if technology enters the profit function as a separate input. Another modelling strategy allows for multiple firms with different reservation prices for entry to industry supply, reflecting differences in their minumum average cost of production, for example Wohlgenant (1996). The nature of the R&D induced supply curve shift then depends in part on which firms along the supply curve adopt the R&D (or which reservation prices are affected) and by how much costs are reduced. Accepting the lack of consensus on this issue, we consider the extreme cases of parallel and pivotal shifts.

[4] This point was made by the Industries Assistance Commission (1976, p. 267).

We begin by outlining the conventional commodity market model for evaluating the effects on market outcomes resulting from R&D, a levy to fund it or both combined. In section 3 we derive formulas for the research-funding levy rates that would maximise national economic surplus and producer surplus, respectively, where the research causes either a parallel shift or a pivotal shift in supply. These solutions are functions of elasticities of supply and demand, the fraction of the commodity that is exported (allowing that the innovating country may be an exporter), the rate of matching government support, and the social opportunity cost of government spending. Theoretical solutions are interpreted in section 4, with particular attention to the effects of matching government grants, or subsidies, for levy rates and research conducted by producer bodies such as RDCs, and the policy implications of the grants. To put the analytical solutions and interpretations into context, in section 5 we present numerical values for the levy rates that would maximise benefits for society versus producers, and the corresponding rates of socially optimal matching grants, for various sets of parameter values. These results are conditioned by various modelling assumptions, including competitive market clearing and the absence of market distortions, and, more fundamentally, our approach of using a partial equilibrium model in which we represent research-induced technological change in terms of shifts of commodity supply functions. In section 6 we review certain assumptions, and some caveats to the results. Section 7 concludes.

2. A heuristic model of the incidence of levy-funded research

In a standard commodity market model of research benefits, research causes the commodity supply curve to shift down and out against a stationary demand curve, giving rise to an increase in quantity produced and consumed, and a lower price. The collection of a levy on the product to finance the research has the opposite effects. The distribution of the costs of the imposition of the levy between producers and consumers depends on the relative elasticities of supply and demand.[5] While the distribution of the benefits and costs of the research-induced supply shift depends on the same elasticities, it also depends on the nature of the supply shift and, less importantly, on the functional forms of supply and demand (Alston *et al.* 1995).

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[5] We use the Marshallian measures of consumer surplus for consumer benefits and of producer surplus for producer benefits. In fact, producer surplus might include quasi-rents to factors owned by farmers, namely land and managerial expertise, and also to suppliers of other factors such as professional advice, fertilisers, and machinery where the supply of these non-farm inputs is less than perfectly elastic. Similarly, consumer surplus might include quasi-rents earned by after-farm input suppliers as well as by final consumers.
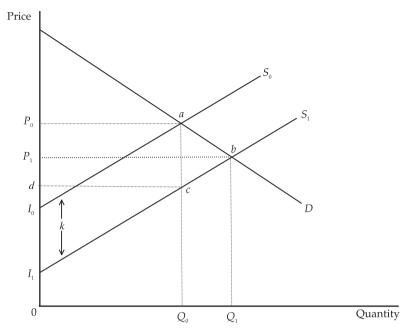
Figure 1 A commodity market model with a parallel supply shift.

Consider first the case of a parallel research-induced supply shift in a model with linear supply and demand. In figure 1, D is the demand curve, S_0 is the initial supply curve, and S_1 is the supply curve following a k per unit research-induced shift down of the supply curve. As a result of the supply shift, price falls from P_0 to P_1, and quantity increases from Q_0 to Q_1. The welfare effects include an increase in consumer surplus given by $\Delta CS =$ area P_0abP_1, and an increase in producer surplus given by $\Delta PS =$ area P_1bI_1 − area P_0aI_0, which equals area P_1bcd under the special assumption of a parallel supply shift.[6] National benefits are given by $\Delta NS = \Delta PS + \Delta CS =$ area I_0abI_1. Now, suppose we introduce a tax of k per unit. This would exactly reverse the price, quantity, and economic welfare impacts of the parallel research-induced supply shift. Hence, if a k per unit tax could finance a research-induced supply shift of greater than k per unit, there would be net benefits to producers, consumers, and the nation as a whole.

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[6] Here, k represents a vertical shift, down, or a k per unit reduction in unit costs. Alternatively we can discuss a horizontal or output-expansion effect as $j = (\partial Q/\partial P)k$, where $\partial Q/\partial P$ is the slope of the supply function. As noted by Alston *et al.* (1995), and more recently elaborated by Oehmke and Crawford (2002), the elasticity of supply can have important implications for measures of research benefits if it is used to translate an assumed horizontal shift into a vertical shift, or vice versa, in this fashion.
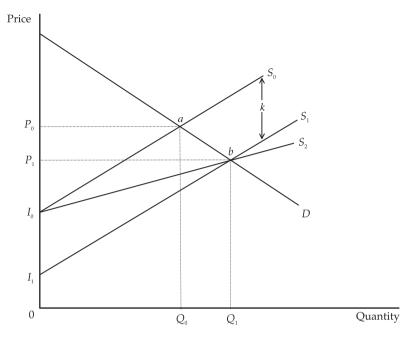
Figure 2 A commodity market model with a pivotal supply shift.

These net benefits would be shared in direct proportion to each group's share of the costs, and so the research investment that would be optimal from the point of view of the nation as a whole would also be optimal for consumers and for producers.[7] In this setting, if producers were empowered to set a levy to fund research, their incentives to maximise their own benefits would be exactly compatible with the national interest, and there would be no reason to encourage producers to do more of it by offering a matching grant to help pay for the research.

Alternatively, suppose research causes a multiplicative (pivotal) supply shift, as shown in figure 2, from S_0 to S_2.[8] The total research benefits are now only roughly one-half of those from a parallel shift that would have

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[7] Specifically, the producer share of both benefits and costs is given by the ratio $\eta/(\eta + \varepsilon)$, where η and ε are the absolute values of the elasticities (or price slopes) of demand and supply respectively. The consumer share is $\varepsilon/(\eta + \varepsilon)$.

[8] For simplicity, we have held constant the effects on quantity of the parallel and pivotal supply shifts, rather than the effects on per unit costs in the vicinity of the equilibrium. The main issue for the comparison is the shapes of the geometric areas, not the sizes of them, but it is worth noting that one source of confusion in the published literature has been differences among studies in what is being held constant in comparing alternative research-induced supply shifts.
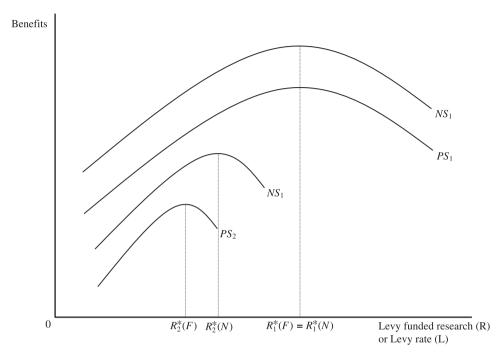
Figure 3 Producer and national incentives for different types of research.

the same price and quantity effects: $\Delta NS = $ area $I_0 ab$. The consumer benefits are the same as from the corresponding parallel shift: $\Delta CS = $ area $P_0 ab P_1$, while the producer benefits are smaller: $\Delta PS = $ area $P_1 b I_0 - $ area $P_0 a I_0$; and if demand were inelastic, producer benefits would be negative.[9] Since the distribution of costs of a per unit levy coincides exactly with the distribution of benefits from a parallel research-induced supply shift, it follows that consumers would receive more than their proportionate share of benefits from (or pay less than their share of costs of) a pivotal research-induced supply shift funded by a per unit levy. Similarly, producers would receive less than their proportionate share of benefits (or pay more than their share of costs), and in this setting, producers would opt to fund less than the national optimum quantity of research.

