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Abstract

This paper analyzes the effects of symmetric and asymmetric taxation on performance-based versus fixed remuneration contracts. I integrate a proportional corporation tax and a proportional wage tax into a binary principal-agent model. The wage tax increases the remuneration costs and makes the agent's employment less attractive. Thus, the principal tends to demand lower rather than higher effort or does not offer a contract at all. In contrast to the wage tax, the corporate tax is irrelevant for the optimal remuneration contract. Under asymmetric corporate taxation, the principal tends to offer contracts less frequently. Fixed remuneration contracts are penalized more heavily by asymmetric taxation than performance-based remuneration contracts.

JEL-Code: H250, M410, M520.

Keywords: asymmetric taxation, loss-offset, principal-agent theory, corporate taxation, wage taxation.

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1 Introduction

Modern corporations are typically characterized by a separation of ownership and control[1]. Owners delegate decisions to managers, who are assumed to have expert knowledge of particular industries or segments of the capital market. Moreover, owners often lack the necessary capacities or qualifications to manage their corporations. For similar reasons, owners might be unable to supervise corporate managers efficiently. Managers who anticipate this lack of supervision could be driven by self-interest, for example, by investing in unprofitable projects ("empire building") or by providing too little effort. Principal-agent literature suggests to avoid the resulting conflicts of interest by offering performance-related remuneration contracts in order to align the interests of owners and managers. If owners and managers maximize equivalent objective values, corporate managers do not have incentives to waste shareholders' resources or to provide sub-optimal effort.

Typically, taxes are neglected in the literature on optimal incentive systems. As a consequence, the impact of taxation on the profitability and the optimal design of incentive schemes has not yet been widely investigated. It is unknown whether corporate taxation and wage taxation increase or decrease the demand for fixed or performance-based remuneration contracts and how these two levels of taxation affect gross managerial remuneration. Given that the current levels of individual income taxation exceed 40% in many OECD countries[2], this research gap is surprising.

Since most corporate tax systems are characterized by loss-offset restrictions, profits and losses are treated asymmetrically. As a consequence, the effects of asymmetric corporate taxation are especially relevant for the demand for and the design of remuneration contracts. The existing principal-agent literature does not address asymmetric taxation. This paper is intended to close this research gap. In a first step, I show the impact of symmetric corporate and wage taxation on the profitability and the design of remuneration contracts. The second step is dedicated to the integration of asymmetric corporate taxation.

The remainder of the paper is organized as follows: After a literature review in section 2 a simple analytical model in the pre-tax case is presented in section 3. In section 4, I investigate the effects of symmetric corporate and wage taxation on the profitability and on the design of incentive schemes. Section 5 analyzes the impact of asymmetric taxation. The derived results are clarified using numerical examples in section 6. Section 7 provides a summary, draws tax policy conclusions, and gives an outlook on future research questions.

[1]See Berle/Means (1932).

[2]See International Bureau of Fiscal Documentation (2010).

2 Literature review

Since the 1970s, one of the main fields of research in the principal-agent literature addresses problems related to manager-owner conflicts. Seminal papers in this field were published by *Ross* (1973) and *Jensen/Meckling* (1976), for example. Moral hazard problems constitute an important branch of the principal-agent literature. *Holmström* (1979) and *Shavell* (1979) published groundbreaking papers in this area of the literature. Models with moral hazard[3] are typically based on the assumption that managerial effort is non-observable. Hence, corporate managers tend to provide too little effort from the owners' perspective. A special case of moral hazard models is given by the LEN model, which was published for the first time by *Spremann* (1987)[4]. Whereas the original LEN model was based on a single managerial action variable, further developments include multiple action variables. Due to the existence of analytical solutions, the LEN model has been widely discussed, especially in the German-language literature[5]. However, the model has been criticized because of its rather restrictive assumptions.

There are few examples of principal-agent models including taxes. *Wolfson* (1985) examines the impact of taxation on the lease-or-buy decision in an agency context. *Fellingham/Wolfson* (1985) show that contracts with optimal division of risk are not necessarily tax-minimizing. *Banerjee/Besley* (1990) analyze the effects of taxation under limited liabiliy. In their model, principal and agent are represented by the fiscal authorities and the corporation manager, respectively. They prove that taxation can improve welfare under market failure due to limited liability. *Kanniainen* (1999, 2000) discusses whether corporate taxation can improve efficiency by reducing managerial empire building. He shows that the efficiency-improving potential of the corporate tax crucially depends on the risk of the underlying investment project.

Due to the growing importance of performance-based remuneration schemes, *Niemann/Simons* (2003) discuss the effects of differential taxation of corporate profits and managerial remuneration on the optimal design of stock option plans. They find that asymmetric capital gains taxation favors the introduction of stock option plans while leaving their optimal conditions unchanged. *Brunello/Comi/Sonedda* (2006) empirically test a standard agency model with taxes. They show that the proportion of performance-based remuneration decreases with an increasing average tax rate. *Göx* (2008) studies the economic consequences of tax deductibility limits on salaries for the design of incentive contracts. His analysis shows that reward for luck can be the optimal response to tax law changes. *Gupta/Viauroux* (2009) investigate the welfare effects of a statutory wage tax sharing rule. Their results indicate that a rule which specifies a solution with 100% of the tax statutorily levied on the employer will maximize effort, expected profit and expected welfare while 100% of the tax statutorily levied on the employee will maximize expected wages.

[3]For an overview see, for example, Macho-Stadler/Perez-Castrillo (2001, p. 35 ff.)

[4]For a critique of the LEN assumptions see Hemmer (2004). A justification of the assumptions is provided by Holmström/Milgrom (1987) and Wagenhofer/Ewert (1993, p. 382 ff.)

[5]See, for example, Wagenhofer/Ewert (1993), Wagenhofer/Ewert (2007, p. 134 ff.)

Until now, the analysis of tax effects in agency models was typically restricted to symmetric taxation. In a moral hazard model of the LEN type, *Niemann* (2008) investigates the impact of a tax system that differentiates between investment projects with different risks. He shows that symmetric taxation leaves managerial portfolio choice unchanged compared to the pre-tax case. By contrast, a tax base reduction increases the proportion of risky projects, whereas a tax rate reduction for risky projects induces ambiguous results, depending on the manager's degree of risk aversion.

In contrast to the principal-agent literature, where taxation plays only a minor role, the impact of asymmetric taxation under symmetric information has been constantly analyzed since the 1940s. A seminal paper was published by *Domar/Musgrave* (1944). They show that risk taking increases under full loss-offset. By contrast, investors' willingness to take risks decreases with stricter loss-offset limitations. Since Domar/Musgrave, asymmetric taxation has been an important field of research in public finance as well as in corporate finance. Major contributions to the literature are the papers by *Barlev/Levy* (1975), *Eeckhoudt/Hansen* (1982), *Auerbach* (1986), *Auerbach/Poterba* (1987), *MacKie-Mason* (1990), *Shevlin* (1990), *Eeckhoudt/Gollier/Schlesinger* (1997), *van Wijnbergen/Estache* (1999), and *Panteghini* (2001a, 2001b). From a corporate finance perspective, *Ball/Bowers* (1982), *Cooper/Franks* (1983), *Majd/Myers* (1986), *Majd/Myers* (1987), and *Schnabel/Roumi* (1990) point to the call option characteristics of the tax claim, which can be assessed using option pricing methods.

