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Proportional Profit Taxes and Resource Management Under Production Uncertainty

Giannis Karagiannis

The impact of proportional profit taxes on input use is analyzed under conditions of production uncertainty and risk aversion. Two kinds of profit taxes are considered: proportional profit taxes with perfect loss offset and revenue-neutral profit taxes. Their impact on optimal input use is examined under various forms of production uncertainty, such as the Just-Pope model and the cases of multiplicative and additive uncertainty. It is shown that the structure of risk attitudes, the form of production uncertainty, the underlying (stochastic) technical interdependencies, and the risk-input relations are crucial features in determining the impact of proportional profit taxes on optimal input use.

Key words: production uncertainty, proportional profit taxes, risk aversion

Introduction

Levying proportional taxes on (pure economic) profit in the agricultural sector can serve as a means for financing agricultural development (e.g., irrigation projects), determining sharecropping, and in allocating public mineral deposits or rangeland. With a proportional profit tax, the government becomes an effective partner in private development projects by bearing a share of risk proportional to the tax rate (Mayshar). Consequently, the number of investment plans undertaken could be larger than would be the case for the same rate of interest, particularly when returns to farmers are very risky. Furthermore, Quiggin suggests that, rather than selling water rights at market prices, the government could allocate them at low cost and impose a proportional profit tax to overcome allocational inefficiencies associated with natural resource use. A similar argument also could be made for publicly owned rangeland allocation.

Two forms of proportional profit taxes have been considered in the literature: profit taxes with perfect loss offset and revenue-neutral profit taxes. Perfect loss offset presupposes that the firm (or its owners) has other income from which any loss can be deducted. In fact, tax laws in many countries provide for loss offset (Sandmo). On the other hand, a revenue-neutral profit tax simultaneously adjusts the marginal rate and the level of exemptions while keeping total tax receipts constant (Holloway).[1] It has been shown that proportional profit taxes have no impact on output level or on optimal input

Karagiannis is senior researcher, Institute of Agricultural Economics and Rural Sociology, National Agricultural Research Foundation of Greece, and visiting associate professor, Department of Economics, University of Crete. The author would like to thank two anonymous reviewers for their helpful comments and Joan Stefan for editorial assistance.

[1] The variance of profit decreases with the imposition of a revenue-neutral tax, but mean profit remains unchanged. In contrast, in the case of a proportional profit tax with perfect loss offset, both the variance and the mean of profit decrease.

use under conditions of complete certainty (Pennèr; Sandmo). This necessarily restricts the potential usefulness of proportional profit taxes to uncertain situations with risk-averse producers.

Based on a review of the literature, all previous studies examining the impact of proportional profit taxes on a firm's production decisions have dealt only with the case of price uncertainty. Their main results may be summarized as follows. First, a proportional profit tax with perfect loss offset increases, leaves unchanged, or reduces output produced by a competitive firm according to whether relative risk aversion is increasing, constant, or decreasing in profit (Penner; Sandmo).[2] Second, a proportional profit tax with perfect loss offset results in output expansion if partial risk aversion is increasing in wealth (Katz; Briys and Eeckhoudt).[3] Third, nondecreasing returns to scale and decreasing absolute risk aversion (DARA) are sufficient conditions for a positive supply response to an increase in the rate of a proportional profit tax with perfect loss offset (Quiggin).[4] This result holds only in the case of increasing returns to scale since constant returns is not compatible with long-run equilibrium in an industry with risk-averse producers (Tressler and Menezes). Fourth, nonincreasing absolute risk aversion is a sufficient condition for a competitive firm to expand production as a response to a revenue-neutral profit tax (Holloway).