Figure 3 represents these ideas graphically, by showing how total and marginal national and producer benefits might be expected to change with changes in the rate of levy or, equivalently, in the rate of spending on research (R) financed by the levy, and the implications for divergences to

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[9] Specifically, in figure 2, $\Delta PS = \frac{1}{2}(P_1 - I_0)Q_1 - \frac{1}{2}(P_0 - I_0)Q_0 = \frac{1}{2}(P_1 Q_1 - P_0 Q_0 - I_0 \Delta Q)$. Given $I_0 \Delta Q > 0$, a necessary condition for producer surplus to increase is for total revenue to increase (i.e., $P_1 Q_1 > P_0 Q_0$), and this requires that demand is elastic.

arise between farmer and national optima, $R^*(F)$ and $R^*(N)$, respectively. The vertical axis measures total net benefits. The uppermost curve (NS_1) represents national benefits in the case of a parallel shift, and the next curve (PS_1) represents the producer benefits from the parallel shift. The third curve down (NS_2) represents national benefits in the case of a pivotal shift, and the fourth (PS_2) represents the producer benefits from the pivotal shift. In this comparison, we assume that the costs of research are comparable for given market outcomes (i.e., effects on prices and quantities) between the two types of supply shifts, and hence the national and producer benefits from the pivotal shift are smaller for any given research investment. In each case the relevant optimum is where marginal net benefits are zero. In the case of the parallel research-induced supply shift, the producer and national optima coincide at $R_1^*(F) = R_1^*(N)$. The national optimal quantity of research is smaller for the pivotal supply shift, and the producer share of benefits is smaller so that the producer optimum in this case is less than the already smaller national optimum.

These results illustrate how, depending on the nature of the research-induced supply shift, levy-based funding arrangements for research may or may not lead to a socially efficient outcome in terms of the total amount of research provided. In the case of a parallel research-induced supply shift, an RDC maximising total producer benefits would also maximise national benefits in the absence of further government intervention. However, some form of matching support from the government may be useful for correcting an under-investment in the case of non-parallel research-induced supply shifts.

The heuristic model has abstracted from some important real-world aspects that are especially relevant to a discussion of matching government grant for research. In particular, most Australian commodities with RDCs are extensively traded, mostly exported to other countries, which means that demand is likely to be elastic, perhaps highly so. Indeed, for many commodities, Australia's relatively small share of world production implies that a small-country assumption often may be a reasonable approximation, which means we can effectively ignore the demand side altogether in our analysis of research benefits and costs. However, for several commodities – for instance, wool, wheat, and beef – it might be argued that, in the relevant intermediate length of run, although the demand for the industry's output is highly elastic, it is not perfectly elastic, reflecting the reality of extensive policy interventions in trade, product heterogeneity, both real and perceived, and the importance of transport costs for low-value bulk commodities. In these cases, the analysis needs to be extended to partition the total demand between domestic and export counterparts, since any benefits to foreigners would be given a different weight (perhaps zero weight) in the

calculus for maximising domestic welfare. This partitioning also means that, in the large-country case, the national social cost is less than a dollar per dollar raised using a commodity levy.

In contrast, the national social cost is more than a dollar per dollar of expenditure from general revenue. Instruments used to raise the tax revenue to fund subsidies distort decisions, for example, between work versus leisure, saving versus spending, the choice of business structure and investment options, and the mix of products produced and consumed. These distortions result in deadweight or efficiency costs of taxes of at least 20 per cent (Campbell and Bond 1997), which may have implications for the socially optimal amount of research to fund, and the least-cost funding mechanism for agricultural R&D.

These issues of matching grants, trade status, and the social opportunity cost of government funds are addressed in the more formal model that is developed in the next section. Then, in subsequent sections, we evaluate the implications of these aspects for the nature of the divergence between producer and national optimal levy rates, and for socially optimal matching grants, in terms of both analytical solutions and numerical examples. Throughout we maintain the assumption that the producer group or 'RDC' seeks to maximise total producer surplus, regardless of the distribution of benefits and costs among producers. As pointed out by a referee, this is an important simplifying assumption. It is unlikely that the collective producer optimum will be optimal for every producer. Even though every producer pays a share of the levy, it is unlikely that each will receive the corresponding share of the total benefits; non-adopters, for instance, will clearly be made worse off by levy-funded R&D. A more realistic model might allow specifically for heterogeneous producers, with RDCs choosing a portfolio of projects, aiming to achieve a more uniform distribution of benefits than might result from simply maximising total benefits – a political trade-off of efficiency for equity in levy-funded research, as discussed by Alston (2002). In our analysis, we effectively have taken the nature of the (portfolio of) levy-funded research and the research-induced supply shift as given, but not the quantity of research. Then it makes sense for the RDC to choose the quantity of such research that will maximise total producer benefits and for the government to encourage the RDC to choose the quantity of such research that will maximise total national benefits, as assumed in our analysis.

3. A more formal model

This section uses a more formal representation of the model of figures 1 and 2 to derive the levy rates, and by implication research quantities, that

society and producers would choose to maximise their respective objectives, under a more-general set of conditions. To begin, we express the initial pre-research and pre-levy demand and supply curves in price dependent form as:

$$D^{-1}(Q) = P = \gamma - \delta Q$$

$$S^{-1}(Q) = P = \alpha + \beta Q$$

where P is the price, Q is quantity, and α, β, γ, and δ are given non-negative parameters.

R&D is funded by a per unit levy, t, supplemented with a matching government grant at a rate, g, such that the research quantity, R, is given by

$$R = (1 + g)\, tQ.$$

Incorporating the effects of the levy, the equilibrium quantity and price are:

$$Q_i = \frac{\gamma - \alpha - t}{\delta + \beta}$$

$$P_i = \frac{\gamma \beta + \delta \alpha + \delta t}{\delta + \beta}$$

where P is the consumer price, gross of tax, and the producer price is given by $P - t$.[10]

The research funded by the levy causes an outward shift of the supply curve, and in what follows we consider two alternatives for the nature of shift. In the case of a parallel shift, denoted by $i = 1$ in the expressions above, research modifies α in equation (2) and hence in equations (4) and (5). In the case of a pivotal shift, denoted by $i = 2$ in the expressions above, research modifies β in equation (2) and hence in equations (4) and (5). In other words, we incorporate the effects of parallel or pivotal research-induced supply shifts in equations (4) and (5) by expressing either α or β as a function of research spending, R, denoted by $i = 1$ or $i = 2$, respectively.

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[10] The results do not depend on whether the policy is defined as a per unit levy or an *ad valorem* levy. Below, we express each solution for an 'optimal' per unit levy, t as an equivalent *ad valorem* rate, τ, where $\tau = t/P$, and identical results would have been obtained if we had defined the policy instrument as an *ad valorem* levy, instead, in the first instance.

3.1 Parallel supply curve shift

For a parallel shift, as in figure 1, the intercept term of the supply curve (α in equation (2)) is a function of R, with $\partial\alpha/\partial R < 0$ and $\partial^2\alpha/\partial R^2 > 0$ to reflect diminishing cost reductions for extra research effort. Then, with levy-funded R&D, the prices and quantities are given by solving

$$P_1 = \gamma - \delta Q_1 \tag{6}$$

$$P_1 - t = \alpha(R) + \beta Q_1, \tag{7}$$

the solution for which will have the same form as equations (4) and (5), with $\alpha(R)$ replacing α.