Due to the path dependence of existing loss-offset restrictions in the context of multi-period investment decisions, analytical methods of capital budgeting typically do not provide useful economic insights into tax effects. Therefore, numerical methods are necessary for the valuation of investment projects carrying tax-deductible losses. Monte-Carlo simulations of loss-offset restrictions were carried out, for example, by *Haegert/Kramm* (1977), *Majd/Myers* (1986), *Majd/Myers* (1987), *Niemann* (2004), and *Dahle/Sureth* (2008).

3 A binary agency model in the pre-tax case

The binary agency model by *Ewert/Wagenhofer* (2008, p. 369 ff.) serves as a starting point for further analysis. It can be regarded as a special case of the moral hazard model by *Macho-Stadler/Perez-Castrillo* (2001, p. 37). In this model, the principal assigns a task to the agent who is supposed to have special knowledge or special qualifications for this job. Moreover, the principal might be lacking the necessary qualification or is subject to time restrictions. The principal's profit depends on a random variable as well as the agent's effort, which cannot be directly observed. The effort also cannot be inferred from the realized profit. Hence, a forcing contract including a penalty for obviously low effort is not possible. However, the principal can offer a performance-based remuneration contract to the agent. For a high profit, the agent receives a high compensation. For a low profit, the agent receives a low compensation. Designed appropriately, this contract induces the agent to provide high effort, increasing the principal's expected profit[6].

This binary agency model is based on the assumptions that[7]

- the principal's profit x_i before deducting remuneration costs can only take two different states $x_2 > x_1$, with $x_2 > 0$ and $x_1 \in \mathbb{R}$[8],
- the principal is risk-neutral and hence maximizes the expected profit after remuneration costs,
- the agent is risk-averse and effort-averse,
- the agent's effort e_j can only take two different values $e_H > e_L$,
- high effort e_H increases the probability for a high profit compared to low effort e_L,
- the agent's disutility of high effort v_H exceeds his disutility of low effort v_L: $v_H > v_L$,
- the agent's utility function $U(\cdot)$ is additive-separable with respect to remuneration and disutility of effort: $U(s_i, e_j) = \sqrt{s_i} - v_j(e_j) = u_i - v_j$, with s_i as remuneration and u_i as utility of remuneration in state i,
- the agent's reservation utility is given by $\underline{U} > 0$. In the following sections, analyzing tax effects requires a separation of the components of reservation utility. Given the agent's utility function $U(s_i, e_j) = \sqrt{s_i} - v_j(e_j)$, the wage from an alternative job s_a, and the alternative disutility of effort v_a, the reservation utility can be written as $\underline{U} = \sqrt{s_a} - v_a$. For reasons of analytical simplicity, I assume that the disutility from an alternative employment is zero, so that the reservation utility solely consists of the utility from the foregone alternative salary. Positive disutilities $v_a > 0$ would just complicate the analysis without providing further insights into the emerging effects.

The probability distribution of profits and effort levels is given by:

probabilities	low profit x_1	high profit x_2
low effort e_L	$\phi_1^L = 1 - \phi_2^L$	ϕ_2^L
high effort e_H	$\phi_1^H = 1 - \phi_2^H$	ϕ_2^H

where ϕ_i^j denotes the probability for the profit x_i given the effort level e_j. For economically useful results the relation $\phi_2^H > \phi_2^L$ must hold, which implies a decreasing likelihood ratio.

In general, the principal has three alternatives denoted by a_k for his optimal employment and compensation decision.

[6]A monotonous relation of payoff and remuneration is optimal only for monotonically decreasing likelihood ratios. See Milgrom (1981, p. 386 f.)

[7]See Ewert/Wagenhofer (2008, p. 369.)

[8]In contrast to Ewert/Wagenhofer (2008, p. 369), I assume that x_1 may take either algebraic sign. This assumption is necessary with respect to loss-offset restrictions analyzed in section 5.

a_1: The principal can refrain from offering a contract to the agent (default alternative). In this case, the profits x_i cannot be realized, and no remuneration costs are incurred, so that the net profit amounts to zero. The value of the principal's objective function Z equals zero: $Z(a_1) = 0$. This result is based on the assumption that the technology owned by the principal cannot be managed without employing the agent and yields zero net returns when left idle. However, for the qualitative results of this model, it does not matter whether the partial objective function $Z(a_1)$ is zero or a positive or negative constant.

a_2: The principal can offer a fixed-compensation contract to the agent. This fixed remuneration does not provide incentives for high effort. However, the contract can be appropriately designed to induce at least low effort. The value of the principal's objective function can be positive, zero, or negative in this case: $Z(a_2) \in \mathbb{R}$.

a_3: In order to motivate the agent to provide high effort, the principal can offer a performance-based compensation contract. Again, the value of the principal's objective function can be positive, zero, or negative: $Z(a_2) \in \mathbb{R}$.

The principal maximizes expected profit less remuneration costs by choosing the optimal alternative: $Z^* = \max\{0, Z(a_2), Z(a_3)\}$. The value of the partial objective functions $Z(a_2)$ and $Z(a_3)$ is the result of an optimization procedure with the remuneration levels as decision variables to be chosen.[9]

For the alternative with a fixed salary a_2, the partial objective function to be maximized denotes:

$$\max_{u_L} Z(a_2) = \phi_1^L x_1 + \phi_2^L x_2 - u_L^2, \tag{1}$$

with u_L^2 as fixed compensation for low effort. The agent is willing to accept the contract only if the participation constraint is met. This constraint requires that the agent obtains at least his reservation utility and a compensation for his disutility of (low) effort:

$$u_L \geq v_L + \underline{U}. \tag{2}$$

In order to maximize the principal's objective function, the participation constraint must hold with equality: $u_L = v_L + \underline{U}$. If a project generates economic rents, this condition implies that the principal receives all economic rents. Since only low effort is required and is already ensured by the participation constraint (2), an incentive constraint is not necessary for the decision alternative a_2. Hence, the principal's objective function is given by:

$$Z(a_2) = \phi_1^L x_1 + \phi_2^L x_2 - (v_L + \underline{U})^2. \tag{3}$$

For the alternative a_3, the partial objective function to be maximized denotes:

$$\max_{u_1, u_2} Z(a_3) = \phi_1^H x_1 + \phi_2^H x_2 - \min_{u_1, u_2} \phi_1^H u_1^2 + \phi_2^H u_2^2. \tag{4}$$

[9] This approach was first presented by Grossman/Hart (1983, p. 33 f.)

In this case, the participation constraint

$$\phi_1^H u_1 + \phi_2^H u_2 \geq v_H + \underline{U} \tag{5}$$

as well as the incentive constraint

$$\phi_1^H u_1 + \phi_2^H u_2 - v_H \geq \phi_1^L u_1 + \phi_2^L u_2 - v_L \tag{6}$$

must be met to induce the agent to accept the compensation contract and to provide high effort. Maximizing the principal's objective function requires that both constraints hold with equality[10]. The resulting linear equation system with two equations and two variables can be solved for u_1^2 and u_2^2, the remunerations for low and high profit, respectively[11]:

$$\begin{aligned} u_1^2 &= \left[v_H + \underline{U} - (v_H - v_L) \frac{\phi_2^H}{\phi_2^H - \phi_2^L} \right]^2 \\ u_2^2 &= \left[v_H + \underline{U} + (v_H - v_L) \frac{1 - \phi_2^H}{\phi_2^H - \phi_2^L} \right]^2. \end{aligned} \tag{7}$$