The objective of this study is to analyze the impact of proportional profit taxes on a firm's production decisions under conditions of production uncertainty. In particular, their impact on optimal input use is examined under various forms of production uncertainty such as the Just-Pope model and the cases of multiplicative and additive uncertainty. It is shown that the structure of risk attitudes, the form of production uncertainty, the underlying (stochastic) technical interdependencies, and the risk-input relations are crucial features in determining the impact of proportional profit taxes on optimal input use.[5] The theoretical results derived in the next section are also compared and contrasted to previous findings concerning the case of price uncertainty in order to provide a more comprehensive view of the impact of proportional profit taxes on the production decisions of a competitive and risk-averse firm. It is shown that different sets of sufficient conditions are requited to determine the impact of proportional profit taxes under price and production uncertainty.

Clearly, the implications of the theoretical results presented here are most important for agriculture, where production uncertainty is the most significant source of risk. Production uncertainty in agricultural activities is mainly attributed to exogenous factors such as climate conditions (temperature, rainfall, drought, and freezes) and to

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[2] Robison and Barry, by using a mean-variance approximation to expected utility, found that the impact of a profit tax on output is positive only in the limited case of constant absolute risk aversion.

[3] Absolute, relative, and partial risk aversion may be defined as a function of profit or wealth. Following Katz, measures of risk aversion are properly defined based upon wealth and not upon profit. Absolute risk aversion is defined as $A(W) = -u_{WW}(W)/u_W(W)$, relative risk aversion as $R(W) = -u_{WW}(W)W/u_W(W)$, and partial relative risk aversion as $P(W_0, \pi) = -u_{WW}(W_0 + \pi)\pi/u_W(W_0)$, where $u(W)$ refers to the utility function, $W = W_0 + \pi$ to wealth, W_0 to initial wealth, and π to profit. A sufficient condition for partial risk aversion to be increasing in after-tax profit is that relative risk aversion is nondecreasing and absolute risk aversion is nonincreasing, with at least one of them being nonconstant (Briys and Eeckhoudt).

[4] The same result holds for the rank dependent expected utility, but not for the more general model of smooth preferences proposed by Machina.

[5] The risk-input relations depend on whether an input is risk-reducing or risk-increasing. An input is said to be marginally risk-reducing (risk-increasing) if, under risk aversion, the expected value of its marginal product is less (greater) than marginal factor cost (Pope and Kramer). Consequently, a risk-averse farmer uses less (more) of a marginally risk-increasing (risk-reducing) input under production uncertainty than otherwise.

risk-input relations of factors used. The existence of price support policies and of futures and option markets, which attempt to reduce price risk, makes price uncertainty a less significant source of farm income variability than otherwise. Production uncertainty remains, however, a significant source of risk even in the presence of crop insurance due to adverse selection and moral hazard problems which do not allow for full coverage against adverse events.

The remainder of this article is organized as follows. The theoretical results are derived in the next section, and they are compared and contrasted to previous findings concerning the case of price uncertainty. Their implications for resource management and policies are discussed in the following section. In the final section, concluding remarks are presented.

Theoretical Results

Consider a risk-averse perfectly competitive firm facing production uncertainty. Suppose that the firm makes its production decision before uncertainty is resolved, and that it has no production flexibility to adjust its output ex post.[6] Production uncertainty is assumed to have the following form: $y = F(\mathbf{x}, e) = f(\mathbf{x}) + h(\mathbf{x})e$ (Just and Pope), where y is the planned output, $F(\mathbf{x}, e)$ is a quasi-concave production function, $\mathbf{x}$ is a vector of variable inputs, and e is a random variable with $E(e) = 0$ and finite variance.[7] In addition, $f_x > 0$, $f_{xx} < 0$, and $h_x >(<) 0$ for every risk-increasing (risk-reducing) input.[8] If $h(\mathbf{x})$ is constant, the above model results in the case of additive production uncertainty. Alternatively, if $f(\mathbf{x}) = h(\mathbf{x})$, the case of multiplicative production uncertainty arises, i.e., $y = f(\mathbf{x})(1 + e)$.