3.1.1 National optimum

National surplus is equal to the sum of domestic producer and consumer surplus minus the cost to taxpayers associated with any matching government support for research. Let us define d as the excess burden per dollar associated with that spending, such that $1 + d$ is the marginal social opportunity cost (or loss of taxpayer surplus) associated with a dollar of government spending on agricultural research. Therefore, the taxpayer cost is $(1 + d)gtQ$, or, using equation (3), $(1 + d)\dfrac{g}{(1 + g)}R$. Then, in the case of a closed economy, with all of the welfare impacts confined to the domestic economy, national surplus, NS_1, is defined as

$$NS_1 = \int_0^{Q_1}\left[D^{-1}(x) - S^{-1}(x)\right]dx - (1 + d)\left(\frac{g}{1 + g}\right)R \tag{8}$$

$$= \frac{1}{2}(\delta + \beta)Q_1^2 - (1 + d)\left(\frac{g}{1 + g}\right)R$$

where the second line of (8) exploits the specific linear functions (6) and (7).

In the case of an exporting country, where domestic consumption is only a fraction, κ, of total production, domestic consumer benefits may be approximated by the corresponding fraction, κ, of the total 'consumer' benefits. Presuming that the government gives no weight to welfare impacts on foreigners, we can approximate the exporter's national benefits using

$$NS_1 = \frac{1}{2}(\kappa\delta + \beta)Q_1^2 - (1 + d\left(\frac{g}{1 + g}\right)R. \tag{9}$$

Then, the nation will choose a research quantity, R, to maximise (9), which will satisfy the first-order condition implied by $\partial NS_1/\partial R = 0$, subject to the constraint that expenditure on research is equal to the revenue raised by the levy plus any matching support provided by the government, as in equation (3).

Solving this maximisation problem yields an equation for the national optimum levy rate, as a function of the elasticity of marginal cost with respect to research, $\varepsilon_{C,R}$, the elasticity of supply, ε, the absolute value of the elasticity of demand, η, domestic consumption as a share of output, κ, the rate of matching government support, g, and the marginal excess burden of taxation to finance government spending, d, which we can represent as follows:[11]

$$\tau \approx \varepsilon_{C,R}\left[1 + (1+d)g\,\frac{\eta + \varepsilon}{\eta + \kappa\varepsilon}\right]^{-1}. \tag{10}$$

Notice that, in this equation, unless the government is applying a matching grant (i.e., $g > 0$), the optimal levy is simply equal to the elasticity of marginal cost with respect to research. Finally, using the definition that, under competitive market clearing, the elasticity of marginal cost with respect to research ($\varepsilon_{C,R}$) is equal to the elasticity of supply with respect to research ($\varepsilon_{Q,R}$) divided by the elasticity of supply (i.e., $\varepsilon_{C,R} = \varepsilon_{Q,R}/\varepsilon$), we can write, equivalently,

$$\tau \approx \frac{\varepsilon_{Q,R}}{\varepsilon}\left[1 + (1+d)g\,\frac{\eta + \varepsilon}{\eta + \kappa\varepsilon}\right]^{-1}. \tag{11}$$

This form is more useful for comparing alternative forms of research-induced supply shift, holding $\varepsilon_{Q,R}$ constant.

3.1.2 Producer optimum
Consider now the RDC or producer objective function, which is to maximise producer surplus, PS, given by

$$PS_1 = (P_1 - t)Q_1 - \int_0^{Q_1} S^{-1}(x)\,dx = \frac{1}{2}\beta Q_1^2. \tag{12}$$

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[11] Details of the solution procedure and the exact solutions for all of the optimal levy rates discussed below are provided in the appendix. The exact solutions for the optimal levy rates in every case (apart from the producers' optimum with a parallel shift, in equation (13)) are quadratic functions, but since research-funding levies are typically less than 1 per cent, the quadratic term is negligible, and the linear approximation will be very close.

Producer surplus is maximised where $\partial PS_1/\partial R = 0$, which in this case is where $\partial Q_1/\partial R = 0$. In other words, producer surplus is maximised when the marginal impact on output of an increase in research spending is just balanced by the marginal impact of the increase in the research levy required to fund that increase in spending. Using this first-order condition with the budget-constraint condition, from equation (3), implies the following solution for the producers' optimal levy rate, τ_p:

$$\tau_p = \varepsilon_{C,R} = \frac{\varepsilon_{Q,R}}{\varepsilon}. \tag{13}$$

Hence, the producer choice of R to maximise (12) implies the same levy rate as the societal choice implied by (11) in the absence of a matching government grant; that is, $\tau_p = \tau$ if $g = 0$, as suggested by the heuristic model.

3.2 Pivotal supply curve shift

For a pivotal supply curve shift, as in figure 2, the β parameter of the supply function (2) is replaced by $\beta\phi(R)$, with $0 < \phi \leq 1$, $\partial\phi/\partial R < 0$ and $\partial^2\phi/\partial R^2 > 0$ to reflect diminishing cost reductions for extra research effort. Then, with levy-funded R&D, the equilibrium price and quantity are given by solving

$$P_2 = \gamma - \delta Q_2 \tag{14}$$

$$P_2 - t = \alpha + \beta\phi(R)Q_2 \tag{15}$$

which yields solutions for the equilibrium quantity and price as expressed in equations (4) and (5), with $\beta\phi(R)$ replacing β.

3.2.1 National optimum
Allowing once again for exports, with the domestic share of consumption and consumer surplus represented by κ, when research causes a pivotal shift of the supply function, national surplus is given by,

$$NS_2 = \frac{1}{2}(\kappa\delta + \beta\phi(R))Q_2^2 - (1 + d\left(\frac{g}{1+g}\right)R. \tag{16}$$

Then, as in the case of the parallel research-induced supply shift, to find the research quantity or levy rate to maximise national surplus, we combine the first-order condition for a maximum with the budget-constraint condition, from equation (3). The result is:

$$\tau \approx \frac{1}{2} \frac{\varepsilon_{Q,R}}{\varepsilon} \left[\frac{2(\eta + \kappa\varepsilon) - (\eta + \varepsilon)}{(\eta + \kappa\varepsilon) + (1 + d)g(\eta + \varepsilon)} \right], \tag{17}$$

where parameters are defined as above.

3.2.2 Producer optimum

Producer surplus, as defined in equation (12), reflects the effects of both the collection of a levy to fund research and the research-induced supply shift. In the case of a pivotal shift, as shown in equation (15) the slope ($\beta\phi$) is a function of research, which changes the implications for producer welfare:

$$PS_2 = \frac{1}{2} \beta\phi(R)Q_2^2. \tag{18}$$

Then, as in the case of the parallel research-induced supply shift, we solve for the levy rate that would maximise producer benefits by combining the first-order condition for a maximum derived from equation (18) with the budget-constraint condition, from equation (3). The result is:

$$\tau_p \approx \frac{1}{2} \frac{\varepsilon_{Q,R}}{\varepsilon} \left(\frac{\eta - \varepsilon}{\eta} \right), \tag{19}$$

where the elasticities are as defined above. As implied by previous work on the incidence of research benefits, it will be worthwhile for producers to levy themselves only if demand is elastic (i.e., $\eta > 1$) since a pivotal supply shift results in a reduction of producer surplus when demand is inelastic, even when the research is provided for free (e.g., see Lindner and Jarrett 1978).[12] Further, equation (19) means that producers will find levy-funded research beneficial only if demand is more elastic than supply (i.e., $\eta > \varepsilon$). Intuitively, the more elastic is demand, the smaller is the price reduction effect of research in reducing producer returns, and the less elastic is supply the greater is the cost reduction gain from a given output expansion.