This version of the compensation contract ensures that the agent receives an expected remuneration that guarantees the reservation utility and compensates for the disutility of effort. As a result, the principal receives all possible economic rents from realizing a project. The principal's expected profit after remuneration costs is:

$$\begin{aligned} Z(a_3) &= \phi_1^H \left(x_1 - u_1^2\right) + \phi_2^H \left(x_2 - u_2^2\right) \\ &= \phi_1^H x_1 + \phi_2^H x_2 - \left(v_H + \underline{U}\right)^2 - (v_H - v_L)^2 \frac{\phi_2^H \left(1 - \phi_2^H\right)}{\left(\phi_2^H - \phi_2^L\right)^2}. \end{aligned} \tag{8}$$

The principal chooses alternative a_3 only if this objective value is positive and exceeds the objective value of alternative a_2:

$$\begin{aligned} Z(a_3) &\geq Z(a_2) \\ \underbrace{(x_2 - x_1)}_{>0} \underbrace{\left(\phi_2^H - \phi_2^L\right)}_{>0} &\geq \underbrace{(v_H - v_L)}_{>0} \underbrace{\left(v_H + v_L + 2\underline{U}\right)}_{>0} + \underbrace{(v_H - v_L)^2 \frac{\phi_2^H \left(1 - \phi_2^H\right)}{\left(\phi_2^H - \phi_2^L\right)^2}}_{>0} \geq 0. \end{aligned} \tag{9}$$

This means that the performance-based contract is optimal only if the high profit sufficiently exceeds the low profit and if the probability for the high profit under high effort increases sufficiently compared to low effort. Otherwise, i.e., if the disutility of high effort

[10] Only in the special case of a binary model is the participation constraint always binding at a second-best optimum. In models with more than two actions this is not necessarily true. See Grossman/Hart (1983, p. 15 f., 30.)

[11] See Ewert/Wagenhofer (2008, p. 371). I assume that negative remunerations cannot occur. This is true for $\underline{U} \geq \frac{v_H \phi_2^L - v_L \phi_2^H}{\phi_2^H - \phi_2^L}$, i.e., if the reservation utility is sufficiently high compared to the disutility of effort.

is much higher than the disutility of low effort, the principal does not offer a performance-based remuneration scheme.

Both the performance-based and the fixed-remuneration contract are only profitable if the profits x_1 and x_2 are sufficiently high and/or the disutilities of effort v_L and v_H are sufficiently low. Otherwise, the principal chooses the default alternative a_1 and does not employ the agent.

The first-best case as a reference case emerges for observable effort. In this case, the incentive constraint can be neglected, because a forcing contract with penalties for low effort is possible. Thus, the agent always receives a compensation that guarantees a fixed utility. For the alternative a_3 (performance-based contract), the agent's fixed utility is given by

$$u_{a_3}^{FB} = v_H + \underline{U} \tag{10}$$

and the principal's objective value amounts to

$$Z^{FB}(a_3) = \phi_1^H x_1 + \phi_2^H x_2 - (v_H + \underline{U})^2 > Z(a_3). \tag{11}$$

Since the principal's objective value increases compared to the second-best case, the high effort will be requested by the principal more frequently in the first-best case.

The alternative a_2 remains unchanged by observability of effort, because even in the second-best case, the agent certainly provides the low effort[12]. In the first-best case, the principal is willing to pay the agent for providing high effort only if the following condition is met:

$$\begin{aligned} Z^{FB}(a_3) &\geq Z^{FB}(a_2) = Z(a_2) \\ \left(\phi_2^H - \phi_2^L\right)(x_2 - x_1) &\geq (v_H - v_L)(v_H + v_L + 2\underline{U}) \geq 0, \end{aligned} \tag{12}$$

i.e., if high effort sufficiently increases the expected profit or if the difference of disutilities of effort is sufficiently low. Obviously, condition (12) is less restrictive than the corresponding condition (9) in the second-best case. This result is intuitive, because non-observability of effort only increases the costs of high effort, whereas the default alternative and the low-effort, fixed-remuneration contract are unaffected.

4 Symmetric corporate tax and symmetric wage tax

Until now it is an open question which types of compensation contracts are favored or penalized by the tax system. Moreover, it is not obvious whether the corporate tax and the wage tax have similar impacts on the frequency and the design of compensation contracts. To answer these research questions, the following assumptions in addition to those mentioned in section 3 are used in our model:

- On the principal's level, a corporate tax is levied at the tax rate s.

[12]See, for instance, Mas-Colell/Whinston/Green (1995, p. 487).

- The tax base of the corporation tax is defined as the difference of taxable profits x_1 or x_2 and the deductible remuneration costs $u_{1,t}^2$, $u_{2,t}^2$, or $u_{L,t}^2$.

- The agent's remuneration is fully subject to the wage tax levied at the rate t.

- The agent's disutilities of high effort (v_H) or low effort (v_L) are irrelevant for tax purposes, because no direct payments are associated with these disutilities.

- The pre-tax parameters x_1, x_2, v_H, v_L, ϕ_1^H, ϕ_1^L, ϕ_2^H, ϕ_2^L are exogenous and unaffected by taxation.

- The impact of taxation on the after-tax reservation utility $\underline{U}_t$ is ambiguous. Two different alternatives are taken into account:

  1. The reservation utility $\underline{U}_t$ is unaffected by the existence and the level of taxation: $\underline{U}_t = \underline{U}$. This interpretation is appropriate if the reservation utility is regarded as the result of inactiveness, that means, as a subsistence level that is either tax-exempt or guaranteed by transfer payments[13].
  2. The reservation utility $\underline{U}_t$ depends on the wage tax rate: $\underline{U}_t = \underline{U}_t(t)$. This interpretation is appropriate if the reservation utility is regarded as the utility from the best alternative employment and if the alternative compensation is also taxable[14]. In this case, analyzing tax effects requires a separation of the components of reservation utility, because the alternative salary is taxable, whereas the alternative disutility of effort is non-deductible. Given the agent's utility function $U(s_i, e_j) = \sqrt{s_i} - v_j(e_j)$, the net wage from an alternative job $(1-t)\,s_a$, and the alternative disutility of effort $v_a = 0$ as defined in section 3, the tax-dependent reservation utility can be written as $\underline{U}_t = \sqrt{(1-t)s_a} - v_a = \underline{U}\sqrt{1-t}$. Hence, the after-tax reservation utility is $\sqrt{1-t}$ times the pre-tax reservation utility.

The principal still has the decision alternatives a_1, a_2, and a_3 as defined in the pre-tax case. The default alternative a_1 does not cause tax payments, because neither profits nor remuneration costs occur. The objective value of the default alternative in the after-tax case is still given by $Z_s(a_1) = 0$[15].

In accordance with the pre-tax case, the principal maximizes the expected profit after remuneration costs and corporate taxes: $Z_s^* = \max\{0, Z_s(a_2), Z_s(a_3)\}$.

If the principal would like the agent to provide low effort, i.e., if he chooses alternative a_2, the resulting partial objective function denotes:

$$\max_{u_{L,t}} Z_s(a_2) = (1-s)\left(\phi_1^L x_1 + \phi_2^L x_2 - u_{L,t}^2\right), \tag{13}$$

[13] See Niemann (2008), p. 284.

[14] Gupta/Viauroux (2009), p. 5 also discuss a tax-dependent reservation utility.