Additive production uncertainty corresponds to cases where output variability is independent of the level of planned output. This may be the case for uncertainty arising from weather or other natural phenomena affecting agricultural production. In the case of multiplicative production uncertainty, the variance of output is positively related to the level of planned output. As an example, consider the case of pest disease where crop losses depend on the level of planned output. Finally, the Just-Pope model allows the simultaneous existence of both risk-increasing and risk-reducing inputs in order to take into account differences in product variability caused by inputs like labor and fertilizer versus capital, machinery, irrigation, and pesticides.

The objective of the firm is to maximize the expected utility of initial wealth plus after-tax profit for any predetermined level of a proportional profit tax with perfect loss offset, τ:

[6] Even though production is uncertain, the cost of production is assumed to be known with certainty, as it is measured in terms of planned rather than actual output.

[7] Loehman and Nelson developed a more general model of production uncertainty that could have been used. However, a disadvantage of using it in this particular case is that specific functional forms, such as exponential or power utility functions, should be used to derive the relevant comparative static results. These functional forms assume constant absolute and relative risk aversion, respectively. Such restrictions on risk attitude compromise the usefulness of this model in analyzing the impact of profit taxes on input use, which mainly depends on the degree of absolute and relative risk aversion.

[8] Hereinafter, subscripts associated with functions denote partial derivatives, i.e., $f_x = \partial f/\partial x$, $f_{xx} = \partial^2 f/\partial x^2$, etc.

$$(1) \qquad \max_x Eu\{W\} = Eu\Big\{W_0 + \pi(1-\tau)\Big\} = Eu\Big\{W_0 + (1-\tau)\big[p\big(f(\mathbf{x}) + h(\mathbf{x})e\big) - \mathbf{r}'\mathbf{x}\big]\Big\},$$

where $u(W)$ is a von Neuman-Morgenstern utility function with $u_W > 0$ and $u_{WW} < 0$, and p and $\mathbf{r}$ are the certain output price and the vector of certain input prices, respectively. The first-order conditions in the above optimization problem for the two-input case are:[9]

$$(2a) \qquad Eu_W(W)\Big\{p\big[f_1(\mathbf{x}) + h_1(\mathbf{x})e\big] - r_1\Big\} = 0,$$

$$(2b) \qquad Eu_W(W)\Big\{p\big[f_2(\mathbf{x}) + h_2(\mathbf{x})e\big] - r_2\Big\} = 0.$$

The second-order conditions require the Hessian matrix $\mathbf{D}$, with typical elements

$$D_{11} = Eu_W p(f_{11} + h_{11}e) + Eu_{WW}\pi_1^2,$$

$$D_{22} = Eu_W p(f_{22} + h_{22}e) + Eu_{WW}\pi_2^2, \text{ and}$$

$$D_{12} = D_{21} = Eu_W p(f_{12} + h_{12}e) + Eu_{WW}\pi_1\pi_2$$

to be negative semi-definite, where $\pi_i = p(f_i + h_i e) - w_i$ for $i = 1, 2$. The second-order conditions are satisfied under risk aversion ($u_{WW} < 0$) and a quasi-concave production function.

To analyze the effect of an increase in profit tax rate on input use, differentiate (2a) and (2b) with respect to τ and solve the resulting system of equations to obtain:

$$(3a) \qquad \frac{\partial x_1}{\partial \tau} = \frac{1}{|\mathbf{D}|}\Big[D_{22}Eu_{WW}(1-\tau)\pi_1\pi - D_{12}Eu_{WW}(1-\tau)\pi_2\pi\Big],$$

$$(3b) \qquad \frac{\partial x_2}{\partial \tau} = \frac{1}{|\mathbf{D}|}\Big[D_{11}Eu_{WW}(1-\tau)\pi_2\pi - D_{12}Eu_{WW}(1-\tau)\pi_1\pi\Big].$$