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[12] de Gorter and Zilberman (1990) compared producer and national optimal investments in R&D, where the research could be funded entirely by producers, entirely by the government, or with a mixture of government and industry funding. Although they do not make this interpretation, given their finding that producers are necessarily made worse off if demand is inelastic, their results are consistent only with technological change that causes a multiplicative supply shift. Further, they assumed that the producer funding would be provided in a lump-sum way, with 100 per cent incidence on producers, rather than through a levy, which enables some of the final incidence to be shifted to consumers.

Table 1 Private (producer) and national optimal research funding levy rates: a large-country exporter with matching grants ($\kappa < 1$; $g > 0$; $\eta < \infty$)

	Parallel shift	Pivotal shift
τ	$(\varepsilon_{Q,R}/\varepsilon)\left[\dfrac{(\eta + \kappa\varepsilon)}{(\eta + \kappa\varepsilon) + (1 + d)g(\eta + \varepsilon)}\right]$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)\left[\dfrac{2(\eta + \kappa\varepsilon) - (\eta + \varepsilon)}{(\eta + \kappa\varepsilon) + (1 + d)g(\eta + \varepsilon)}\right]$
τ_p	$\varepsilon_{Q,R}/\varepsilon$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)(\eta - \varepsilon)/\eta$
τ_p/τ	$\left[\dfrac{(\eta + \kappa\varepsilon) + (1 + d)g(\eta + \varepsilon)}{(\eta + \kappa\varepsilon)}\right]$	$\left[\dfrac{(\eta + \kappa\varepsilon) + (1 + d)g(\eta + \varepsilon)}{2(\eta + \kappa\varepsilon) - (\eta + \varepsilon)}\right](\eta - \varepsilon)/\eta$

4. Interpretation of analytical results

Table 1 summarises the analytical results in terms of equations for optimal levy rates, for both the pivotal and parallel research-induced supply shifts, from the points of view of both the nation (i.e., τ) and producers (i.e., τ_p).[13] The ratio of the producers' optimum to the national optimum provides an indication of whether producers might over- or under-invest in levy-funded research from the national viewpoint. As table 1 shows, in general the equations for producer and national optimal levy rates differ. The nature and causes of those differences can be illustrated by considering various special cases. To consider the implications of the country's trade status, we first assume the absence of government grants. Then we turn to a consideration of the 'optimal' rates of matching government grants.

4.1 Implications of trade status

Table 2 includes the optimal levy rates implied by the more general counterparts in table 1 in the case with no matching government grants (i.e., $g = 0$). These results are consistent with our expectations, from the heuristic analysis in section 2. Specifically, in the case of a parallel research-induced supply shift the producer incentives for levy-funded research are compatible with the national interest, and producers' choice of a levy rate that maximises producer surplus will also maximise national economic surplus. These results hold regardless of whether the commodity is traded or whether the nation has market power in trade. Hence, in the case of a

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[13] If the research provides spillover benefits in the form of lower production costs for rest-of-world producers, the optimum levy rates for producers and for the nation as an aggregate will be lower than these equations imply.

2 Private (producer) and national optimal research funding levy rates: a large-country exporter with no matching grants ($\kappa < 1$; $g = 0$; $\eta < \infty$)

	Parallel shift	Pivotal shift
τ	$\varepsilon_{Q,R}/\varepsilon$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)\left[\dfrac{2(\eta+\kappa\varepsilon)-(\eta+\varepsilon)}{(\eta+\kappa\varepsilon)}\right]$
τ_p	$\varepsilon_{Q,R}/\varepsilon$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)(\eta-\varepsilon)/\eta$
τ_p/τ	1	$\left[\dfrac{(\eta+\kappa\varepsilon)}{2(\eta+\kappa\varepsilon)-(\eta+\varepsilon)}\right](\eta-\varepsilon)/\eta$

Table 3 Effects of trade status on producer and national optimal research funding levy rates for a pivotal research-induced supply shift with no matching grants

	Large exporter $\eta < \infty$; $\kappa < 1$	Closed economy $\eta < \infty$; $\kappa = 1$	Small exporter $\eta = \infty$; $\kappa < 1$
τ	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)\left[\dfrac{2(\eta+\kappa\varepsilon)-(\eta+\varepsilon)}{(\eta+\kappa\varepsilon)}\right]$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)$
τ_p	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)(\eta-\varepsilon)/\eta$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)(\eta-\varepsilon)/\eta$	$\dfrac{1}{2}(\varepsilon_{Q,R}/\varepsilon)$
τ_p/τ	$\left[\dfrac{(\eta+\kappa\varepsilon)}{2(\eta+\kappa\varepsilon)-(\eta+\varepsilon)}\right](\eta-\varepsilon)/\eta$	$(\eta-\varepsilon)/\eta$	1

parallel research-induced supply shift, a matching grant means that the producers' optimal levy exceeds the national optimum. In contrast, and also as expected, in general the producer and national optima do not co-incide in the case of a pivotal research-induced supply shift, and a matching grant might be warranted in this case.

To explore these and related aspects further we consider some other special cases for the case of a pivotal research-induced supply shift. In table 3 we replicate the results for the case of a large-country exporter (i.e., $\eta < \infty$, and $\kappa < 1$) from table 2, and we compare these with the corresponding results for a non-traded good (i.e., $\eta < \infty$, and $\kappa = 1$), and a small-country exporter (i.e., $\eta = \infty$, and $\kappa < 1$), all in the absence of matching government grants (i.e., $g = 0$). The results in table 3 show that, in the small-country case such that demand is perfectly elastic (i.e., $\eta = \infty$), $\tau_p = \tau$; the producer and national optima coincide. In this case there are no price falls or consumer benefits, so producer benefits represent national benefits. In the closed economy case, however, where demand is less than perfectly elastic, the producers' levy choice, τ_p is less than the national optimum τ, and the RDC

will invest less than the social optimum in R&D. In this case, consumers do receive some benefits, and the more elastic is supply relative to demand, the larger is the discrepancy between the producer optimum and the national optimum. This result formalises the earlier discussion suggesting that, with a pivotal supply curve shift, the producers' share of the levy costs is greater than their share of the benefits from research. Hence, a subsidy may be required to induce producers to choose the socially optimal levy rate. Further, considering the results in table 2 and table 3 together, we can see that in the case of a small exporter or a closed economy, the nation's optimal levy in the case of a pivotal shift is half that for a parallel shift.[14]

4.2 Optimal rates of matching government grant

This section draws on the preceding results to assess the consequences of matching grants for levy rates and draw implications for the 'optimal' rate of matching grant; that is, that rate that will result in a producer or RDC choice of levy rate that will maximise net national benefits ($\tau = \tau_p$). In the case of a parallel supply shift, the optimal rate of matching grant is zero, regardless of the other elements of the model. However, in the case of a pivotal supply shift, the optimal rate of subsidy will vary with the relative elasticities of demand and supply. To find the optimal rate of matching support, we set τ from equation (17) equal to τ_p from equation (19) and solved for g. The result is:

$$g^* = \frac{\kappa\varepsilon}{(1+d)(\eta-\varepsilon)} = \kappa\left[(1+d)\left(\frac{\eta}{\varepsilon}-1\right)\right]^{-1}. \tag{20}$$

Then, the optimal matching grant is greater, the less important are exports, the more elastic is supply relative to demand, and the smaller is the social opportunity cost of government revenue. Only by an unlikely coincidence will equation (20) imply a value of $g = 1$, necessary to warrant a dollar for dollar matching grant.