[15] For a non-zero objective value of the default alternative, the after-tax objective value would be given by $Z_s(a_1) = (1-s)Z(a_1)$.

with $u_{L,t}^2$ as the agent's taxable fixed gross salary for low effort. Consequently, the agent's net income after wage tax amounts to $(1-t)\,u_{L,t}^2$. Given a profit-maximizing principal, the participation constraint after taxes must hold with equality again:

$$u_{L,t}^2 = \frac{(v_L + \underline{U}_t)^2}{1-t}. \tag{14}$$

Obviously, the agent demands a compensation for the wage tax, because only the net remuneration is disposable for consumption. For a tax-independent reservation utility (alternative 1, $\underline{U}_t = \underline{U}$), the gross remuneration is increased by the factor $\frac{1}{1-t}$ compared to the pre-tax case. If the reservation utility decreases with increasing wage tax rate (alternative 2, $\underline{U}_t = \underline{U}\sqrt{1-t}$), the increase is not as high. However, the necessary gross salary is still strictly higher than without taxes: $u_{L,t}^2 > u_L^2$.

Since the agent always receives only his reservation utility and compensation for his disutility of effort, the principal collects all economic rents from the project. In return, the entire wage tax burden is borne by the principal as long as the reservation utility is tax-independent. Shifting the tax burden onto the agent is impossible, because the agent would simply refuse to sign the contract. Under tax-dependent reservation utility, however, the agent bears a part of the total tax burden, because the alternative salary reflected by the reservation utility would also be taxed.

Using the gross salary $u_{L,t}^2$ the principal's partial objective function becomes:

$$Z_s(a_2) = (1-s)\left[\phi_1^L x_1 + \phi_2^L x_2 - \frac{(v_L + \underline{U}_t)^2}{1-t}\right]. \tag{15}$$

Increasing the corporate tax rate s reduces the principal's objective value, but does not affect the relative profitability of alternative a_2 compared to the default alternative. Even for extremely high corporate tax rates, the algebraic sign of (15) does not change. By contrast, increasing the wage tax rate t reduces the principal's net profit until $Z_s(a_2)$ eventually becomes negative and the principal refrains from hiring the agent. As a consequence, a fixed-salary contract might be profitable in the pre-tax case, but loss-making after the integration of taxes. The employment-reducing effects of the wage tax are especially evident for a tax-independent reservation utility[16].

If the principal would like the agent to provide high effort, he chooses alternative a_3, so that the resulting partial objective function after taxes is:

$$\max_{u_{1,t},u_{2,t}} Z_s(a_3) = (1-s)\left(\phi_1^H x_1 + \phi_2^H x_2 - \min_{u_{1,t},u_{2,t}} \phi_1^H u_{1,t}^2 + \phi_2^H u_{2,t}^2\right), \tag{16}$$

with $u_{1,t}^2$ and $u_{2,t}^2$ as the agent's taxable gross salaries for low and for high profit, respectively. Apart from the participation constraint

$$\phi_1^H u_{1,t} + \phi_2^H u_{2,t} = \frac{v_H + \underline{U}_t}{\sqrt{1-t}} \tag{17}$$

[16]This result is obvious in the low-wage sector, which is typically not analyzed from a principal-agent perspective.

the incentive constraint

$$\begin{aligned}\phi_1^H u_{1,t}\sqrt{1-t}+\phi_2^H u_{2,t}\sqrt{1-t}-v_H &= \phi_1^L u_{1,t}\sqrt{1-t}+\phi_2^L u_{2,t}\sqrt{1-t}-v_L \\ \left(\phi_2^H-\phi_2^L\right)\left(u_{2,t}-u_{1,t}\right) &= \frac{v_H-v_L}{\sqrt{1-t}} \qquad (18)\end{aligned}$$

must hold. The resulting linear equation system can be solved for the optimal remunerations $u_{1,t}^2$ and $u_{2,t}^2$:

$$\begin{aligned}u_{1,t}^2 &= \frac{1}{1-t}\left[v_H+\underline{U}_t-\left(v_H-v_L\right)\frac{\phi_2^H}{\phi_2^H-\phi_2^L}\right]^2 \\ u_{2,t}^2 &= \frac{1}{1-t}\left[v_H+\underline{U}_t+\left(v_H-v_L\right)\frac{1-\phi_2^H}{\phi_2^H-\phi_2^L}\right]^2. \qquad (19)\end{aligned}$$

Similar to alternative a_2 the agent demands a compensation for the wage tax. Even if the reservation utility is reduced by taxation ($\underline{U}_t=\underline{U}\sqrt{1-t}$), the wage tax strictly increases the necessary gross salaries compared to the pre-tax case: $u_{1,t}^2>u_1^2$, $u_{2,t}^2>u_2^2$. The reason for this effect is the non-deductibility of the disutilities of effort v_H and v_L. If the principal erroneously offers remuneration levels that are optimal in the pre-tax case, these salaries are insufficient to induce the agent to provide high effort in a world with wage taxation. For $\left(v_L+\underline{U}_t\right)/\sqrt{1-t}<v_H+\underline{U}<\left(v_H+\underline{U}_t\right)/\sqrt{1-t}$, the incentive constraint is violated and the agent provides only low effort at inefficiently high costs. For $v_H+\underline{U}<\left(v_L+\underline{U}_t\right)/\sqrt{1-t}$ even the participation constraint does not hold and the agent refuses to participate. Thus, neglecting wage taxation in the design of compensation contracts might induce harmful decisions.

Given the optimal state-dependent salaries in the after-tax case, the principal's objective function is given by:

$$\begin{aligned}Z_s\left(a_3\right) &= (1-s)\left[\phi_1^H\left(x_1-u_{1,t}^2\right)+\phi_2^H\left(x_2-u_{2,t}^2\right)\right] \\ &= (1-s)\left[\phi_1^H x_1+\phi_2^H x_2-\frac{\left(v_H+\underline{U}_t\right)^2}{1-t}-\frac{\left(v_H-v_L\right)^2}{1-t}\frac{\phi_2^H\left(1-\phi_2^H\right)}{\left(\phi_2^H-\phi_2^L\right)^2}\right]. \qquad (20)\end{aligned}$$

The principal chooses alternative a_3 only if this objective function is positive and exceeds $Z_s\left(a_2\right)$:

$$\begin{aligned}Z_s\left(a_3\right) &\geq Z_s\left(a_2\right) \\ \left(x_2-x_1\right)\left(\phi_2^H-\phi_2^L\right) &\geq \frac{1}{1-t}\left[\left(v_H-v_L\right)\left(v_H+v_L+2\underline{U}_t\right)+\left(v_H-v_L\right)^2\frac{\phi_2^H\left(1-\phi_2^H\right)}{\left(\phi_2^H-\phi_2^L\right)^2}\right]. \qquad (21)\end{aligned}$$

Regardless of whether or not the reservation utility is tax-dependent, condition (21) is more restrictive than the corresponding condition (9) in the pre-tax case. As a result, there will be fewer performance-based contracts than in a world without taxes. However, this effect only depends on the wage tax t. The corporate tax s does not affect the conclusion and the design of a contract.

The performance-based contract a_3 as well as the fixed-remuneration contract a_2 carry a wage tax penalty. Increasing the wage tax t may impede employment. Projects which are profitable for the principal, the agent, and the fiscal authorities under sufficiently low wage tax rates will otherwise, under higher wage tax rates, be skipped.