Given that $\pi_2 = \delta\pi_1 = (h_2/h_1)\pi_1$ (Pope and Kramer), substitution of the expressions for D_{11}, D_{12}, and D_{22} into (3a) and (3b) yields:

$$(4a) \qquad \frac{\partial x_1}{\partial \tau} = \frac{1}{|\mathbf{D}|}\Big[Eu_{WW}(1-\tau)\pi_1\pi\Big\{p\Big(Eu_W F_{22} - \delta Eu_W F_{12}\Big)\Big\}\Big],$$

$$(4b) \qquad \frac{\partial x_2}{\partial \tau} = \frac{1}{|\mathbf{D}|}\Big[Eu_{WW}(1-\tau)\pi_2\pi\Big\{p\Big(Eu_W F_{11} - (1/\delta)Eu_W F_{12}\Big)\Big\}\Big],$$

[9] Even though the model can be extended to the n-input case, algebraic manipulations are increasingly difficult as the number of inputs increases. The results derived for the two-input case hold for the n-input case without any further ramifications.

where $F_{ij} = f_{ij} + h_{ij}e$ for all $i, j = 1, 2$.[10] The sign of $\partial x_i / \partial \tau$ depends on the sign of the bracketed term, as the sign of $|\mathbf{D}|$ is always positive in the two-input case from the second-order conditions.

■ PROPOSITION 1. *Under stochastic complementarity and similar risk-input relations, a competitive firm decreases (increases) the use of risk-reducing (risk-increasing) inputs as a response to a marginal increase in proportional profit tax with perfect loss offset as long as partial relative risk aversion is increasing (IPRRA) in after-tax profit. Under stochastic substitutability, different risk-input relations, and IPRRA, a firm decreases the use of risk-reducing inputs and increases the use of risk-increasing inputs.*

Proof. Lemmas 1 and 2 in the appendix, along with the second-order conditions, are sufficient to ensure that $\partial x_i / \partial \tau \leq (\geq) 0$, as $h_i \leq (\geq) 0$ and IPRRA.

An intuitive explanation of the above result is as follows. As the rate of profit tax increases, farmers face less risk, without any change in their initial wealth. At the same time, the variance of profit decreases along with expected profit. Under IPRRA, the risk premium falls more than proportionally and farmers are ready to assume more risk (Briys and Eeckhoudt).[11] Thus, they will shift toward the use of risk-increasing inputs. The stronger fiscal pressure on profit, due to increased tax rate, causes risk-averse producers to increase the use of risk-increasing inputs and to reduce the use of risk-reducing inputs. There is empirical evidence that farmers' risk attitudes are characterized by IPRRA. For example, IPRRA has been found for Iowa corn producers (Love and Buccola), Kansas wheat farmers (Saha, Shumway, and Talpaz), and Israeli farmers (Bar-Shira, Just, and Zilberman), whereas the hypothesis of constant partial relative risk aversion has been rejected for Idaho potato growers (Pope and Just).

From Proposition 1, we can derive an interesting result concerning the scale of production. A proportional profit tax with perfect loss offset may increase (decrease) the scale of production under stochastic complementarity and IPRRA as long as all inputs marginally reduce (increase) risk. In the case of stochastic substitutability, which seems much more plausible, the impact of a proportional profit tax on output is ambiguous. It depends primarily on the magnitude of the elasticities of substitution between the marginally risk-reducing and risk-increasing inputs. It is more likely that the scale of production will decrease in the presence of weak substitutability and factor normality.

■ COROLLARY 1. *Under multiplicative production uncertainty, a competitive firm increases the use of all inputs as the rate of proportional profit tax with perfect loss offset increases, if IPRRA and stochastic factor complementarity prevail.*

Proof. Given that the form of multiplicative production uncertainty can only allow for risk-increasing inputs, the proof follows immediately from Proposition 1.

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[10] In the Just-Pope model, F_{ij} instead of f_{ij} is used to define complementarity and substitutability. Specifically, $F_{ij} >(<) 0$ implies stochastic complementarity (substitutability) (Pope and Kramer).