In summary, we have identified several scenarios in which an RDC seeking to maximise domestic producer surplus could be expected to choose the levy and quantity of research that will maximise national research benefits. This incentive compatibility is found regardless of elasticities or the country's

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[14] In table 2, in the case of a parallel shift regardless of trade status the national optimum is $\tau = \varepsilon_{Q,R}/\varepsilon$, and in table 3 in the case of a pivotal shift for a closed economy or a small open economy the national optimum is $\tau = \frac{1}{2}\varepsilon_{Q,R}/\varepsilon$.

trade status in cases when research causes a parallel shift of the supply curve, but only if all of the commodity is exported (i.e., $\kappa = 0$) or demand is perfectly elastic in cases when research causes a pivotal shift of the supply curve. In any of these scenarios, justification for government matching grants for the types of applied research funded by RDCs would have to be based on either the view that surplus accruing to producers and consumers of the commodity does not represent national benefits (owing to spillover benefits to other commodities and parts of the economy, as considered by the Industry Commission 1994),[15] or a perception that RDCs were not seeking simply to maximise total domestic producer surplus, regardless of its distribution (for reasons such as those suggested by Alston (2002), including diversity of interests among heterogeneous producers within an industry covered by an RDC, and inter-temporal distributional aspects).

In contrast, we have shown that where research leads to pivotal shifts of the supply curve, and demand is less than perfectly elastic, producers will choose a lower levy rate and less research than would be optimal for society. Here there is a *prima facie* case for some form of government subsidy. However, our analysis finds against a blanket dollar for dollar matching grant (i.e., $g = 1$) for all situations. First, if demand is inelastic, or the demand elasticity is less than the supply elasticity, producers will choose a zero levy even though society would benefit from research, regardless of a matching grant, making it an ineffective subsidy instrument. Second, even in those scenarios where producers would in their own interests levy themselves to fund research, but by less than would maximise national welfare, the optimal matching grant will vary with the commodity supply and demand elasticities and with the importance of trade.

5. Illustrative numbers

This section provides estimates of the levy rates that would maximise benefits to producers and the nation under a range of market assumptions, to illustrate the contrasts and similarities between these rates under different market circumstances. In particular, the illustrations highlight the importance of parallel versus pivotal research-induced supply shifts and, for the case of a pivotal supply curve shift, the importance of different demand and supply elasticities and export shares of total sales. In all the illustrations we assume an elasticity of output with respect to research, $\varepsilon_{Q,R}$ of 0.01. For a parallel supply curve shift and supply elasticity of $\varepsilon = 1$, the

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[15] Given the emphasis of RDC research portfolios on applied research, the relative importance of cross-commodity spillovers has been challenged (e.g., Industry Commission 1994).

Table 4 Effects of elasticities on choices of levy rates by society and producers to fund pivotal and parallel research-induced supply shifts in a closed economy

Supply elasticity	Demand elasticity	Parallel shift $\tau_p = \tau$	Pivotal shift		
			τ	τ_p	g
		– optimal rates times 100 per cent –			
1.0	0.2	1.00	0.50	–	–
	0.5	1.00	0.50	–	–
	1.0	1.00	0.50	–	–
	2.0	1.00	0.50	0.25	1.00
	4.0	1.00	0.50	0.38	0.33
2.0	0.2	0.50	0.25	–	–
	0.5	0.50	0.25	–	–
	1.0	0.50	0.25	–	–
	2.0	0.50	0.25	–	–
	4.0	0.50	0.25	0.13	1.00

elasticity of output with respect to research is equal to the elasticity of marginal and average cost with respect to research, $\varepsilon_{Q,R} = \varepsilon_{C,R}$, and the optimal levy rate for both producers and the nation is $\tau_p = \tau = 0.01$, or 1 per cent. Current Australian RDC levy rates are less than 1 per cent.

Table 4 reports values of the research levy rates expressed in percentage terms (i.e., τ_p or τ times 100), which maximise either national welfare or producer surplus for the case of a non-traded commodity (i.e., where domestic consumption equals production and $\kappa = 1$). We combine supply elasticities of 1.0 or 2.0 with a domestic demand elasticity of 0.2, 0.5, 1.0, 2.0, or 4.0, and consider cases where R&D shifts the supply curve either in a parallel fashion or pivotally. For example, with a supply elasticity of 1.0 and a demand elasticity of 0.2, for a parallel supply shift both producers and society would chose a 1.0 per cent levy rate, but for a pivotal shift society would set a 0.5 per cent levy and producers a zero levy rate. In this setting, with $\varepsilon = 1$ and $\eta = 2$, a matching grant of one dollar per dollar would be optimal if the marginal social opportunity cost of government spending is $A1.00 (i.e., $d = 0.0$), 83.3 cents per dollar if the marginal social opportunity cost is $A1.20 (i.e., $d = 0.20$). But these are comparatively unlikely elasticity scenarios. In most cases the domestic demand for agricultural products is likely to be highly inelastic, and this means that demand for non-traded goods is likely to be less elastic than supply such that producers will not profit from pivotal supply shifts.

The levy rates in table 4 can be read in conjunction with the general propositions illustrated in figure 3. For a parallel supply curve shift, producers and society choose the same levy rate. The levy rate does not depend on the demand elasticity, but a larger supply elasticity reduces the levy rate

Table 5 Effects of trade status on choices of levy rates by society and producers, and the optimal rate of matching grant, for a pivotal supply shift, $\varepsilon = 1$ and $\varepsilon_{Q,R} = 0.01$

Export share of sales $((1-\kappa) \times 100)$	Export demand elasticity (η_e)	Total demand elasticity (η)	Levies (%) National optimum $(\tau \times 100)$	Producer optimum $(\tau_p \times 100)$	Optimal matching grants (%) $(g \times 100)$ $(d = 0.0)$	$(d = 0.2)$
100 (%)	∞	∞	0.50	0.50	0.0	0.0
	20	20	0.48	0.48	0.0	0.0
	10	10	0.45	0.45	0.0	0.0
	5	5	0.40	0.40	0.0	0.0
	1	1	0.00	0.00	0.0	0.0
80 (%)	∞	∞	0.50	0.50	0.0	0.0
	20	16.0	0.48	0.47	1.3	1.1
	10	8.0	0.45	0.44	2.8	2.4
	5	4.0	0.41	0.38	6.6	5.5
	1	0.8	0.12	0.00	–	–
50 (%)	∞	∞	0.50	0.50	0.0	0.0
	20	10.1	0.48	0.45	5.5	4.5
	10	5.1	0.46	0.40	12.2	10.2
	5	2.6	0.42	0.31	31.3	26.0
	1	0.6	0.27	0.00	–	–
20 (%)	∞	∞	0.50	0.50	0.0	0.0
	20	4.1	0.48	0.38	25.3	21.1
	10	2.1	0.47	0.27	69.0	57.5
	5	1.2	0.45	0.07	500.0	416.7
	1	0.4	0.41	0.00	–	–
Non-traded	–	0.2	0.50	0.00	–	–

Entries are based on domestic supply and demand elasticities of $\varepsilon = 1.0$, and $\eta_d = 0.2$
$\eta = \kappa \eta_d + (1 - \kappa) \eta_e$

because it translates a given quantity increase resulting from research into a smaller per unit cost reduction. For a pivotal supply curve shift, the national optimum levy rate is half of that for a parallel shift. The producers' optimum levy rate is smaller again, and the results in table 4 confirm that producers would not invest in levy-funded R&D when demand is inelastic and, when it is elastic, only when demand is more elastic than supply. The majority of situations covered in the table would see no producer investment in levy-funded research, even though such activity would be of value to society.