The first-best case as a reference case emerges for observable effort. Neglecting the incentive constraint leads to a fixed gross salary of

$$\left(u_{a_3}^{FB}\right)^2 = \frac{\left(v_H + \underline{U}_t\right)^2}{1-t} \tag{22}$$

and yields an expected profit after remuneration costs of

$$Z_s^{FB}\left(a_3\right) = (1-s)\left[\phi_1^H x_1 + \phi_2^H x_2 - \frac{\left(v_H + \underline{U}_t\right)^2}{1-t}\right] > Z_s\left(a_3\right). \tag{23}$$

In accordance with the pre-tax case, the principal's after-tax demand for high effort increases with observability.

Comparing the alternatives a_2 and a_3 in the first-best case after taxes gives similar results as the pre-tax case. In the first-best case the principal is willing to pay the agent for high effort only if:

$$\begin{aligned} Z_s^{FB}\left(a_3\right) &\geq Z_s^{FB}\left(a_2\right) = Z_s\left(a_2\right) \\ \left(\phi_2^H - \phi_2^L\right)\left(x_2 - x_1\right) &\geq \frac{\left(v_H - v_L\right)\left(v_H + v_L + 2\underline{U}_t\right)}{1-t} \geq 0. \end{aligned} \tag{24}$$

Since this condition is more restrictive than the corresponding pre-tax condition (12), the wage tax might prohibit the conclusion of a forcing contract with obligatory high effort. Although the principal's demand for high effort in the first-best case exceeds the demand in the second-best case, the wage tax is still an obstacle for employment and effort.

5 Asymmetric corporate tax and symmetric wage tax

Real-world corporate tax systems are characterized by asymmetric taxation of profits and losses. Whereas profits are subject to the full corporate tax rate, losses do not entitle the investor to equivalent tax reimbursements. Typically, losses can only be offset against future profits. This delayed loss recognition corresponds to a limited tax reimbursement.

Technically, tax asymmetries are modeled by using a loss-offset parameter $0 \leq \gamma \leq 1$. This coefficient represents the proportion of deductible losses[17]. For $\gamma = 1$ the special case

[17] In most jurisdictions the use of losses for tax purposes depends on the amount of losses incurred. Losses that cannot be offset against current profits must be carried forward to subsequent periods, which induces a negative time effect. The higher a loss, the later it can be offset against future profits. Such a model specification would require extensive assumptions regarding future profits, which are difficult to justify in the one-period setting considered here. Hence, I assume γ to be constant. Since a one-period model does not permit the analysis of time effects of taxation, time effects have to be approximated by tax base effects. See also Ewert/Niemann (2010).

of symmetric taxation emerges. For $\gamma = 0$, the future use of losses is entirely prohibited. More restrictive loss-offset rules correspond to a reduction of γ. Typical corporate tax systems have loss-offset coefficients $0 < \gamma < 1$. As a result, positive profits are subject to the corporate tax rate s, negative corporate tax bases trigger a tax reimbursement by using the effective tax rate γs.

On the agent's individual level the utility function $U(s_i, e_j) = \sqrt{s_i} - v_j$ is not defined for negative remunerations[18]. Consequently, loss-offset restrictions do not apply at the agent's level. Since both the participation constraints and the incentive constraint are unaffected by the corporate tax, the optimal salaries derived in section 4 have to be used in the case of asymmetric corporate taxation as well:

$$\begin{aligned} u_{L,t}^2 &= \frac{(v_L + \underline{U}_t)^2}{1-t}, \\ u_{1,t}^2 &= \frac{1}{1-t}\left[v_H + \underline{U}_t - (v_H - v_L)\frac{\phi_2^H}{\phi_2^H - \phi_2^L}\right]^2, \\ u_{2,t}^2 &= \frac{1}{1-t}\left[v_H + \underline{U}_t + (v_H - v_L)\frac{1-\phi_2^H}{\phi_2^H - \phi_2^L}\right]^2. \end{aligned} \tag{25}$$

By contrast, asymmetric corporate taxation affects the principal's objective value. Whereas the default alternative a_1 does not induce tax consequences and is therefore unaffected by loss-offset restrictions[19], alternative a_2 (request for low effort) as well as alternative a_3 (request for high effort) are penalized by asymmetric taxation if the tax base is negative for at least one of both possible states. For evaluating the principal's objective value a differentiation between positive and negative tax bases is necessary.

The partial objective function for alternative a_2 under asymmetric taxation is given by:

$$\begin{aligned} \max_{u_{L,t}} Z_s(a_2) &= \phi_1^L\left[(1-\gamma s)\min\left\{0; x_1 - u_{L,t}^2\right\} + (1-s)\max\left\{0; x_1 - u_{L,t}^2\right\}\right] \\ &\quad + \phi_2^L\left[(1-\gamma s)\min\left\{0; x_2 - u_{L,t}^2\right\} + (1-s)\max\left\{0; x_2 - u_{L,t}^2\right\}\right]. \end{aligned} \tag{26}$$

Equation (26) does not exclude negative tax bases and hence negative objective values for both possible profit levels. In this case, however, the default alternative a_1 would be optimal. Thus, alternative a_2 can only be considered if the tax base is positive at least for the high profit x_2. I therefore assume $x_2 > u_{L,t}^2$:

$$\begin{aligned} \max Z_s(a_2) &= (1-\gamma s)\,\phi_1^L \min\left\{0; x_1 - u_{L,t}^2\right\} + (1-s)\,\phi_1^L \max\left\{0; x_1 - u_{L,t}^2\right\} \\ &\quad + (1-s)\,\phi_2^L\left(x_2 - u_{L,t}^2\right). \end{aligned} \tag{27}$$

For $x_1 \geq u_{L,t}^2$ the objective value under symmetric taxation from (15) emerges. For $x_1 < u_{L,t}^2$ the principal's objective value after substituting $u_{L,t}^2$ is given by:

$$Z_s(a_2) = (1-\gamma s)\,\phi_1^L x_1 + (1-s)\,\phi_2^L x_2 - \left[(1-\gamma s)\,\phi_1^L + (1-s)\,\phi_2^L\right]\frac{(v_L + \underline{U}_t)^2}{1-t}. \tag{28}$$

[18] Complex-valued utilities are disregarded.

[19] For a non-zero objective value of the default alternative, the after-tax objective value would be given by $Z_s(a_1) = (1-\gamma s)\min\{0; Z(a_1)\} + (1-s)\max\{0; Z(a_1)\}$.

If the principal demands high effort (alternative a_3) the objective function after asymmetric taxation denotes:

$$\begin{aligned}\max_{u_{1,t},u_{2,t}} Z_s(a_3) &= \phi_1^H\left[(1-\gamma s)\min\left\{0; x_1-u_{1,t}^2\right\}+(1-s)\max\left\{0; x_1-u_{1,t}^2\right\}\right]\\ &\quad +\phi_2^H\left[(1-\gamma s)\min\left\{0; x_2-u_{2,t}^2\right\}+(1-s)\max\left\{0; x_2-u_{2,t}^2\right\}\right]. \qquad (29)\end{aligned}$$

Again, I assume that loss-offset restrictions can only apply in case of a low profit x_1 and are not binding for the high profit, i.e., $x_2 \geq u_{2,t}^2$. Using this assumption excludes two economically irrelevant cases:

1. A loss after deducting remuneration costs occurs in both states x_1 and x_2. Then, the default alternative a_1 should be preferred.
2. The difference of the high profit and the (high) remuneration costs is negative ($x_2 - u_{2,t}^2 < 0$), whereas the difference of the low profit and the (low) remuneration costs is positive ($x_1 - u_{1,t}^2 \geq 0$). If this were true, the principal had no incentive to induce the agent to provide high effort, because the additional profit would be overcompensated by the higher remuneration costs. Thus, alternative a_2 would be advantageous[20].