[11] IPRRA requires farmers to have a utility function in which marginal utility diminishes at a rapidly decreasing rate and a proportional increase in risk results in a more than proportional increase in aversion to risk. The first property implies DARA, and the second implies increasing relative risk aversion.

■ COROLLARY 2. *A proportional profit tax with perfect loss offset has no impact on input use under additive production uncertainty.*

Proof. In the case of additive production uncertainty, $\pi_i = 0$ for all i, and thus (4a) and (4b) imply that $\partial x_i/\partial\tau = 0$ for all i.

The result for the case of multiplicative production uncertainty is similar to that for the case of output price uncertainty, and thus all implications analyzed by Penner hold. That is, a proportional profit tax with perfect loss offset can be shifted in the short run by expanding output. On the other hand, a profit tax does not affect output if production uncertainty has an additive form. This result is similar to that for the case of risk-neutral producers or the case of complete uncertainty.

In the case of a revenue-neutral taxation scheme, a proportional tax rate τ is accompanied by a portion of profit exempted from taxation, γ, and the firm's objective function is given as:

$$\text{(5)} \qquad \max_x Eu\{W\} = Eu\Big\{W_0(1-\tau)\pi + \gamma\tau\Big\} = Eu\Big\{W_0 + (1-\tau)\big[p\big(f(\mathbf{x}) + h(\mathbf{x})e\big) - \mathbf{r}'\mathbf{x}\big] + \gamma\tau\Big\}.$$

The first- and the second-order conditions are similar to those in the case of proportional profit tax with perfect loss offset, with the only difference being the arguments included in the utility function.

To analyze the effect of an increase in profit tax rate on input use, differentiate the first-order conditions with respect to τ; note that γ changes according to τ in order to keep tax revenue constant $(d\gamma/d\tau = [E(\pi) - \gamma]/\tau)$; substitute the expressions for D_{11}, D_{12}, and D_{22}; and solve the resulting system of equations to obtain:

$$\text{(6a)} \qquad \frac{\tilde{\partial} x_1}{\partial\tau} = \frac{1}{|\mathbf{D}|}\left[\left(\frac{p^2h}{h_1}\right)Eu_{WW}\pi_1 h_1 e\Big\{Eu_W F_{22} - \delta Eu_W F_{12}\Big\}\right],$$

$$\text{(6b)} \qquad \frac{\tilde{\partial} x_2}{\partial\tau} = \frac{1}{|\mathbf{D}|}\left[\left(\frac{p^2h}{h_2}\right)Eu_{WW}\pi_2 h_2 e\Big\{Eu_W F_{11} - (1/\delta)Eu_W F_{12}\Big\}\right],$$

where

$$\frac{\tilde{\partial} x_i}{\partial\tau} = \left.\frac{\partial x_i}{\partial\tau}\right|_{dEG=0} = \frac{\partial x_i}{\partial\tau} + \left(\frac{\partial x_i}{\partial\gamma}\right)\left(\left.\frac{\partial\gamma}{\partial\tau}\right|_{dEG=0}\right)$$

is the Slutsky-type equation used by Holloway, and G refers to total tax payments to the Treasury. The sign of $\tilde{\partial} x_i/\partial\tau$ depends on the sign of the bracketed term, as the sign of $|\mathbf{D}|$ is always positive from the second-order conditions.

■ PROPOSITION 2. *Under stochastic complementarity and similar risk-input relations, a competitive firm decreases (increases) the use of risk-reducing (risk-increasing) inputs as a response to a revenue-neutral tax as long as absolute risk aversion is* *nonincreasing. Under stochastic substitutability, different risk-input relations, and nonincreasing absolute risk aversion, a firm decreases the use of risk-reducing inputs and increases the use of risk-increasing inputs.*

Proof. By combining Lemma 2 in the appendix, Pope and Kramer's Lemma 3 (p. 493), and the second-order conditions, $\partial \tilde{x}_i / \partial \tau \leq (\geq) 0$, as $h_i \leq (\geq) 0$ and nonincreasing absolute risk aversion.