Table 5 reports estimates of the national and producer optimal levy rates for the case of an exported product where R&D causes a pivotal shift of the supply curve, under various market circumstances, as well as the corresponding rates of matching government grants required to equate the national and producer optimal levy rates. Estimates were computed by

combining export shares (100 times $1 - \kappa$) of 100 per cent, 80 per cent, 50 per cent, or 20 per cent with export demand elasticities of ∞, 20, 10, 5 or 1, and a domestic supply elasticity of 1 (comparable results using a supply elasticity of 2 are reported in table 6). For all cases the domestic demand elasticity is held constant at 0.2, and the elasticity of output with respect to research is set at 0.01, as for table 4. The derived aggregate demand elasticity in the third column is the share-weighted average of the export demand elasticity and the fixed domestic demand elasticity (e.g., an export elasticity of 10 with 50 per cent exports gives a derived total demand elasticity of 5.1). This means that changes in the domestic share (κ) imply changes in the overall demand elasticity (η), and in our solutions the indirect effect on η is more important than the direct effect of changing κ. Each row of the table shows the optimal levy rates and optimal rates of matching grant implied by a particular combination of elasticities. For instance, where 80 per cent of the product is exported, with an export demand elasticity of 5 and a supply elasticity of 1, society would choose a levy rate of 0.41 per cent, and producers would choose a lower levy rate of 0.38 per cent. In this scenario, if the government were to offer a matching grant of $g = 6.6$ per cent (or 6.6 cents per dollar of levy revenue), the producers' optimal choice of levy rate would become the rate that would maximise national welfare. If, however, a dollar of government spending entailed a marginal opportunity cost of $A1.20 per dollar, the optimal rate of matching grant would be reduced to 5.5 per cent.

Some key results highlighted in table 5 are as follows. When export demand is perfectly elastic, or when all of the product is exported, there are no domestic consumer benefits from research, and producers choose the levy rate that would maximise national net benefits. In all other cases producers choose a lower levy rate, and the difference is greater the less important are exports and the less elastic is export demand (i.e., when the overall demand is less elastic). Table 6 replicates table 5 using a supply elasticity of 2.0 instead of 1.0. It can be seen that a larger supply elasticity reduces the levy rates that would be chosen by both the nation and producers, but the patterns in the results are otherwise similar.

In many cases, with a pivotal supply shift, the levy rate chosen by producers will be very different from the national optimum. This divergence increases as we move down the tables (5 and 6), increasing the domestic consumption share, the main consequence of which is to reduce the overall demand elasticity, reducing the export demand elasticity, which also reduces the overall demand elasticity, or both. In extreme cases (with 20 per cent or less of the commodity exported and an export demand elasticity of 10 or less), the implied overall demand elasticity is 2.1 or less. Given a supply elasticity of 1 or 2, such a small demand elasticity implies a very large

Table 6 Effects of trade status on choices of levy rates by society and producers, and the optimal rate of matching grant, for a pivotal supply shift, $\varepsilon = 2$ and $\varepsilon_{Q,R} = 0.01$

Export share of sales $((1 - \kappa) \times 100)$	Export demand elasticity (η_e)	Total demand elasticity (η)	Levies (%) National optimum $(\tau \times 100)$	Levies (%) Producer optimum $(\tau_p \times 100)$	Matching grants (%) $(g \times 100)$ $(d = 0.0)$	Matching grants (%) $(g \times 100)$ $(d = 0.2)$
100 (%)	∞	∞	0.25	0.25	0.0	0.0
	20	20	0.23	0.23	0.0	0.0
	10	10	0.20	0.20	0.0	0.0
	5	5	0.15	0.15	0.0	0.0
	1	1	0.00	0.00	0.0	0.0
80 (%)	∞	∞	0.25	0.25	0.0	0.0
	20	16.0	0.23	0.22	2.9	2.4
	10	8.0	0.20	0.19	6.6	5.5
	5	4.0	0.16	0.13	19.6	16.3
	1	0.8	0.00	0.00	0.0	0.0
50 (%)	∞	∞	0.25	0.25	0.0	0.0
	20	10.1	0.23	0.20	12.4	10.3
	10	5.1	0.21	0.15	32.3	26.9
	5	2.6	0.18	0.06	166.7	138.9
	1	0.6	0.09	0.00	–	–
20 (%)	∞	∞	0.25	0.25	0.0	0.0
	20	4.1	0.23	0.13	74.1	61.7
	10	2.1	0.22	0.02	1000.0	833.3
	5	1.2	0.21	0.00	–	–
	1	0.4	0.20	0.00	–	–
Non-traded	–	0.2	0.25	0.00	–	–

Entries are based on domestic supply and demand elasticities of $\varepsilon = 2.0$, and $\eta_d = 0.2$
$\eta = \kappa \eta_d + (1 - \kappa)\eta_e$.

rate of matching grant, but the implied rate is very sensitive to changes in the parameters. In contrast, in the case of a parallel research-induced shift in supply, the optimal levy rates chosen by both the nation and producers for all market circumstances described in table 5 would be 1 per cent for a supply elasticity of 1 and 0.5 per cent for a supply elasticity of 2, with no influence by the export demand elasticity or share of product exported on the levy rate.

6. Some caveats

We have assumed that all of the benefits and costs of the levy-funded research accrue to the producers and consumers of the commodity being levied. This assumption has a number of elements, which we will address in turn.[16] First, the assumption ignores spillover benefits of research to other

commodities and public good benefits, such as the benefits to the wider society from, say, greater environmental amenity and biodiversity. Of course this is unrealistic; however, in practice only a small share of the funds distributed by Australian RDCs has gone to projects for basic research or to generate public good type environmental benefits.[17] In contrast, technology resulting from levy-funded research might nevertheless entail substantial positive or negative externalities (associated with the environment, food safety, or something else) and to the extent that this is so there will be divergences between social and private benefits and hence between social and private optimal research levy rates, even when research causes a parallel shift in the supply function.

  Second, the competitive market model assumes negligible policy distortions, and also the absence of external costs and benefits, for the commodity. The absence of agricultural policy interventions is a reasonable assumption for almost all Australian agricultural commodities. The associated assumption of no market power of firms is satisfactory for farm production and also on the commodity demand side when the actual and potential threat of international trade is recognised. However, agricultural policy distortions are of significance for most countries. As shown by Alston *et al.* (1988), Martin and Alston (1994), Alston and Martin (1995) and others, policy distortions alter the total benefits from R&D, and especially the distribution of benefits between producers and other groups in society. Extrapolating from these studies we can infer that policy distortions could result in substantial discrepancies between the levy rates that would maximise benefits to producers versus society. The same results also would suggest that the nature and extent of the differences between producer and national optimal levy rates will depend crucially on the details of the policy, the international trade status of the commodity, and the type of supply curve shift. Similar

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[16] We can interpret these elements as left out benefits (or costs) accruing to the economy more broadly, to producers and consumers of closely related commodities, to technology suppliers or other agribusiness firms that have market power in the commodity or the technology, to consumers of environmental amenities, or to taxpayers through government revenues where commodity price policies are applied.

[17] AFFA (2002) report that many RDC projects provide benefits for the environment, food safety and for regions. Arguably, most of these benefits accrue to the producers and consumers of the commodities, and are fully reflected in the returns to producers, consumers, and society, as measured in the present paper. Some other benefits reduce external costs associated with production and can be regarded as savings to producers through reduced costs of current or future regulations or taxes on pollution externalities. A relatively small share of the research benefits from these projects have public-good properties that would show up in social benefits but not in benefits to producers or consumers. Also, those RDCs most involved in supporting projects yielding public-good environmental benefits, for example Land and Water Australia, are fully government funded with no producer levy.

findings would apply where markets are distorted as a result of market power of firms or environmental externalities (e.g., see Alston *et al.* 1995).