After focussing on the relevant cases, the partial objective function for alternative a_3 denotes:

$$\begin{aligned}Z_s(a_3) &= \phi_1^H\left[(1-\gamma s)\min\left\{0; x_1-u_{1,t}^2\right\}+(1-s)\max\left\{0; x_1-u_{1,t}^2\right\}\right]\\ &\quad +\phi_2^H(1-s)\left(x_2-u_{2,t}^2\right). \qquad (30)\end{aligned}$$

For $x_1 \geq u_{1,t}^2$ the objective function under symmetric taxation from (20) emerges. For $x_1 < u_{L,t}^2$ the objective function after substituting $u_{1,t}^2$ is given by:

$$Z_s(a_3) = \phi_1^H(1-\gamma s)\left(x_1-u_{1,t}^2\right)+\phi_2^H(1-s)\left(x_2-u_{2,t}^2\right). \qquad (31)$$

Due to the asymmetries for $\gamma < 1$ a further simplification of this expression is not possible. Therefore, the impact of corporate taxation on the optimal remuneration parameters cannot be derived analytically. However, the effects of tightening loss-offset rules can be described as follows: For any given loss-offset parameter $\gamma < 1$ increasing the corporate tax rate s reduces the principal's net profit more than under symmetric taxation ($\gamma = 1$). As will be shown numerically in section 6.2, loss-offset restrictions have an asymmetric impact on the alternatives a_2 and a_3.

Apart from the varying impact of the corporate tax rate s, direct effects of varying the loss-offset parameter γ can be identified. For any positive probability $\phi_2^L > 0$ the fixed salary under low effort (alternative a_2) exceeds the variable salary under low profit given a performance-based contract (alternative a_3): $u_{L,t}^2 > u_{1,t}^2$. Given the low profit, this effect implies that the tax base for alternative a_2 always falls short of the tax base for alternative a_3:

$$u_{L,t}^2 > u_{1,t}^2 \quad \Leftrightarrow \quad x_1 - u_{L,t}^2 < x_1 - u_{1,t}^2. \qquad (32)$$

From (32) three possible effects of varying the loss-offset parameter γ can be derived:

[20] A proof is provided in the appendix.

1. $x_1 - u_{L,t}^2 < x_1 - u_{1,t}^2 < 0$: A loss occurs for both alternatives a_2 and a_3. The loss from alternative a_2 exceeds the loss from alternative a_3. Therefore, tighter loss-offset restrictions reduce both alternatives' objective values, the reduction being higher for alternative a_2.

2. $x_1 - u_{L,t}^2 < 0 < x_1 - u_{1,t}^2$: Given the low profit, a loss occurs for alternative a_2 only. Loss-offset restrictions only affect alternative a_2, while alternative a_3 remains unchanged.

3. $0 < x_1 - u_{L,t}^2 < x_1 - u_{1,t}^2$: Both alternatives are characterized by positive tax bases. Loss-offset limitations are irrelevant in this case.

In absolute terms, alternative a_2 as well as a_3 are penalized by loss-offset restrictions. Thus, the default alternative a_1 benefits from asymmetric taxation. Since the possible loss is higher for alternative a_2 it is penalized relatively compared to a_3. As a result, the principal could prefer low effort (alternative a_2) under symmetric taxation and high effort (alternative a_3) under asymmetric taxation, because a performance-based contract might reduce or avoid negative tax bases. As a performance-based compensation contract shifts risks from the risk-neutral principal onto the risk-averse agent, it contributes to an inefficient risk allocation. As a main result of this model, this inefficiency can still be aggravated by asymmetric taxation.

6 Numerical examples

This section clarifies numerically and graphically the tax effects derived formally in sections 4 and 5.

6.1 Symmetric taxation

The tax effects under symmetric taxation are derived formally in section 4. Varying the corporate tax rate s neither alters the sign of the partial objective functions $Z_s(a_2)$ and $Z_s(a_3)$ nor does it affect the relative advantage of alternatives a_2 and a_3. By contrast, the wage tax rate t is relevant for the design of remuneration contracts. For the parameter setting

$$x_1 = 500;\ x_2 = 1,500;\ \phi_2^H = 0.7;\ \phi_2^L = 0.3;\ \underline{U}_t = 24\sqrt{1-t};\ v_H = 6;\ v_L = 1;\ s = 0.25$$

the objective functions $Z_s(a_2)$ and $Z_s(a_3)$ are strictly decreasing functions of the wage tax rate t:

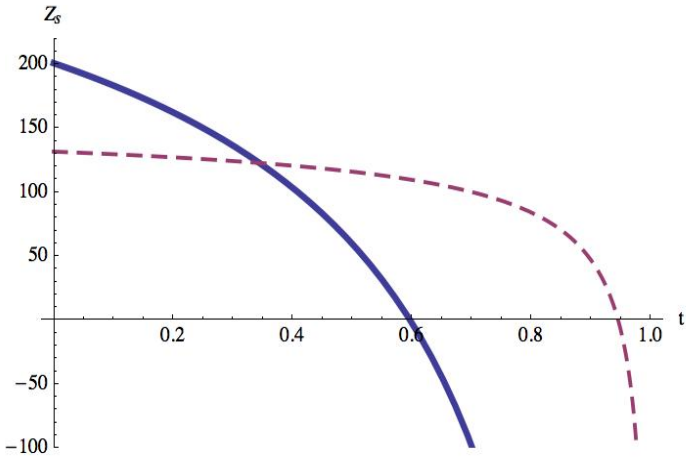

Figure 1: objective functions $Z_s\,(a_2)$ and $Z_s\,(a_3)$ as functions of the wage tax rate t

The solid line represents the principal's objective function under high effort (a_3), the dashed line shows the principal's objective function for low effort (a_2). Both functions are strictly decreasing in the wage tax rate. Above a critical threshold for t, both partial objective functions become negative. The principal's objective value for the performance-based contract a_3 decreases faster in the wage tax rate than the objective value for the fixed-compensation contract a_2. In our example, the performance-based contract is optimal for the interval $t \in [0;\, 0.345]$, whereas the fixed-compensation contract is chosen for $t \in [0.345;\, 0.945]$.

Given the tax-independent reservation utility $\underline{U}_t = 20$, the results are very similar:

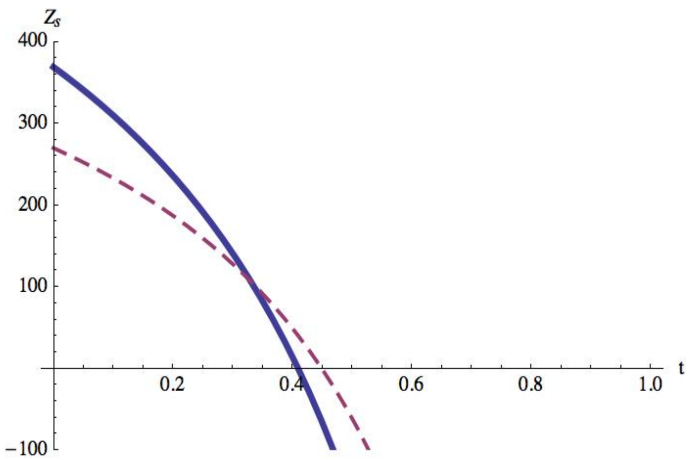

Figure 2: objective functions $Z_s\,(a_2)$ and $Z_s\,(a_3)$ as functions of the wage tax rate t

In this case, both objective functions are far more sensitive with respect to variations of the wage tax rate. The performance-based contract a_3 is optimal for the interval $t \in [0; 0.33]$, whereas the fixed-compensation contract a_2 is chosen for $t \in [0.33; 0.449]$. Adjusting parameters appropriately results in examples for which either alternative a_2 or a_3 in combination with the default alternative a_1 dominates the other contract for the entire tax rate interval $[0; 1]$.