For an intuitive explanation of this result, note that as the rate of profit tax increases, risk faced by farmers decreases since the variance of profit decreases, but their initial wealth as well as expected profit remain unchanged. Given that profit variability decreases more than proportionally to expected profit, which actually remains unchanged, there is a tendency for farmers to undertake more risk. DARA sufficiently ensures that the risk effect of the profit tax, which is associated with profit variability, dominates the effect on expected profit. This results in expanded use of risk-increasing inputs and contracted use of risk-reducing inputs up to the level allowed by the technical characteristics of production and as long as expected profit is unchanged. If stochastic complementarity prevails and all inputs marginally increase risk, output is expected to expand. Otherwise, the impact of a marginal tax rate increase on the scale of production is ambiguous.

■ COROLLARY 3. *Under multiplicative production uncertainty, a competitive firm increases the use of all inputs as a response to a revenue-neutral tax if absolute risk aversion is nonincreasing in after-tax profit and stochastic factor complementarity prevails.*

Proof. It follows immediately from Proposition 2 by noting that only risk-increasing inputs can be considered under multiplicative production uncertainty.

■ COROLLARY 4. *Under additive production uncertainty, a revenue-neutral tax has no impact on input use.*

Proof. In the case of additive production uncertainty, $\pi_i = 0$ for all i, and thus (6a) and (6b) imply that $\partial \tilde{x}_i / \partial \tau = 0$ for all i.

The result for the case of multiplicative production uncertainty is similar to that for the case of output price uncertainty analyzed by Holloway, where a revenue-neutral increase in the marginal tax rate causes firms to expand output. On the other hand, a revenue-neutral change in the marginal tax rate has no impact on a firm's output under additive production uncertainty. This result is similar to that for the case of risk-neutral producers or for the case of complete certainty.

Policy Implications

The above theoretical results have several useful policy implications for agriculture where production uncertainty is pervasive. First consider the case of the 1986 Tax

Reform Act, which may be viewed as a revenue-neutral tax policy.[12] Under price uncertainty, Holloway found that a reduction in the marginal tax rate induced by the Act causes farmers to contract output. Under production uncertainty, the results of the present study indicate that a reduction in the marginal tax rate is expected to cause an increase in the use of risk-reducing inputs (e.g., pesticides, capital, irrigation) and a decrease in the use of risk-increasing inputs (e.g., fertilizer, hired labor). Output contraction is expected only in the case of multiplicative production uncertainty and stochastic factor complementarity.

From a policy point of view, proportional profit taxes may be used as a means for implementing environmental policies and also as a way of improving the compatibility of agricultural and resource policies. For example, by imposing a proportional profit tax when production is uncertain, it is expected that farmers will increase the use of fertilizer, which is usually considered to be a risk-increasing input, but they will reduce the use of pesticides (fungicides, herbicides, and insecticides), which are often viewed as risk-reducing inputs.[13] These results may be used along with those of Leathers and Quiggin and of Karagiannis, which concern commodity and input price taxes under production uncertainty, to design and implement policies in agriculture. It is worth mentioning, however, that a proportional profit tax (such as taxes) cannot provide complete environmental protection by itself, because while it promotes the contracted use of some inputs which cause environmental and health problems, it fails to bring about the contracted use of other inputs.

With respect to the role of proportional profit taxes on the allocation of natural resources, consider the cases for groundwater and public grazing. Stochastic surface water deliveries are the primary source of irrigation water in states such as California, while groundwater serves as a means of buffering farmers against drought. Private property rights and central control are more efficient allocation mechanisms for groundwater than common property arrangement. Instead of assigning exclusive and tradable groundwater stock permits to individual farmers at a market price, as proposed by Provencher and Burt, the government may allocate rights for pumping at a low cost and impose a proportional profit tax to overcome inefficiencies. According to the above theoretical results, this will also ensure a contracted use of groundwater, given its risk-reducing characteristic and the decreased variability of profit due to taxation. At the same time, a more expanded use of surface water is expected.