Third, our analysis ignores cross-commodity impacts of the collection of the levy or the research it is used to fund. It is easy to imagine a scenario in which research on one commodity (and, indeed, the levy to fund it) has significant impacts on the market for another commodity that is closely related in production, consumption, or both (for instance, beef and lamb in Australia or beef and pork in the USA). Our partial equilibrium model assumes that second-round and feedback effects of changes in the commodity studied on prices and quantities in the rest of the economy are of second-order importance. Given the relative unimportance of the agricultural sector, it seems reasonable to prefer the simplicity of a partial equilibrium model versus a general equilibrium model, but in some cases a multi-commodity model may be necessary to capture all the relevant effects. Again, this is an empirical issue, to be determined on a case by case basis.

Fourth, we have ignored the possibility of technology firms having market power – through patents, trade secrets or other forms of intellectual property – in either the technology being produced or the technology it replaces. If firms have property rights over technologies, and collect monopoly rents accordingly, then a complete analysis of the social benefits must account for changes in rents to technology providers, which do not show up in the commodity market measures of consumer and producer surplus (e.g., see Moschini and Lapan 1997). Further, levy-funded research results might be subject to intellectual property protection with implications for the total benefits and their distribution. These aspects are probably of minor importance in the context of Australian levy-funded research to date, but are likely to become more important with time.

We can anticipate some general implications of these various factors. To the extent that there are spillovers or other benefits beyond the producers and consumers of the commodity being levied, our results understate the social benefits from the R&D, and they understate the desirable level of matching government grant. On the other hand, when new agricultural technology results in excessive consumption of natural resource stocks or involves other negative externalities, or other costs beyond the commodity being levied, the converse may be true. To make more specific statements would require more specific information. In the Australian context, however, we would suggest that for most commodities and for most types of levy-funded research, it is not unreasonable to set these complications aside for the type of work being done in the present paper.

Finally, our results are based on a premise that total producer surplus (measured off the commodity supply function at wholesale, say) is the relevant measure of benefits to be maximised by the RDC. Increasingly,

however, RDCs are being directed to consider community-wide priorities – such as concerns with externalities associated with agricultural production – when allocating funds, and they have to report against them as an element of meeting requirements for the matching government grants. The extent to which such externalities exist or are effectively addressed and mitigated by RDC-funded research remains a matter for speculation. Nevertheless, it seems likely that the concern with community-wide impacts has received enough attention such that it is an effective constraint on the RDC research portfolios, to the extent that RDCs will have changed both their true research priorities and how they report their actions and achievements. If such a constraint is meaningful, the producer benefit from a given amount of research spending will be lower while the social benefit may be higher or lower, with an ambiguous effect on the size of the discrepancy between the private and social optimal levy rates, and the rate of matching government grant. In addition, where levy-funded research has unequal impacts on heterogeneous producers, it may be too simple to assume that the RDC chooses a levy rate and a research portfolio strictly aiming to maximise total producer net benefits, without regard to the distribution of those benefits among producers.[18] An extension to allow for more complex objective functions would be challenging and is beyond the scope of the present work.

7. Conclusion

It has been suggested by some authors that compulsory levy-based funding supported by matching government grants is, in principle, a fair and efficient way of financing applied agricultural research, and that this approach helps account for Australia's comparatively high public agricultural research intensity ratio (e.g., Alston *et al.* 1999). Some have quantified the implications of these arrangements for the distribution of the benefits and costs of different types of agricultural research (e.g., Mullen *et al.* 1989; Zhao 2003; Zhao *et al.* 2003). In the present paper we have questioned some of the premises from the previous studies concerning the fairness and efficiency of levy-based funding. To do this we formally modelled the decision calculus of producer bodies such as RDCs, and compared their optimal rates of research levies with the rates that would be optimal for the nation as a whole. We explored how this comparison depends on the nature of the research-induced technical change and market conditions such as the

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[18] A reviewer suggested that unequal impacts among heterogeneous producers might be a further reason why a matching grant may be required to encourage producer organisations to implement research levies. Alston (2002) offers some more detailed discussion.

elasticities of supply and demand, and the country's trade status in the commodity in question.

A conventional approach would use producer surplus measured off the commodity supply function as the maximand for the RDC, with national benefits equal to the sum of producer surplus and domestic consumer surplus. Hence, we assumed all the benefits and costs of the levy and the research it funds accrue to the producers and consumers of the commodity – that is, there are no inter-industry spillover effects of the R&D, and any effects of distortions arising from government price policies, market power of firms, and external benefits and costs in production, are minimal. Using this approach, producer incentives and national interests coincide exactly for levy-funded research under a range of circumstances. These include 100 per cent levy funding that gives rise to a parallel research-induced supply shift, regardless of the demand elasticity, or a pivotal research-induced supply shift when demand is perfectly elastic or all of the product is exported. In the pivotal case, when demand slopes down, the producer optimum is less than the national optimum. Importantly, when demand is inelastic, or demand is less elastic than supply, the producer optimum is zero, even when some investment in research is clearly in society's interest.

Our analysis provides several observations on the virtues of matching government grants for producer levies for research. Where demand is perfectly elastic or all production is exported, or where research leads to parallel supply curve shifts, producers already have appropriate incentives in the absence of a matching grant. More generally, with pivotal supply curve shifts and a less than infinitely elastic demand, the required matching grant to induce producer decisions consistent with the social optimum varies with the export share and with the elasticities of product demand and supply, and only by coincidence would the socially optimal matching grant be dollar for dollar. When demand is inelastic, or the demand elasticity is less than the supply elasticity, producers will choose a zero levy rate regardless of the matching grant. Against these observations, current general policy of a blanket dollar for dollar matching grant is clearly sub-optimal, even without the complications of spillovers, environmental impacts, commodity price policies, or other distortions. The socially optimal policy is strictly an empirical question that will vary from industry to industry and case to case, and within industries, among different types of levy-funded research. Theoretical analysis such as that in the present paper, alone, cannot answer this question but has demonstrated the importance of further work to pursue a specific answer.

Clearly, our simplifying assumptions of no spillover R&D benefits and no market distortions will not fit the facts for every situation, and the implications of relaxing these assumptions represent areas for further

model development as well as qualifications to the policy implications. The simplifying assumptions are not unreasonable for the Australian setting. For most projects, but certainly not all projects, funded by RDCs in Australia, in our judgement the majority of anticipated benefits, including those directed at the environment and food safety, initially go to producers and consumers of the products. For Australian primary industries, distortions from government policies are small, but obviously this is not the case for many other countries. On the other hand, in some cases production involves external costs, for example waste chemicals, and these will imply different relations between social and producer benefits from various types of research than those considered in the present paper. And, as noted above, heterogeneity of producers means that the assumed RDC objective of maximising producer surplus may be too simple. The incorporation of such complications can be expected to add to the potential for discrepancies between national and producer optimal choices, reinforcing the conclusion that the simple blanket policy of 1:1 matching grants is likely to be suboptimal but that to do better is likely to require specific, careful, and difficult empirical analysis.

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Appendix

The equations for the optimal levy rates discussed in sections 3 and 4 are derived below.

Parallel supply curve shift

For the case of a parallel shift in supply, the equilibrium quantity and price are found by solving equations (6) and (7), namely:

$$Q_1 = \frac{\gamma - \alpha(R) - t}{\delta + \beta} \tag{21}$$

$$P_1 = \frac{\gamma\beta + \delta\alpha(R) + \delta t}{\delta + \beta} \tag{22}$$

where P_1 is the consumer price, gross of tax, and the producer price is given by $P_1 - t$.