6.2 Asymmetric taxation

Under asymmetric taxation of profits and losses the tax effects are not as obvious as under symmetric taxation and a graphical representation is especially useful. In contrast to symmetric taxation the corporate tax rate s is relevant for the optimal contract. For the parameters

$$\begin{aligned} x_1 &= 500;\ x_2 = 1,500;\ \phi_2^H = 0.65;\ \phi_2^L = 0.35;\ \underline{U}_t = 25\sqrt{1-t};\ v_H = 5;\ v_L = 1; \\ t &= 0.4;\ \gamma = 0.7 \end{aligned}$$

the following partial objective functions a_2 and a_3 as functions of the corporate tax rate emerge:

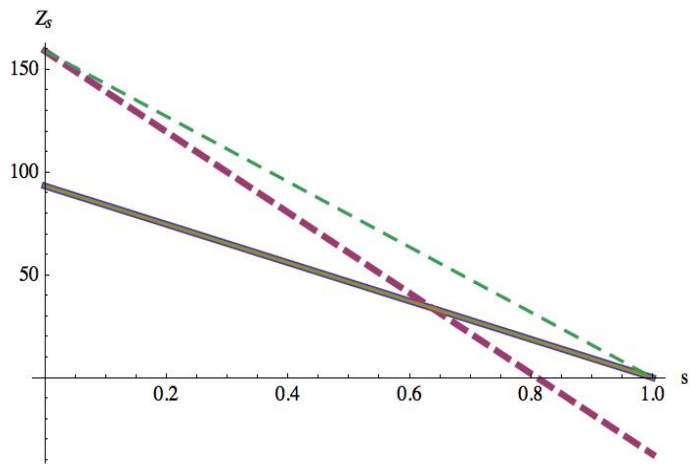

Figure 3: objective functions $Z_s(a_2)$ and $Z_s(a_3)$ as functions of the corporate tax rate s

The solid line represents the principal's objective function under performance-based compensation (a_3). For this contract under the given parameter setting, losses do not occur, implying that loss-offset restrictions are irrelevant. By contrast, the fixed-compensation contract (a_2) causes a loss for the low profit x_1. Under asymmetric (symmetric) taxation, the fixed-compensation contract is displayed by the thick (thin) dashed line. The intersection of the solid line and dashed thick line indicates that the level of the corporate tax rate has decisive impact on the optimal contract. For $s \leq 0.638$ the fixed-compensation contract is optimal, for $s \geq 0.638$ the performance-based contract. Whereas the objective functions $Z_s(a_2)$ and $Z_s(a_3)$ do not intersect the abscissa under symmetric taxation, asymmetric taxation might alter the algebraic sign of the objective functions, implying that higher corporate tax rates may induce the principal to choose the default alternative a_1.

The impact of the loss-offset parameter γ was analyzed in section 5. Both the fixed-salary contract and the performance-based contract are penalized by restricting loss-offset. However, the fixed-salary contract suffers more from reducing γ. This effect is illustrated in the following figure using the parameter setting

$$\begin{aligned} x_1 &= -25;\ x_2 = 275;\ \phi_2^H = 0.66;\ \phi_2^L = 0.34;\ \underline{U}_t = 8\sqrt{1-t};\ v_H = 3;\ v_L = 0.2; \\ s &= 0.25;\ t = 0.4: \end{aligned}$$

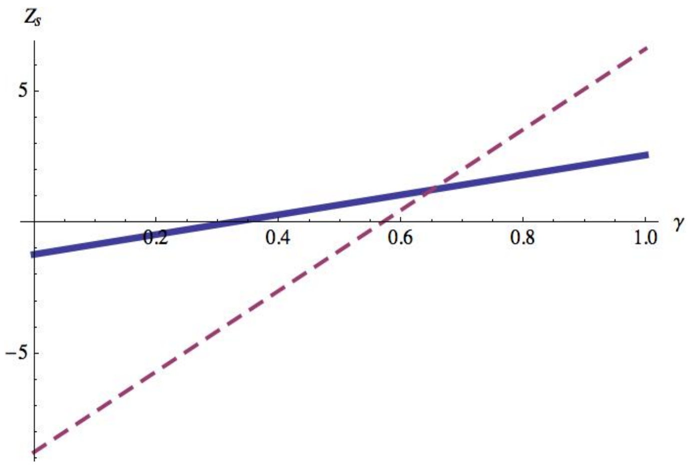

Figure 4: objective functions $Z_s(a_2)$ and $Z_s(a_3)$ as functions of the loss-offset parameter γ

The solid line represents the performance-based contract (a_3), the dashed line the fixed-compensation contract (a_2). The intersection of the functions reveals that loss-offset rules affect the remuneration decision. For $\gamma \in [0.326; 0.65]$ the optimal contract is performance-based, for $\gamma \in [0.65; 1]$ the optimal contract is a fixed-compensation contract. Obviously, tighter loss-offset restrictions might alter the algebraic sign of the principal's objective functions. As a consequence, the principal should not offer a compensation contract for $\gamma \in [0; 0.326]$.

7 Summary and conclusions

This paper analyzes the impact of symmetric and asymmetric taxation on the conclusion and the design of remuneration contracts using a binary principal-agent model. I integrate corporate taxation at the principal's level and wage taxation at the agent's level. The principal chooses the optimal of three possible alternatives:

- He does not offer a contract to the agent. This means that cooperation does not occur and that the net profit equals zero.
- The principal can offer a fixed-compensation contract, which induces the agent to provide low (but positive) effort.
- The principal can offer a performance-based remuneration contract ensuring a high effort by the agent.

Under symmetric taxation of profits and losses the corporate tax does not affect the conclusion and the optimal design of a compensation contract. The corporate tax just reduces the principal's objective function proportionally and does not alter its algebraic sign. Under asymmetric taxation, however, increasing the corporate tax potentially reduces the net profit below zero. Hence, sufficiently tight loss-offset restrictions might prevent the principal from offering a compensation contract. With respect to the choice between fixed and performance-based remuneration, asymmetric taxation penalizes fixed-salary contracts – which are equivalent to the first-best case – more than performance-based contracts, which induce a welfare loss compared to the first-best case. This result implies that loss-offset restrictions might aggravate inefficiencies caused by suboptimal division of risk. As a consequence, neglecting corporate taxation might provoke wrong decisions only under asymmetric taxation.

In our model the agent's salary is always positive. Thus, loss-offset restrictions are irrelevant for the agent. The effects of the wage tax do not depend on whether or not the corporation tax is symmetric. Increasing the wage tax rate always increases the agent's gross salary and reduces the principal's net profit. Consequently, for sufficiently high wage tax rates the principal's net profit after remuneration costs becomes negative and the principal refrains from offering a contract. In a qualitative sense, this result does not depend on whether the agent's reservation utility is a function of the wage tax. The wage tax reduces employment in all the situations considered. Moreover, I show that the wage tax penalizes performance-based contracts more heavily than fixed-salary contracts. Apart from its employment-reducing effects, the wage tax also reduces incentives for high effort. Neglecting the wage tax might cause harmful decisions in any of the considered cases.