Similarly, a proportional profit tax may overcome conflicts arising between the common grazing fee established for federal land and the private grazing fees that vary across states. As an alternative to a permanent transfer of public grazing rights to the private sector suggested by LaFrance and Watts, the U.S. Forest Service and the

[12] In fact, the revenue neutrality targeted by the 1986 Tax Reform Act was neutrality in the aggregate. This did not imply that every individual taxpayer would pay the same (expected) tax as before the reform. I would like to thank an anonymous reviewer for raising this point. Complete consistency between the revenue neutrality assumed in the theoretical model and revenue neutrality in the aggregate is ensured only in the presence of a representative producer.

[13] Leathers and Quiggin considered pesticides as risk-reducing inputs, while Pannell, and Horowitz and Lichtenberg raised some concerns about its risk-input relation. Recent empirical evidence shows that fungicides behave as risk-increasing inputs in Swiss wheat production (Gotsch and Regev; Regev, Gotsch, and Rieder). Empirical evidence with respect to the risk-input relation of fertilizers is also mixed. Nelson and Preckel; Love and Buccola; and Regev, Gotsch, and Rieder found nitrogen to be risk-increasing, while Lambert found it to be risk-reducing. Potassium has been found to be risk-increasing (Nelson and Preckel; Love and Buccola). Nelson and Preckel found phosphorous to be risk-increasing, while Love and Buccola found it to be risk-reducing.

Bureau of Land Management could implement a uniformly low public grazing fee, as they did prior to Rangeland Reform '94. Then, they may use a proportional profit tax to redistribute benefits across grazers more evenly. Profit differentials reflect differences in the nutritive content of forage and its availability, the availability and proximity of water for forage sources, and the local market prices for livestock and substitute feed.[14] By taking this into account, a proportional profit tax may resolve some of the inefficiencies associated with a nationwide uniform public grazing fee. In addition, the proposed policy would not affect either agency's coffers or administration cost. Moreover, it would not result in a more intensive use of the grazing resources in the short run as long as forage is considered to be a risk-reducing input in cattle production.

On the other hand, proportional profit subsidies may be employed as a means of enhancing agricultural mechanization, in addition to other uses (Binswanger). As long as machinery is considered to be a risk-reducing input, such a policy provides an incentive for farmers to invest in more advanced mechanical technology.[15] A proportional profit subsidy may also induce adoption of modern irrigation technologies. It may be used as an alternative to water taxes, proposed by Caswell and Zilberman, to promote the use of sprinkler, center pivot, and drip technologies. Irrigation is considered to be a risk-reducing input as it increases (or keeps constant) yield when a drought occurs during the crop session, but it does not affect yield when rainfall is adequate and timely. Given that sprinkler and drip irrigation are water-saving technologies compared to surface irrigation, a reduction in water use can be indirectly achieved.

Concluding Remarks

It has been shown that proportional profit taxes have similar effects on input use under output price and production uncertainty as long as in the latter case the distribution of profit is independent of input quantities, i.e., multiplicative production uncertainty. If, however, the distribution of profit depends on the level of inputs used, the impact of a profit tax on input use depends on the degree of risk aversion and risk-input relations. In this case, different effects arise for risk-reducing and risk-increasing inputs.

The impact of proportional profit taxes on output also depends on the source of uncertainty. Given IPRRA, a profit tax with perfect loss offset has an output-expanding effect under output price uncertainty, but this is not necessarily true under production uncertainty—except for the case of multiplicative production uncertainty and factor complementarity. A similar argument holds for the case of a revenue-neutral tax and DARA. Thus, the source of uncertainty is important in determining the impact of proportional profit taxes on the scale of production.