Recall the expression for net national surplus allowing for trade and the marginal excess burden of taxation (equation (9)):

$$NS_1 = \frac{1}{2}(\kappa\delta + \beta)Q_1^2 - (1 + d\left(\frac{g}{1+g}\right)R. \tag{23}$$

Differentiating with respect to R, the first-order condition for the optimum is:

$$\frac{\partial NS_1}{\partial R} = (\kappa\delta + \beta)Q_1\frac{\partial Q_1}{\partial R} - (1 + d\left(\frac{g}{1+g}\right) = 0, \quad \text{or} \tag{24}$$

$$\frac{\partial Q_1}{\partial R} = \frac{(1 + d)}{Q_1(\kappa\delta + \beta)}\frac{g}{1+g}. \tag{25}$$

Differentiating the solution for Q_1 in equation (21) with respect to R,

$$\frac{\partial Q_1}{\partial R} = -\frac{1}{\delta + \beta}\left[\frac{\partial\alpha}{\partial R} + \frac{\partial t}{\partial R}\right]. \tag{26}$$

Further, differentiating the market-clearing condition

$$R = (1 + g)tQ \tag{27}$$

with respect to R, and simplifying,

$$\frac{\partial t}{\partial R} = t\left[\frac{1}{R} - \frac{1}{Q}\frac{\partial Q}{\partial R}\right]. \tag{28}$$

Substituting the expression for $\partial t/\partial R$ from equation (28) into equation (26), and defining $\varepsilon_{C,R} = -\partial\alpha/\partial R \cdot R/P$, we obtain an alternative expression for $\partial Q_1/\partial R$ that holds at the equilibrium:

$$\frac{\partial Q_1}{\partial R} = \frac{\varepsilon_{C,R}P_1 - t}{t(1 + g)[Q(\delta + \beta) - t]}. \tag{29}$$

Setting the expression for $\partial Q_1/\partial R$ from the first-order condition, equation (25), equal to the expression for $\partial Q_1/\partial R$ from the market clearing conditions, equation (29), we can eliminate the $\partial Q_1/\partial R$ terms altogether and solve for the optimal levy rate $\tau = t/P$:

$$\tau = \varepsilon_{C,R}\left[1 + (1+d)g\,\frac{\eta + \varepsilon}{\eta + \kappa\varepsilon}\right]^{-1} + \tau^2(1+d)g\frac{\eta\varepsilon}{(\eta + \kappa\varepsilon)}\left[1 + (1+d)g\,\frac{\eta + \varepsilon}{\eta + \kappa\varepsilon}\right]^{-1}. \tag{30}$$

For typical values of τ, well less than 0.01, the last term in equation (30) will be very close to zero and we can use equation (10) above, which excludes the last term, as an approximation. Further, when $g = 0$, as is optimal for a parallel supply shift, the last term equals zero.

For the producer optimum, the objective function is (equation (12)):

$$PS_1 = \frac{1}{2}\beta Q_1^2, \tag{31}$$

and setting the derivative with respect to R equal to zero yields the first-order condition for the producer's maximisation problem:

$$\frac{\partial Q_1}{\partial R} = 0. \tag{32}$$

Equations (26) through (29) still hold, because they are implied by the market-clearing conditions, so that

$$\tau_p = \varepsilon_{C,R} = \frac{\varepsilon_{Q,R}}{\varepsilon}. \tag{33}$$

Pivotal supply curve shift

For the case of a pivotal shift in supply, the equilibrium quantity and price are found by solving equations (14) and (15):

$$Q_2 = \frac{\gamma - \alpha - t}{\delta + \beta\phi(R)} \tag{34}$$

$$P_2 = \frac{\gamma\beta\phi(R) + \delta\alpha + \delta t}{\delta + \beta\phi(R)} \tag{35}$$

where P_2 is the consumer price, gross of tax, and the producer price is given by $P_2 - t$.

Recall the expression for net national surplus (equation (16)):

$$NS_2 = \frac{1}{2}(\kappa\delta + \beta\phi(R)Q_2^2) - (1 + d)\left(\frac{g}{1 + g}\right)R.$$ (36)

Differentiating with respect to R, the first-order condition for the optimum is:

$$\frac{\partial NS_2}{\partial R} = \frac{\beta}{2}Q_2^2\frac{\partial\phi}{\partial R} + (\kappa\delta + \beta\phi)Q_2\frac{\partial Q_2}{\partial R} - (1 + d)\left(\frac{g}{1 + g}\right) = 0,\text{ or}$$ (37)

$$\frac{\partial Q_2}{\partial R} = \frac{1}{Q_2(\kappa\delta + \beta\phi)}\left[(1 + d)\frac{g}{(1 + g)} - \frac{\beta}{2}Q_2^2\frac{\partial\phi}{\partial R}\right].$$ (38)

Using the definition of $\varepsilon_{Q,R} = -(\partial\phi/\partial R)R$, equation (38) simplifies to:

$$\frac{\partial Q_2}{\partial R} = \frac{2t(1 + d)g + \beta Q_2\varepsilon_{Q,R}}{2t(1 + g)(\kappa\delta + \beta\phi)Q_2}$$ (39)

Differentiating the solution for Q_2 in equation (34) with respect to R,

$$\frac{\partial Q_2}{\partial R} = -\frac{1}{\delta + \beta\phi}\left[\frac{\partial t}{\partial R} + Q_2\beta\frac{\partial\phi}{\partial R}\right].$$ (40)

The expression for $\partial t/\partial R$ in equation (28) is still valid, since the definition of research spending holds regardless of the assumption about the type of research-induced supply shift. Substituting the expression for $\partial t/\partial R$ into equation (40) and using the definition of $\varepsilon_{Q,R} = -(\partial\phi/\partial R)R$, we obtain an alternative expression for $\partial Q_2/\partial R$ that holds at the equilibrium:

$$\frac{\partial Q_2}{\partial R} = \frac{\varepsilon_{Q,R}\beta Q_2 - t}{t(1 + g)[Q_2(\delta + \beta\phi) - t]}.$$ (41)

Setting the expression for $\partial Q_2/\partial R$ from the first-order condition, equation (39), equal to the expression for $\partial Q_2/\partial R$ from the market clearing conditions,

equation (41), we can eliminate the $\partial Q_2/\partial R$ terms altogether and solve for the optimal levy rate $\tau = t/P$:

$$\tau = \frac{\varepsilon_{Q,R}}{\varepsilon} \left[\frac{2(\eta + \kappa\varepsilon) - (\eta + \varepsilon)}{2(\eta + \kappa\varepsilon) + 2(1 + d)g(\eta + \varepsilon) - \eta\varepsilon_{Q,R}} \right]$$

$$+ \tau^2 \left[\frac{2(1 + d)g\eta\varepsilon}{2(\eta + \kappa\varepsilon) + 2(1 + d)g(\eta + \varepsilon) - \eta\varepsilon_{Q,R}} \right]. \tag{42}$$

For typical values of τ and $\varepsilon_{Q,R}$, both well less than 0.01, the last term in equation (42) will be very close to zero and we can use equation (17) above, which excludes the last term from (42), as an approximation.

For the producer optimum, the objective function is (equation (18)):

$$PS_2 = \frac{1}{2} \beta\phi(R)Q_2^2, \tag{43}$$

and setting the derivative with respect to R equal to zero yields the first-order condition for the producer's maximum:

$$\frac{\partial Q_2}{\partial R} = \frac{\varepsilon_{Q,R}}{2t(1 + g)}. \tag{44}$$

Equation (41) still holds, because it is implied by the market-clearing conditions. Setting equation (41) equal to equation (44) allows us to solve for the producer's optimal levy rate:

$$\tau_p = \frac{\varepsilon_{Q,R}}{2 - \varepsilon_{Q,R}} \left(\frac{\eta - \varepsilon}{\eta\varepsilon} \right), \tag{45}$$

which is approximated by equation (19), which is good for typical values of $\varepsilon_{Q,R}$, less than 0.01.