In order to draw tax policy conclusions from our model, it has to be determined whether tax policy should keep economic decisions unaffected (neutral taxation) or whether it should be used to reach a particular outcome (active tax policy). For neutral taxation, the reference case is given by the pre-tax second-best case because the informational asymmetry is simply taken as given. If the tax legislator were interested in neutral taxation they should refrain from levying a wage tax and should realize tax revenue exclusively by a symmetric corporate tax. This tax system would guarantee the same remuneration contracts as in the pre-tax case.

As an alternative, an active tax policy could be designed to correct informational asymmetries in order to reach the first-best pre-tax solution, which serves as the appropriate reference case[21]. By comparing the first-best pre-tax and the second-best after-tax solutions, which tax parameters can be effectively used to reach a particular contract choice or effort level, can be analyzed. Also in this case, the desired tax revenue should be realized exclusively by a symmetric corporate tax. Moreover, for employment and effort levels similar to the pre-tax first-best case, subsidising employment contracts could be necessary.

Given the distinctive tax effects derived in our model, its assumptions should be critically scrutinized in order to avoid premature tax policy conclusions. As a main caveat, the model's binary structure potentially limits its explanatory power. However, it should be noted that this discrete structure permits analytical solutions. The LEN model as a possible alternative model with a continuous state space cannot be applied, because asymmetric corporate taxation violates the linearity assumption[22]. Another limitation arises from the model's one-period setting which requires time effects of taxation to be approximated by tax rate effects. This assumption is conducive to analytical solvability. Hitherto, multi-period principal-agent models including taxation do not exist[23]. Therefore, the possible additional insights from this class of models are still unknown. In any case, the extensive tax effects in the binary model indicate that neglecting taxation requires strong arguments.

By contrast, the existence of analytical solutions is an argument in favor of investigating open research questions using binary models. These open research questions include the effects of bonus taxation at the agent's level or the effects of progressive income taxes for both the principal and the agent[24].

[21]Kanniainen (1999) investigates whether the corporation tax can correct failures in corporate governance.

[22]See Niemann (2008, p. 288 f.)

[23]See Schöndube (2009) and the references cited there for multi-period agency models in the pre-tax case.

[24]For the effects of progressive income taxation on risk taking see, for example, Ahsan (1974), Schneider (1980), Bamberg/Richter (1984).

Appendix: Proof of the proposition in section 5

Proposition:

$$x_2 - u_{2,t}^2 < 0 \wedge \; x_1 - u_{1,t}^2 \geq 0 \Rightarrow Z_s(a_2) > Z_s(a_3).$$

Proof:

1.) From $x_2 - u_{2,t}^2 < 0 \wedge x_1 - u_{1,t}^2 \geq 0$ follows:

$$\begin{aligned}
x_2 - u_{2,t}^2 &< x_1 - u_{1,t}^2 \\
x_2 - \frac{1}{1-t}\left[v_H + \underline{U}_t + (v_H - v_L)\frac{1-\phi_2^H}{\phi_2^H - \phi_2^L}\right]^2 &< x_1 - \frac{1}{1-t}\left[v_H + \underline{U}_t - (v_H - v_L)\frac{\phi_2^H}{\phi_2^H - \phi_2^L}\right]^2 \\
(x_2 - x_1)(1-t) &< \left[v_H + \underline{U}_t + (v_H - v_L)\frac{1-\phi_2^H}{\phi_2^H - \phi_2^L}\right]^2 \\
&\quad - \left[v_H + \underline{U}_t - (v_H - v_L)\frac{\phi_2^H}{\phi_2^H - \phi_2^L}\right]^2 \\
(x_2 - x_1)(1-t) &< \frac{v_H - v_L}{\phi_2^H - \phi_2^L}\left[2\left(v_H + \underline{U}_t\right) + \frac{v_H - v_L}{\phi_2^H - \phi_2^L}\left(1 - 2\phi_2^H\right)\right]
\end{aligned} \tag{33}$$

2.) From (24) follows:

$$\begin{aligned}
Z_s(a_2) &> Z_s(a_3) \\
(x_2 - x_1)\left(\phi_2^H - \phi_2^L\right) &< \frac{1}{1-t}\left[(v_H - v_L)\left(v_H + v_L + 2\underline{U}_t\right) + (v_H - v_L)^2 \frac{\phi_2^H\left(1-\phi_2^H\right)}{\left(\phi_2^H - \phi_2^L\right)^2}\right] \\
(x_2 - x_1)(1-t) &< \frac{(v_H - v_L)\left(v_H + v_L + 2\underline{U}_t\right)}{\phi_2^H - \phi_2^L} + \frac{(v_H - v_L)^2}{\left(\phi_2^H - \phi_2^L\right)^3}\phi_2^H\left(1 - \phi_2^H\right)
\end{aligned} \tag{34}$$

3.) In order to show that condition (33) is more restrictive than condition (34), the following inequality must hold:

$$
\begin{array}{rcl}
\frac{v_H - v_L}{\phi_2^H - \phi_2^L}\left[2\left(v_H + \underline{U}_t\right) + \frac{v_H - v_L}{\phi_2^H - \phi_2^L}\left(1 - 2\phi_2^H\right)\right] & < & \frac{\left(v_H - v_L\right)\left(v_H + v_L + 2\underline{U}_t\right)}{\phi_2^H - \phi_2^L} \\
 & & + \frac{\left(v_H - v_L\right)^2}{\left(\phi_2^H - \phi_2^L\right)^3}\phi_2^H\left(1 - \phi_2^H\right) \\
2\left(v_H + \underline{U}_t\right) + \frac{v_H - v_L}{\phi_2^H - \phi_2^L}\left(1 - 2\phi_2^H\right) & < & \left(v_H + v_L + 2\underline{U}_t\right) + \frac{v_H - v_L}{\left(\phi_2^H - \phi_2^L\right)^2}\phi_2^H\left(1 - \phi_2^H\right) \\
v_H - v_L + \frac{v_H - v_L}{\phi_2^H - \phi_2^L}\left(1 - 2\phi_2^H\right) & < & \frac{v_H - v_L}{\phi_2^H - \phi_2^L}\frac{\phi_2^H\left(1 - \phi_2^H\right)}{\phi_2^H - \phi_2^L} \\
\frac{v_H - v_L}{\phi_2^H - \phi_2^L}\left(1 - 2\phi_2^H + \phi_2^H - \phi_2^L\right) & < & \frac{v_H - v_L}{\phi_2^H - \phi_2^L}\frac{\phi_2^H\left(1 - \phi_2^H\right)}{\phi_2^H - \phi_2^L} \\
\left(1 - \phi_2^H - \phi_2^L\right) & < & \frac{\phi_2^H\left(1 - \phi_2^H\right)}{\phi_2^H - \phi_2^L} \\
\left(1 - \phi_2^H - \phi_2^L\right)\left(\phi_2^H - \phi_2^L\right) & < & \phi_2^H\left(1 - \phi_2^H\right) \\
-\phi_2^L\left(1 - \phi_2^L\right) & < & 0.
\end{array}
\tag{35}
$$

Inequality (35) is always satisfied, because $0 \leq \phi_2^L \leq 1$ is a probability. Hence, condition (33) is always more restrictive than condition (34). Although it is possible that $x_2 - u_{2,t}^2 < 0 \wedge x_1 - u_{1,t}^2 \geq 0$ occur, in this case $Z_s\left(a_2\right) > Z_s\left(a_3\right)$ holds, so alternative a_3 cannot be optimal.

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