The results concerning revenue-neutral profit taxes are applicable to a large number of farmers, as nonincreasing absolute risk aversion is only a counterpart of the sufficient conditions for IPRRA. Furthermore, a revenue-neutral profit tax seems to be a much more easily accepted policy, as it does not affect expected profit. In fact, the results

[14] According to LaFrance and Watts, these factors along with landlord services (i.e., fencing, water access, periodic moving, checking, supplemental feeding) determine the differences in private grazing fees across states.

[15] Some doubts may be raised as to whether all machinery/equipment marginally reduces risk. Actually, this is an empirical question and further research is needed in this direction.

associated with a revenue-neutral profit tax are more likely to hold for all farmers, as nonincreasing absolute risk aversion is a widely accepted form of risk attitude. This does not mean, however, that the results concerning profit taxes with perfect loss offset have only academic interest. In contrast, recent empirical evidence reported by Love and Buccola; Saha, Shumway, and Talpaz; and Bar-Shira, Just, and Zilberman provides support for Arrow's thesis about IPRRA.

Evaluating the potential impact of proportional profit taxes is a difficult task due to the limited number of empirical studies providing information about farmers' risk attitudes and risk-input relations. Given that uncertainty gives rise to real economic problems only in the presence of risk (aversion), these pieces of information are interrelated and can be valuable only if they are obtained simultaneously. Further empirical research is required in this area since production uncertainty is pervasive in agriculture, and thus it should be considered seriously in designing and implementing policies.

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Appendix

■ LEMMA 1. $Eu_{WW}(W_0, \pi(1-\tau))\pi\pi_x \geq (\leq)\, 0$, as $h_x \leq (\geq)\, 0\ \forall x$.

Proof. Let e^* be that value of e such that $\pi_x = 0$, and the corresponding partial relative risk-aversion coefficient is $P(W_0, \bar{\pi}(1-\tau)) = 0$. IPRRA implies that

$$P(W_0, \pi(1-\tau)) = -u_{WW}(W_0, \pi(1-\tau))\pi(1-\tau)/u_W(W_0, \pi(1-\tau)) \geq (\leq)\, P(W_0, \bar{\pi}(1-\tau)),$$

as $e \geq (\leq)\, e^*$ (Briys and Eeckhoudt). Multiplying both sides by π_x and noting that π_x is positive (negative), as $h_x \leq (\geq)\, 0$ (Pope and Kramer), the above expression yields:

$$-u_{WW}(W_0, \pi(1-\tau))\pi(1-\tau)\pi_x \leq (\geq)\, P(W_0, \bar{\pi}(1-\tau))u_W(W_0, \pi(1-\tau))\pi_x,$$

as $h_x \leq (\geq)\, 0\ \forall e$. Taking expectations of both sides and using the first-order conditions results in $Eu_{WW}(W_0, \pi(1-\tau))\pi(1-\tau)\pi_x \geq (\leq)\, 0$, as $h_x \leq (\geq)\, 0$. Q.E.D.

■ LEMMA 2. $Eu_W(W_0, \pi(1-\tau))F_{22} - (h_2/h_1)Eu_W(W_0, \pi(1-\tau))F_{12} < 0$ *if: (i) inputs have the same risk characteristics and they are stochastic complements to each other, or (ii) inputs have different risk characteristics and they are stochastic substitutes.*

Proof. The quasi-concavity of $y = f(\mathbf{x}) + h(\mathbf{x})e$ implies that $Eu_W(W_0, \pi(1-\tau))F_{22} < 0$. $Eu_W(W_0, \pi(1-\tau))F_{12} < (>)\, 0$ under stochastic substitutability (complementarity). In addition, $-(h_2/h_1) < (>)\, 0$ if both inputs are risk-reducing or risk-increasing (one is risk-reducing and the other is risk-increasing). Q.E.D.